INTELIGENCIA DE NEGOCIOS EN EL PROCESO DE SELECCIÓN DE ASPIRANTES A POSGRADOS DE CALIDAD: DISEÑO E IMPLEMENTACIÓN DE UN DATA WAREHOUSE

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***Resumen*— El objetivo de este paper es presentar una propuesta de data warehouse para la aplicación de inteligencia de negocios en el proceso de selección de aspirantes a posgrados que pertenecen al Padrón Nacional de Posgrados de Calidad (PNPC). Se utilizó una adaptación de la metodología de Kimball, a través de la cual se obtuvieron los requerimientos del negocio, se identificaron los indicadores clave (KPI) para el proceso de selección de aspirantes, se generó el modelo dimensional y finalmente se diseñó el proceso de extracción, transformación y carga (ETL, por sus siglas en inglés) utilizando la herramienta PENTAHO. Para validar el data warehouse desarrollado se utilizó una prueba "ad hoc" comparando los resultados del proceso de selección en su versión actual contra los resultados obtenidos y desplegados en un dashboard diseñado en Power BI.**

***Palabras clave*— Inteligencia de negocios, Data Warehouse, metodología Kimball, posgrados de calidad, proceso de admisión.**

Introducción

El uso de la información cada día se hace más elemental para los sistemas de inteligencia de negocios, son de los recursos más apreciados y su aplicación en el campo de la gestión educativa no es la excepción. Estos recursos de información se generan en sistemas transaccionales que almacenan gran cantidad de datos que sin el uso de sistemas de inteligencia de negocios estos datos pasan desapercibidos, por lo contrario el explotar y analizar los datos de los sistemas transaccionales proporcionan conocimiento para la toma de decisiones, así lo expresan Calzada & Abreu (2009). "Hoy en día, la cantidad de datos que ha sido almacenada en las bases de datos excede nuestra habilidad para reducir y analizar los datos sin el uso de técnicas de análisis automatizadas. Muchas bases de datos comerciales transaccionales y científicas crecen a una proporción fenomenal" (Molina and García (2006), p.1).

En un estudio de tipo cuantitativo desarrollado por Valdés, Vera, Carlos, & Estévez (2013) se propusieron identificar los perfiles de estudiantes de posgrado en el estado de Sonora perteneciente a programas ubicados en el Padrón Nacional de Posgrados del CONACYT indica lo siguiente:

- Alta importancia de las competencias en sus currículos.
- Alto desarrollo de competencias científicas.
- Alto grado de involucramiento en la investigación.
- Productividad académica aceptable.

La automatización de los procesos de gestión de los posgrados de calidad en una IES del noroeste del país será un factor importante para la fácil recuperación de datos, que con el actual proceso pasan desapercibidos, y no pueden ser explotados sistemáticamente, ni utilizarlos como herramientas de información. Cada vez existen más datos para extraer y organizar, para ello se requiere de métodos de gestión hábiles para recopilar, encontrar, interpretar, analizar y recrear el conocimiento potencialmente útil, expresan León, Saucedo, Avendaño, Martínez, & Carcaño (2015).

En el posgrado de calidad en una IES del noroeste del país se desarrolla un sistema que administre el proceso de admisión, donde el aspirante y profesor podrán verse beneficiados al poder manejar su información con la ayuda de esta plataforma. Se podrán obtener los datos requeridos para poder realizar un data warehouse del

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proceso de admisión, para esto se pretende utilizar métodos y técnicas de Inteligencia de Negocios integrados y Learning Analytics con el fin de minimizar las deserciones futuras a lo largo del posgrado, que pudiera perjudicar la pertenencia del programa en el PNPC.

Al mismo tiempo la selección de aspirantes es un proceso complejo en el que intervienen un conjunto amplio de factores en la toma de decisiones y que deben estar alineados a los criterios de un perfil deseable de los estudiantes de un posgrado de calidad en TI. Por lo tanto, no aprovechar la información disponible de los aspirantes y aplicar Inteligencia de Negocios para la toma de decisiones, pone en desventaja al programa respecto aquellos que si lo hacen.

Descripción del Método

Para el desarrollo del data warehouse se hizo una adaptación de la metodología propuesta por Kimball (1998) (ver Figura 1) que abarca desde la planificación hasta la implementación del data warehouse, ver tabla 1.

Metodología de Kimball

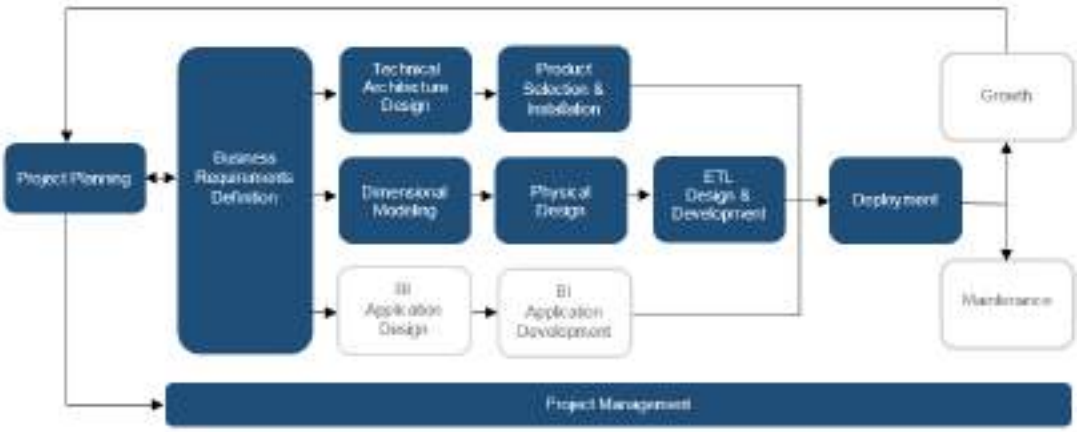

Figura 1. Metodología de Kimball.

Fase	Descripción
Planificación del Proyecto	En esta fase se definirá el alcance del proyecto, sus recursos y cronograma del proyecto. Se desarrolla basado en recursos, perfiles, tareas y secuencias de las fases.
Definición de los requerimientos del negocio	En esta fase se establecerán los elementos clave para el desarrollo del data warehouse de forma que se diseñe correctamente para las fases siguientes.
Diseño técnico de la arquitectura	En esta fase se requiere planificar antes de iniciar, por ello que el diseño es la comunicación entre clientes y diseñadores, se establecen métricas de esfuerzos y materiales.
Selección de productos e instalación	En esta fase se evalúan distintas herramientas para el almacenamiento del data warehouse y el desarrollo del ETL o herramienta pertinente. Una vez evaluados y seleccionados se instalarán y harán pruebas.
Modelo dimensional	En esta fase se plantea el modelo estrella basado en los requerimientos del negocio que determinarán los indicadores clave para el usuario del negocio, son los datos necesarios con un enfoque diferente a los sistemas operacionales.
Diseño físico	Esta fase se enfoca en la selección de estructuras físicas para el soporte del data warehouse, sus principales elementos constan de la definición de convenciones estándares de nombres y la configuración del entorno de la base de datos.
Diseño y desarrollo del ETL	Esta fase tiene sub fases que son: extracción, trasformación y carga de los datos hacia el data warehouse, estos datos pueden ser extraídos de

	diferentes fuentes. Esto se realiza para que los datos sean de mayor calidad y coherencia al mostrar al usuario del negocio.
Implementación	En la implementación se publicará el data warehouse en un dashboard de Power BI donde muestren los indicadores claves establecidos en los requerimientos del negocio.
Gestión del proyecto	La gestión del proyecto abarca todo el proyecto, se asegura de monitorear que las fases se realicen correctamente y mantener una comunicación con los requerimientos del negocio.

Cuadro 1. Descripción de la metodología de Kimball.

Resultados

El análisis de la información de los candidatos en el proceso de admisión se realiza de forma manual con la ayuda de la paquetería de Microsoft Office basado en criterios establecidos por el núcleo académico del posgrado de calidad. Este tipo de análisis para la toma de decisiones al seleccionar un candidato puede llegar a requerir una inversión de tiempo alrededor de 2 días, debido al proceso manual y las diversas interrupciones que pueda haber en las juntas realizada para tomar las decisiones. Por este motivo es necesario desarrollar un sistema de inteligencia de negocios, data warehouse, que con la ayuda de un sistema operacional obtenga los datos necesarios para hacer transformaciones adecuadas a los datos para posteriormente realizar análisis y así finalmente poder ser mostrados al coordinador y núcleo académico.

Planificación del proyecto

El proyecto se desarrolló en el proceso de admisión de un posgrado de calidad en una IES del noroeste del país. Se implementó un data warehouse para la preservación y explotación de datos en la gestión educativa basado en criterios establecidos por el posgrado.

Tiene como objetivos:

- Incrementar el uso de Inteligencia de negocios.
- Apoyar el proceso de admisión.
- Reducir riesgos en la selección de candidatos.
- Reducción de tiempo de la toma de decisiones.

Este proyecto pretende analizar las necesidades para definir indicadores clave en el proceso de admisión, basados en criterios establecidos por la experiencia del núcleo académico del posgrado; con el apoyo de estos criterios desarrollar un data warehouse.

Definición de los requerimientos del negocio

Se acordó que se ocuparía desarrollar un sistema de inteligencia de negocios para la toma de decisiones especialmente en el proceso de admisión.

Requerimientos establecidos para el proceso de admisión:

- Realizar un diagrama con cada una de las actividades del proceso de admisión.
- Conocer los requerimientos e información que se obtiene en cada uno de las actividades.
- Analizar y comprender la naturaleza del negocio, obteniendo los requerimientos e indicadores claves del negocio.
- Generar un data warehouse de los datos del proceso de admisión 2016 y 2018.
- Desplegar resultados de indicadores claves basados en los criterios establecidos por el posgrado.
- Generar un dashboard para una mayor comprensión de la información.

Diseño técnico de la arquitectura

Para el diseño técnico de la arquitectura el posgrado proporcionó infraestructura para almacenar los datos, a continuación, se describen las herramientas tecnológicas a usar para lograr los objetivos del proyecto en la tabla 2.

Equipo	Uso
Servidor	• Almacenar el sistema operacional y data warehouse. • Herramienta Pentaho Data Integration y Power Bi.
Ordenador institucional	• Proporciona el acceso al servidor para el desarrollo del proyecto.
Internet institucional	• Otorga acceso a internet.

Cuadro 2. Infraestructura

En la Figura 2 se muestra gráficamente como está conformada la infraestructura en que se desarrolla el proyecto.

Figura 2. Infraestructura

El posgrado cuenta con acceso permanente de internet a través de internet, la infraestructura con la que se cuenta es básica pero suficiente para poder desarrollar el proyecto.

Selección del producto e instalación

Para la implementación del prototipo se tiene Windows 7 Professional y MySQL como motor de base de datos donde se va a almacenar el data warehouse. Para llevar a cabo el ETL se utilizó la herramienta de Pentaho Data Integration y para mostrar los indicadores clave la herramienta de Power BI. Ninguna de las versiones utilizadas tiene costo.

Modelo dimensional

Para el desarrollo del modelo dimensional en este proyecto los datos se obtuvieron de un sistema operacional utilizado por el posgrado, de aquí se requieren los siguientes datos para cumplir con los requisitos del negocio, en la Tabla 3 se detallan esa información requerida.

Tabla	Datos
Examen de conocimientos	Promedio del examen
Exani III	ICNE (Puntaje CENEVAL), Áreas del Exani
Tiempo	Fecha
Aspirante	Nombre, Sexo, Estado Civil, Hijos, Institución, Promedio de universidad, Tipo de titulación
Entrevista	Puntaje de las áreas de la entrevista
Documentos	Título, Cédula, TOEFL, Carta de exposición de motivos, Certificado de estudios

Cuadro 2. Datos para el modelo dimensional

Estos datos son la base de proceso de admisión, con ellos se conoce al candidato y se evalúa su desempeño del mismo, son de gran importancia pero para ello se requiere dar un formato estándar con el fin de que sea entendible para el posgrado, en el proceso de ETL son transformados para que tengan una calidad basada en los estándares del posgrado, con esta ayuda la reducción de tiempos en captura de datos y toma de decisiones disminuirá grandemente.

Diseño Físico

El diseño físico y construcción del data warehouse se llevó a cabo en MySQL de Oracle Corporation (2018), aquí se estarán ingresando los datos de cada proceso de admisión del posgrado de calidad. Para esto se requirió analizar el origen de los datos, realizar un respaldo de las tablas que se ocupan para posteriormente hacer el proceso ETL.

Diseño y desarrollo del ETL

El proceso de extracción, transformación y carga (ETL) se realizó con la extracción de datos desde el sistema de origen; estos datos con un análisis previos se hacen las transformaciones correspondientes y son cargados al data warehouse. A continuación, se describen cada una de las etapas del proceso ETL.

Extracción de datos

Para poder hacer la extracción de los datos se utilizó la herramienta de pentaho data integration de Hitachi Vantara (2018) donde se hace la conexión a la base de datos del sistema de origen y el respaldo con la información necesaria para generar el data warehouse.

Esta extracción de los datos se realizó justo antes de la transformación y carga de los datos al data warehouse que está programada para que se actualice cada día durante el proceso de admisión.

Transformación y Carga de los datos

Una vez que se hizo la extracción de los datos, son transformados para poder hacer las dimensiones basadas en los requerimientos del negocio y hacer el correspondiente data warehouse; este proceso se hace en pentaho data integration, en una transformación se hacen las distintas dimensiones como se observa en la Figura 3.

Figura 3**.** Transformación de los datos

Para cada salida de dimensión puede venir de una, dos o más tablas que son unidas y transformadas generando la dimensión deseada de los indicadores clave. Algunas de las transformaciones son:

- Concatenar el nombre de los aspirantes.
- Inner Join entre tablas.
- Encontrar valores null y remplazar su valor.
- Seleccionar y renombrar atributos.
- Ordenar valores.
- Desnormalizar datos.
- Utilizar formulas con la calculadora de pentaho.
- Eliminar valores duplicados.
- Agrupar valores.

Por último, ya transformados con éxito todos los datos son cargados en la tabla de dimensiones y en la tabla de hechos.

Implementación

Por último, el data warehouse se mostrará con la herramienta de Power Bi de Microsoft (2018), dando a conocer los indicadores claves establecidos en las reuniones con el coordinador del posgrado. En la figura 4 se muestra el modelo dimensional y en la figuras 5 se observa el Dashboard finalizado.

Figura 4. Modelo dimensional

Figura 5. Dashboard.

De igual manera se hizo una validación ad hoc donde se observó que los resultados de la consulta en un Excel previamente realizado como base de datos (antes de estar en la base de datos MySQL) son iguales a los encontrados en una consulta en el programa de Pentaho.

Gestión del proyecto

En el desarrollo de todo el proyecto se realizaron juntas continuas para revisión de avance y toma de decisiones.

Conclusiones y recomendaciones

En este artículo se desarrolló un data warehouse enfocado en la selección de candidatos del proceso de admisión de un posgrado de calidad con la ayuda de la herramienta pentaho data integration, se partió de los datos de una plataforma con la información requerida para conocer a los candidatos. Con la metodología de Kimball, tomando las áreas de la tecnología y datos de la metodología, se desarrolló un Data Warehouse, primeramente, aplicando el proceso de extracción, transformación y carga de los datos relevantes del candidato. Se logró implementar esta solución de inteligencia de negocios que proporciona una toma de decisiones amigable para el coordinador del programa ya que es sencilla e interactiva, no solo eso sino tienen la información de manera inmediata y en todo momento que se tenga acceso a internet.

En futuros trabajos futuros, se pretende contrastar los criterios que actualmente toman en cuenta con unos recomendados por investigaciones relacionadas a posgrados de calidad y un análisis de los datos de las generaciones que han pasado por el posgrado para ponderar los nuevos criterios. También se pretende realizar minería de datos para realizar predicciones en los estudiantes, evitando futuras deserciones en el posgrado.

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InCense IoT: A Collective Sensing System for Behavior Data in Shared Spaces †

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Abstract: Behavioral sensing systems collect data from smartphones, wearables, and other devices with the aim of analyzing and making sense of them. In this work, we present InCense IoT, a collective sensing system which uses mobile and ubiquitous sensors for collecting behavior data of groups of participants in shared spaces. This paper describes the concept of collective sensing, an implementation onto InCense called InCense IoT, innovative features, advantages over individual-centric sensing systems. Finally, this paper presents results of a use case using it in monitoring behaviors in mother-child interactions.

Keywords: collective sensing; mobile sensing; behavioral sensing system

1. Introduction

In recent years, the Internet of Things (IoT) has become popular due to the implementation of useful applications in different areas (e.g., activity recognition). Researchers typically relate this term with technologies such as sensors, actuators, and mobile devices, which combine efforts to solve problems of daily life. Due to the advancement and popularity of IoT, there is interest in using IoT-based systems in the industry such as security, transportation, environmental monitoring, and many others.

Researchers have created various tools which can be used for creating mobile sensing campaigns. These tools, which we refer to as Behavioral Sensing Systems (BSS), are responsible for monitoring human subjects using smartphones, wearables, and other devices. These BSSs have been applied in several domains such as health care. For instance, in [1] implemented a BSS as an alert mechanism for in-hospital emergencies. Also, there are specialized platforms in health monitoring for patients with chronic diseases for home care, hospital or in travel environments [2]. BSSs are used in transport domain to measure and locate delays in public roads and reroute the user [3]. Also, BSSs have been used to identify the user's transport method [4,5].

Although BSSs have been previously proposed, such as [6–10], they have several limitations, such as the following: (1) BSSs are not standardized nor very flexible, so each time an investigation or sensing campaign is planned, a sensing system is typically created or extended; (2) Apart from battery limitations, mobile phones, wearables are heterogeneous, meaning that the model and brand determines the types of sensors included, the quality of them, as well as the quality of data they can collect; (3) Finally, the majority of BSSs are individual-centric [6,7,10–12], therefore some group context can be difficult to infer. We will explain this in the following sections.

In scenarios in which studying family members and their context is important, an integral sensing system is required so that is can collect data from the family members' mobile phones and sensing devices positioned in locations where the family gathers such as the kitchen, the living room or the backyard. Beyond that, from a research point of view, the researcher must be capable of configuring the sensing system to collect and pre-process selective data without too much hassle. Although sensing platforms can indeed collect data from fixed sensors, they mainly focus on collecting continuous streams of data regardless of their significance or user privacy [13,14] or portraying objects as data/service providers [15,16]. Having a platform that can be configured to collect individual (e.g., mobile phone sensor data) and group context (e.g., sensor data from a fixed device in the living room) from the researcher's desk at pre-deployment or at runtime are particularly rare. This is desirable since sensing campaigns (i.e., data collection protocols) requirements can vary across time as they can be running for months.

Conventional BSSs mainly focused on the sensors placed in the mobile phone. Using fixed devices positioned at particular locations in the home setting can open the possibility of using much more specialized sensors than those used in mobile devices (e.g., indoor temperature, carbon dioxide levels). Needless to say, in particular scenarios or studies, this can enrich context to the extent that making sense of collected data would be otherwise difficult. Furthermore, since BSSs focus typically on inferring human activities, using individual and collective context can provide a better understanding of them. For instance, some studies have shown that there is a link between mood and outside weather [17]. Studying similar variables, and family dynamics, can help explain, and perhaps infer, much more complex variables such as mood changes in patient with bipolar disorder being monitored. Again, several sensors that may be of interest are not typically included in off-the-shelf devices such as smartphones.

In this work, we extend a mobile phone sensing platform [18–20] by including non-mobile sensors placed in commercial IoT devices such as Raspberry Pi or Intel Edison. By adding non-mobile sensors, and readily use them in a sensing campaign, altogether with smartphones, we are able to design a unique sensing campaign and collect behavior data from groups or collectivities. We also present how we extended the mobile phone sensing platform and how it was implemented in a semi-controlled setting to collect data from a dyad being monitored. Even when non-mobile sensors have been previously used in sensing campaigns, using a single platform to configure mobile phones and non-mobile devices can be useful for rapidly deploying sensing campaigns. This is indeed one of the advantages of the proposed approach.

This paper presents a novel approach for implementing sensing campaigns, using an extensible architecture of an existent sensing platform. In the following sections we describe the concept collective sensing, our implementation of a platform which supports collective sensing, its advantages over other similar platforms, and the main architecture and features of the platform. Also, we present a use case to illustrate how the platform can be deployed in such settings.

2. Collective Sensing

Collective sensing consists of using diverse mobile and non-mobile devices capable of selectively collecting group context when they interact with each other either in shared spaces or when they are not together. Also, collective sensing provides the ability to sense groups such as families, classroom or campus-wide studies, guest buildings, conferences, or any other type of groups or communities, which scientists can be interested in studying.

One of the appeals of collective sensing, as presented in this work, is not necessarily on full streams of raw data collected and aggregated on a central repository, which implies challenges of its own such as sensor stream synchronization or data fusion, but rather *when* those raw sensor data are collected and *how* are treated by the mobile and non-mobile devices. All this can be done at design stage of the sensing campaign from the researcher's desk. That is, the effort put when deploying devices and preparing them for a sensing campaign can be minimal, but also in redeploying a sensing campaign at runtime since once connected to the network participating devices can be (re)programmed from the researcher's desk through a web-based interface. The mobile and

non-mobile devices used run operating systems (OS) such as Android or Linux, which facilitate remote manipulation and configuration at runtime.

The advantages of collective sensing, when compared to most individual-centric sensing platforms, are (1) better understanding of group context, (2) greater coverage of the environment beyond the individual, (3) higher data richness due to specialized sensors typically lacking in mobile devices, and (4) greater control over the sensing platform at design stage and runtime through a single web-based interface through which configure and deploy sensing campaigns. The latter is particularly useful since researchers have typically little time or technical knowledge needed for reconfiguring or reprogramming smartphones or devices such as a Raspberry Pi.

We can envision several applications for collective sensing with the scope presented. First, studying the behavior of older adults in nursing homes, their affective state when they are together in a group, and the effects the environment may have on their wellness. Also, one could study dysfunctional families to better understand what and how family dynamics influence individual behavior, and the other way around. Another study of interest, such as the one of [21], can be students' performance with respect to their environment and group coexistence. The latter is a less controlled environment since student life can involve several locations such as the home, university campus (e.g., library, classroom), a friend's house, and public locations such as restaurants, which can be difficult to implement with some existing platforms.

Currently, there is no BSS that supports the requirements of collective sensing. As mentioned, most BSS are individual-centric, making use of mobile devices such as smartphones, typically leaving aside the group context. The implementation of collective sensing facilitates and enriches research that requires studying multiple participants who gather or cohabit in the same space. Important requirements for a collective sensing platform include: (1) flexible sensing campaign configuration at runtime, enabling the researcher to have multiple options for sensing (2) campaign editing at any time, in case the user has to make corrective changes on the fly, without delaying the re-deployment of devices, (3) automatic creation of sensing components, saving time of programming to the user, (4) automatic programming of non-mobile devices, and (5) security and privacy of collected data with isolated instances of relational databases and raw data preprocessed before leaving the participating devices.

There are several challenges associated with the implementation of collective sensing, among which are: (a) homogenization of collected data from different vendors; (b) aggregation of data for analysis; (c) web-based management of sensing campaigns; (d) support of both mobile (e.g., smartphones), and non-mobile devices (e.g., Raspberry Pi); (e) different energy consumption and uptime for mobile and non-mobile devices. Furthermore, in regards to formal research, there are also challenges associated with deploying a sensing campaign in scenarios like those discussed above. First, informed consent can be easier when dealing with individuals. Group members can surely sign informed consents, but it may be difficult to disaggregate group context when some of them do not consent to collect, say, temperature data from them.

A Scenario for Collective Sensing

"Andrew is a psychologist who wants to study dysfunctional families to a different level. He has been working for years on this topic, but would really like to have a breakthrough in his area. He just heard about a new way in which mobile technologies can be used. As a trial, he has invited a mid-class family who live in the suburbs, the Johnston family, to collaborate in the study. A few devices have been setup in their home, and everyone agreed to install an app in their mobile phones. Andrew was interested in the time they spent together, and types of places the members of the family were at when they were not together. The devices at home enabled Andrew to have an idea of when they were having conversations, and through their mobiles, he knew exactly who were talking to whom. In addition, Andrew had information about specific aspects of the house such as interior temperature per room, luminosity, motion sensors, and other aspects that haven been reported in the literature to have effects on day-to-day mood. Since he has a psychological background of each member, he knew that John, the youngest one, was particularly prone to detachment which affected

Julia, his mother, and this in turn affected Pedro, the father, who at the time was unemployed. Pedro was having episodes of substance abuse, which made him more verbally aggressive toward Julia and Mary, one of the oldest children. Julia felt overly neglected and had depressive symptoms. Mary, on the other hand, did not know if she was to blame for her father's behavior. After 16 weeks of collecting data, Andrew found that the more time they spent together in the kitchen, the less likely they displayed aggressive behaviors. He also found an interesting connection between the weather and mood changes of John. Andrew was very satisfied with the technology he acquired, since he did not consider himself to be tech-savvy"

3. InCense IoT: A Collective Sensing System for Sensing Campaigns

We extended InCense [7,19,20] a mobile sensing platform to include IoT devices. InCense is a mobile sensing platform running on Android powered devices (e.g., mobile phones, Google Glass) with which several investigations have been carried out. Some of the core features are: (a) Dynamic reconfiguration, (b) Data condensation, (c) Data transmission, and (d) Graphical User Interface (GUI) for configuring sensing campaigns [7].

We extended the physical architecture of InCense, which is now composed of different hardware and software components, we named this extension InCense IoT. The InCense server directs the flow of the configuration of the sensing campaigns. A web platform runs on the InCense server for configuring and setting up the sensing campaigns. An Application Programming Interface (API) is used for receiving the data coming from the IoT devices. Also, an encoder component is now responsible for generating source code for the IoT devices (e.g., Edison, Raspberry Pi) and the database, which at the moment is located on the InCense server.

In the extended architecture, mainly text-based data, mainly text-based are collected in JavaScript Object Notation (JSON) representations. Audio streams are collected in audio files, and then processed for extracting features of interest, usually without the captured audio file leaving the participating device for privacy and network performance. Once on the InCense server, preprocessed data are stored in the data structure (see Figure 1). For the scientist's convenience, the platform provides credentials for the direct management of the database, in case this is required. The owner of each campaign can provide data access to collaborators, according to the role they have in the study (e.g., participant, principal scientist, student).

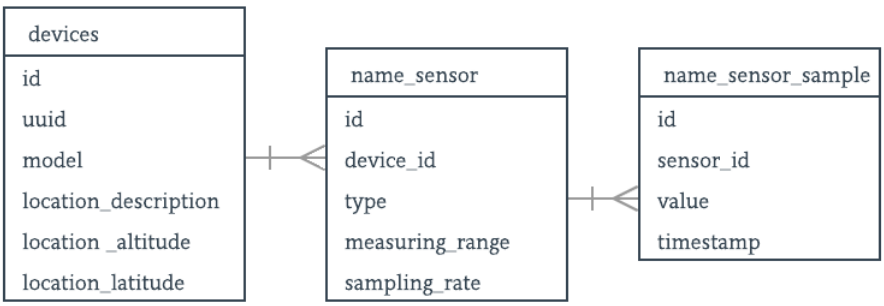

Figure 1. Basic data structure of the extended architecture of InCense.

The data structure is based on a relational database diagram, in which each device has a one-to-many relationship with the sensors, and the sensors a one-to-many relationship with the collected samples. In this structure, the device's universally unique identifier (UUID), model (i.e., Intel Edison), human-readable location, and geo-coordinates (i.e., latitude, longitude) of the device. The data stored for each sensor varies depending on its capabilities (e.g., celsius_accuracy for temperature sensor). A table was defined in the structure (schema) for each type of sample associated with a sensor. A value and a timestamp fields are defined for each sample. Using a data structure has some advantages such as the scientist has a greater understanding of the characteristics of the samples and sensors. It also allows making use of queries using database engines.

The scientist running the campaign can create several sensing campaigns at the same time. Each campaign is assigned an individual database to manage the collected data in an isolated and safe way. Only the owner of the campaign has full access to the collected data, the owner's collaborators have access to the features the owner wants, such as campaign editing, graphs visualization. Database credentials are provided only to the owner. Currently, the researcher cannot manipulate data through the web-based interface; the only way to manipulate the collected data is using standard SQL language using the credentials. Its storage efficiency is the same as a relational database with the pros and cons they currently have. To start the campaign, it is necessary to upload a configuration JSON file to the system through the web-based GUI. This file can be generated by the InCense platform or manually created by a programmer (if desired), and it includes the configuration file for the sensing campaign. At the moment, the GUI and the background routines translate this campaign into source code (e.g., Python) for the IoT devices. Once the campaign is configured, it can be modified by the InCense IoT platform, if necessary. Sensing campaigns metadata can also be modified: collaborators, devices, sensors, and the name, description and status of the sensing campaign (see Figure 2).

The configuration of the sensing campaign includes several sections. The Main section provides access to the following data: status, name, and description. The Collaborators section: A collaborator can be added by entering the email and the permissions (info campaign, edit campaign). The Device section: model, UUID, location description, location latitude, location longitude. The Sensors section: associated device, sensor type, sampling rate, and specific fields for each type of sensor. Once the sensing campaign is set up, the non-mobile devices are programmed automatically to collect data with the chosen configuration.

The GUI displays the information using time-based data graphs. In this way, the researcher has an overview of the data before analysis (Figure 3). This visualization allows monitoring the sensing campaign at any time with a dynamic interface, with the option of selecting the device, the sensor, and the time interval in which the data were collected. Finally, the geographical location of the associated device is shown on a map. This location is based on the Google Maps API, thus the granularity for indoor positioning can be still widely unavailable.

Following Figure 4, The *Encoder* interprets the configuration of the sensing campaign in JSON format to create the necessary scripts for sensing in non-mobile devices i.e., InCense IoT. What it does is that it takes the code template in Python (Figure 5) associated with the sensor, and replaces the indicated lines of code with the specifications of the campaign. This template file is manipulated through a JavaScript library. Based on this template, for each sensor configured a new file is created and stored in a Git repository, accessible to the non-mobile devices. Also, there is a file which is configured in the creation of the sensing campaign which is executed by the CRON (Daemon) of the OS. This python file executes all the scripts in a multithread way, which begins the sensing process transparently for the IoT device.

Figure 2. GUI of the Sensing Campaigns Manager.

Figure 3. GUI for data visualization.

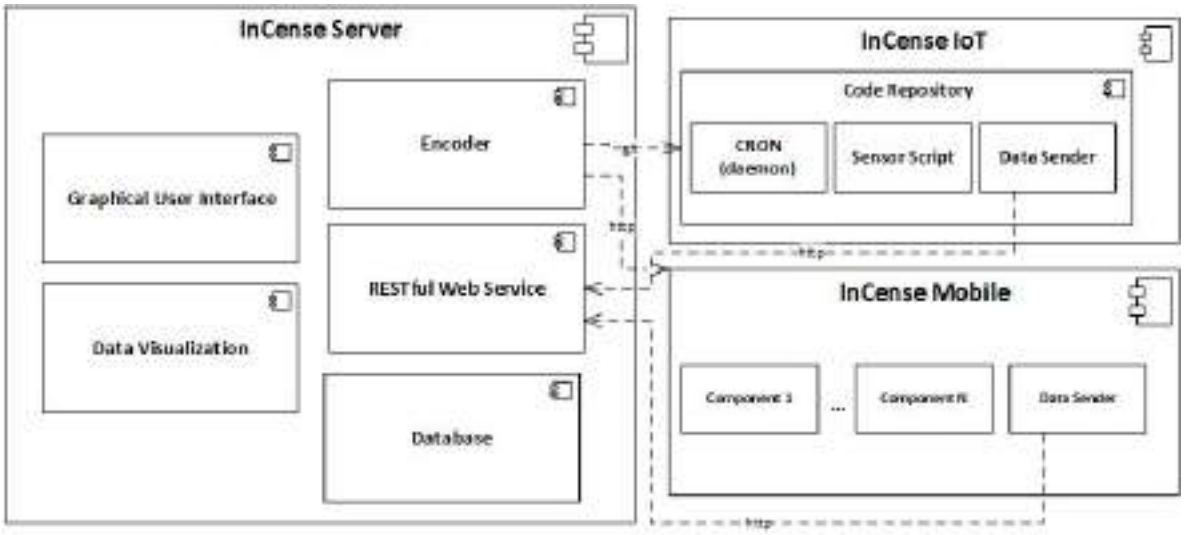

Figure 4. Extended InCense Architecture.

In the IoT device i.e., non-mobile device, data are stored in JSON representations. The devices are then synchronized to send the files to the server at a specific time of the day, usually at night. This configuration is executed by the CRON routines of the OS. Then, data are received by RESTful methods implemented on the InCense server, and are stored in the database associated with the

sensing campaign. Data can be accessed in three different ways: (1) a web-based visualization system, (2) accessing the database with the corresponding credentials, and (3) downloading the SQL file with the schema and data collected, that is, the SQL dump files.

```
MAIN ()
 1:   temperature <- grove->GroveTemp(__PIN__)
 2:   WHILE true THEN
 3:      begin <- time()
 4:      data->append([time(), __VALUE__])
 5:      cont ++
 6:      IF cont == __FILE__ THEN
 7:         finish <- time()
 8:         json->add(data)
 9:         cont <- 0
10:      END IF
11:      wait(__SAMPLE__)
12:   END WHILE
```

Figure 5. Pseudocode Script Example from the Encoder.

4. Use Case: Piloting InCense IoT and Collective Sensing

In order to illustrate how the InCense can be used by researchers from the social sciences, we include a use case in which we collected data from a mother-child in a semi-controlled environment. The purpose of this use case is two-fold: (1) illustrate how InCense IoT can be deployed to collect the data of interest, and (2) provide social scientists with a relatively simple use case that can help them envision the potential usefulness in their research.

This data collection protocol was designed by therapists of children with disabilities who were interested in studying how mothers behave when their children are faced with a mildly-challenging task. In particular, therapists were interested in mothers' directive behaviors, which are important since they can have several implications for child's self-management and self-determination.

For the data collection protocol, the task was defined to be putting a puzzle together, for which we implemented InCense IoT. The project was approved by an IRB, and we obtained an informed consent from all mothers.

For directive behaviors, we collected physical proximity and direct intervention, and voice directions or instructions by the parents. Through the therapists, we recruited 12 mother-child dyads. All children are individuals with Down syndrome. The sessions briefly consisted of a child putting 3 puzzles together in direct supervision of the mother (see Figure 6b). The child received three boxes, each containing a puzzle with increasing number of pieces, 4, 9 and 21 pieces, respectively. Each child received one box at a time, the ones with fewer pieces first.

(**a**) (**b**)

Figure 6. Collective sensing use case.

For this use case, we used a sensing campaign configured with the implemented platform creating components that could help us monitor parents' behavior (Figure 7). InCense Mobile was

running on an Android-based smartphone, using a mic headset. This was used for detecting the mother's voice directions. Audio data was treated in discrete samples of 1000ms. We used standard pitch-based algorithms for detecting when the mother was speaking. For inferring mother's intervention, we used an accelerometer sensor for the smartphone, and the ultrasonic sensor in the IoT device to detect when she approached her child. These two components can be combined to monitor mothers' directive behaviors using rule-based inferences or other approaches such as fuzzy logic or neural networks.


```
{
    "campaign": "Monitoring Parents' Behaviors for Self-management in Children with Disabilities",
    "begin": "1523718070",
    "end": "1523721670",
    "mobile-devices": [{
        "model": "Android Device",
        "os_version": "8.1",
        "participant_id": "1",
        "sensors": [{
                "component": "voice_directions",
                "filter": "volume",
                "sampling_rate": "1000ms",
                "type": "microphone_sensor"
            },
            {
                "component": "hands_motion",
                "sampling_rate": "500ms",
                "type": "accelerometer_sensor"
            }
        ]
    }],
    "iot-devices": [{
        "location_description": "Room A",
        "location_latitude": 27.4708107,
        "location_longitude": -109.93227,
        "model": "Intel Edison",
        "uuid": "480ccf9d-e05d-40b0-9ad5-9c5eefc69bbd",
        "sensors": [{
            "component": "physical_proximity",
            "pin": "AIO Pin 1",
            "sampling_rate": "1000ms",
            "type": "ultrasonic_sensor"
        }]
    }]
}
```


Figure 7. JSON representation of the sensing campaign.

For the audio data, a volume filter was applied combined with a rule-based for recording audio excerpts. It records an audio excerpt when it detects a pitch and it stops when it detects a 3-s silence. Also, a filter was applied to the distance data. The boundaries were configured 0–3 m distance between the parent and the child.

Apart from the technical aspects enabling the implementation of this data collection protocol, and the obvious limitations such as the reduced number of participants, it is important to highlight how a platform such this one can help social scientists, physicians, psychologists, or therapists. One of the most obvious ones is automatic labeling of events in semi-controlled or potentially naturalistic environments. Typically social scientists base their research on self-report through questionnaires or interviews. Self-report based on users' accounts has been reported to be prone to unintended bias and is often unreliable [7]. Other research methods used in controlled or semi-controlled environments by behavioral scientists is direct or indirect observation (using typically two observers for unbiased analysis) based on video analysis or in situ observation, which is time consuming and exhausting not only to plan, and perform, but also to analyze. Using automatic or semi-automatic labeling of events of interest can speed up and scale up studies such as the ones shown

5. Discussion

Technology such as the one discussed in this paper can help social scientists, physicians, psychologists, or therapists to better understand scenarios where multiple people interact with each other, particularly in contexts wherein group interaction can be meaningful. Apart from recording human activity of interest, researchers can utilize this technology to automatically label events of interest. This in turn can be used to better tailor certain therapies or non-pharmacological interventions.

There are several challenges associated with this. One of them is disaggregating group context, in case this is required. Having the individual and the group as separate units for analysis can be definitely useful for advancing research. We believe that collective context can have several implications for advancing research in areas where collective and individual contexts may both matter, as one may be interested in understanding which one influences the other.

Our technical work has still several limitations, like knowing in advance which IoT device i.e., hardware will be deployed, and which sensors and in what pins they have been mounted. This is because at design stage sensing campaigns program devices to selectively collect context, which implies that not all data streams are considered at once. Although for some areas collecting all raw sensor data can be desirable and may be needed at the same time (e.g., machine learning), in practical applications such as a household this can be unfeasible for privacy and security (i.e., on-device processing), network usage, and costs associated with storage, retrieval, and computing of those data.

6. Conclusions

In this paper, we presented a BSS that can be used for collective sensing, a paradigm for sensing campaigns which augments mobile sensing campaigns. It provides a paradigm capable of studying groups combining sensors in fixed locations with mobile sensing. Also, it makes use of a GUI for creating sensing campaigns without deep technical aspects of programming, since the platform is responsible for making the necessary code for the devices. It stores the data collected in a schema previously defined in a relational database. The researcher is provided with credential for accessing collected raw data.

Our current implementation enables adding more researchers to the campaign, so they can contribute, the owner grants privileges through the platform (information, edit, visualization). The visualization of the data is a feature in which the researcher can select the time interval of the data to visualize as well as the specific device and sensor can be selected. We are planning several improvements for this visualization feature, like adding new graphs which can give more sense to the data, the graphs interactions have a lot of potential for the researchers in terms of data analysis and advanced visualization features.

As future work, we are going to provide support to several IoT devices and typical sensors for behavior analysis. The reason for adding more devices is to give researchers more than one alternative in terms of the devices they can use. Our initial device (i.e., Edison) is no longer being manufactured by Intel. However, we are abstracting the complexity by using high-level languages running on Linux-based open-source boards such as Raspberry Pi 3. In the long run, we plan to implement a web-based tool capable of analyzing collected data, with the features to make statistical operations and apply strategies for patterns recognition such as fuzzy logic or neural networks using standard Python libraries. We plan to release a public version of our platform soon.

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A mechanism for biasing the appraisal process in affective agents

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Abstract

In this paper we present a mechanism to model the influence of agents' internal and external factors on the emotional evaluation of stimuli in computational models of emotions. We propose the modification of configurable appraisal dimensions (such as desirability and pleasure) based on influencing factors. As part of the presented mechanism, we introduce influencing models to define the relationship between a given influencing factor and a given set of configurable appraisal dimensions utilized in the emotional evaluation phase. Influencing models translate factors' influences (on the emotional evaluation) into fuzzy logic adjustments (e.g., a shift in the limits of fuzzy membership functions), which allow biasing the emotional evaluation of stimuli. We implemented a proof-of-concept computational model of emotions based on real-world data about individuals' emotions. The obtained empirical evidence indicates that the proposed mechanism can properly affect the emotional evaluation of stimuli while preserving the overall behavior of the model of emotions.

Keywords: Appraisal process; Influencing factor; Computational model; Proof of concept; Affective agent

1. Introduction

Autonomous Agents (AAs) are software entities capable of perceiving changes within their environment and performing actions autonomously to accomplish their goals. In general, AAs may have abilities for agent-to-agent and human-to-agent communication, coordination, negotiation, learning, among others (Perlovsky & Kuvich, 2013; Wang, Zatarain, & Valipour, 2017). In particular, providing AAs with capabilities for synthetic emotion generation and emotion recognition allows this type of intelligent system to perceive its environment from an emotional perspective, exhibit social behaviors, and maintain natural interactions with human users. Application domains in which this type of AAs are useful range from analysis of social aspects of human behavior (Dancy & Schwartz, 2017) and simulation of emergency situations (Pan, Han, Law, & Latombe, 2006; Tsai et al., 2011; Zoumpoulaki, Avradinis, & Vosinakis, 2010) to virtual environments that require extensive interaction between AAs and human users such as intelligent tutoring systems (Ammar, Neji, Alimi, & Gouardères, 2010; Mao & Li, 2010), personalized virtual assistants (Chen, Zhou, Tao, Yang, & Hu, 2018; Eyben et al., 2010), and robots for health care (Broadbent, Stafford, & MacDonald, 2009; Kirby, Forlizzi, & Simmons, 2010).

According to literature from psychology, human emotions can be seen as a process that involves a subjective appraisal of significant events as well as the preparation

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of the organism for dealing with such events (LeDoux & Hofmann, 2018). Emotions are elicited when an individual perceives a relevant stimulus. This relevance is determined by diverse factors such as the individual's current needs, motivations, beliefs, mood, and goals (Ortony, Clore, & Collins, 1990; Roseman, Spindel, & Jose, 1990; Scherer, 1999). Regarding the preparation for dealing with events, emotions impose the execution or suspension of actions to individuals according to the subjective assessment of their emotional environment. In general, emotions involve various sub-systems such as the motivational, behavioral, perceptual, and attentional. Moreover, human's individual differences (e.g., personality and culture) play an essential role in assessing perceived emotional stimuli and the kind of emotional responses exhibited (Kitayama, Mesquita, & Karasawa, 2006; Larsen & Buss, 2009; Mesquita & Karasawa, 2002; Rusting, 1998).

The design and implementation of Computational Models of Emotions (CMEs) have been the main approach adopted to incorporate affective mechanisms in AAs. A CME is a software system designed to synthesize some of the phases, processes, and mechanisms of the human emotion process. In general, this type of model implements mechanisms to define (i) the emotional evaluation of perceived stimuli (fast and slow assessments), (ii) the elicitation of emotions, and (iii) the generation of emotion-driven behaviors. Through these three general phases, CMEs attempt to provide AAs with capabilities to recognize emotions from humans and artificial agents, simulate and express emotional feelings, and execute emotional responses, among others. We describe the main objective of each of these three phases as follows (Castellanos, Rodríguez, Castro, & Gutierrez-Garcia, 2018; Rodríguez & Ramos, 2014, 2015; Rodríguez, Gutierrez-Garcia, & Ramos, 2016):

- The phase of *emotional evaluation* is concerned with the emotional assessment of stimuli perceived by agents. This assessment process depends on, among other aspects, agents' current internal condition, their beliefs about these stimuli, previous experiences, and the situation in which agents are involved. In addition, given that each agent is designed to maintain different beliefs and therefore attain very distinctive internal conditions, the emotional significance assigned to the perceived stimuli is particular to each agent. The output of this phase is an evaluation of the stimuli perceived by agents in terms of their emotional significance.
- The phase of *elicitation of emotions* defines agents' emotional states on the basis of the information provided by the emotional evaluation. The evaluations conducted in the first phase lead to the generation of emotions and the agents' emotional states. These emotions are elicited and differentiated on the basis of agents' current conditions and other elements such as their personality and beliefs. As in the previous phase, given that each agent has a different internal condition across time and situations, the emotion to be elicited is particular to each agent. Emotions elicited have an intensity level that decays over time at a certain rate. Finally, the dynamics of emotions experienced by agents update their mood states.
- The phase of *generation of emotion-driven responses* influences the behavior of AAs based on their previously recognized emotional state. Particularly, the emotional state modulates cognitive and affective processes leading to changes in agents' verbal and nonverbal behaviors. In this manner, all kinds of behaviors performed by agents consistently reflect their internal emotional state. According to the types of emotions elicited and their level of intensity, such behaviors may be developed voluntarily (consistent to agents' current external and internal conditions) or involuntarily (e.g., fast reactions such as those of fight-or-flight). Finally, the emotional behavior implemented by agents and their emotional state may be regulated when they contravene their social context or goals.

Although the three phases have been implemented in most CMEs reported in the literature, each of these phases still pose complex challenges towards the modeling of emotion-related mechanisms (Rodríguez & Ramos, 2014, 2015). These challenges comprise development process issues such as strategies for re-utilization of components, scalable architectures, domain-independent models, definition of standards, benchmarks, software tools and methodologies to support the design and development process. Other relevant challenges comprise theoretical issues such as devising complex mechanisms that mimic the way humans evaluate emotional stimuli (based on individual aspects such as personality and motivations), the elicitation of basic and complex synthetic emotions corresponding to actual agents' affective status, the expression of such elicited emotions, and the generation of emotional behaviors regulated by current social contexts as occurs with humans.

In particular, most CMEs (reported in the literature) implement the phase of *emotional evaluation of stimuli* based on the *appraisal theory* (see Fig. 1) (Breazeal, 2003; El-Nasr, Yen, & Ioerger, 2000; Gebhard, 2005; Marsella & Gratch, 2003; Rodríguez & Ramos, 2015). This theory proposes that emotions are elicited on the basis of the relationship between individuals and their environment (Lazarus, 1991; Ortony et al., 1990; Roseman et al., 1990; Roseman, 1996; Scherer, 1999; Smith & Kirby, 2000, 2009; Scherer, 2001). Appraisal theories assume that emotions arise from the cognitive evaluation of situations, objects, and agents (within the environment) that directly or indirectly impact on goals, plans, and beliefs of the individual. The evaluation of the individual-environment relationship is carried out using a series of *appraisal dimensions* such as *pleasantness*, *goal-conduciveness*, *suddenness*, *novelty*, and *controllability*. After assessing its environment, an agent should be capable of determining how pleasant a certain event is, how well it can cope with that event, and how well it can adjust itself to the consequences,

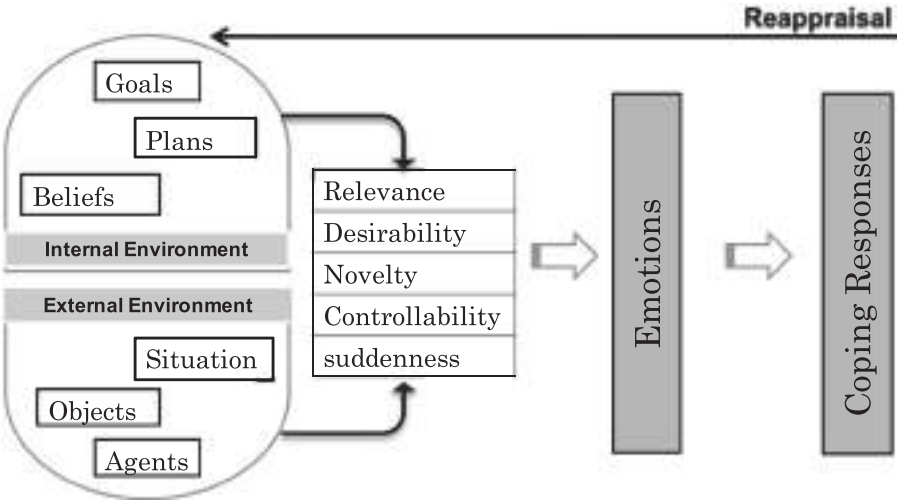

Fig. 1. Emotional assessment of perceived stimuli according to the *Appraisal Theory*.

among other aspects. According to appraisal theories, once this information is collected, coherent emotions can be elicited. The type of emotion elicited depends on the specific values of all the *appraisal dimensions* used in the evaluation process.

In CMEs based on the appraisal theory, a critical task associated with the emotional evaluation phase is the development of computational mechanisms for each *appraisal dimension* utilized. The emotions elicited in AAs depend on the resulting values of these mechanisms underlying appraisal dimensions. For example, fear may be associated with low pleasure, low goal-conduciveness, and low controllability of the perceived event. Particularly, a key challenge associated with the emotional evaluation phase is that the mechanisms of appraisal dimensions should take into account a variety of factors such as agents' current goals, beliefs, motivations, personality, culture, social context, and physical context. According to the evidence that explains human emotions, these types of factors influence the way humans assess and assign an emotional significance to the perceived stimuli. For example, appraisal theories postulate that the assessment of the environment involves factors associated with (i) the individual's current internal condition (e.g., mood), (ii) his/her beliefs about these stimuli (e.g., how pleasant the stimuli are), and (iii) the context in which the individual is involved (e.g., a particular cultural context), among others. Furthermore, evidence from fields such as neuroscience demonstrates that the emotional evaluation of stimuli in humans involves data projections from several cognitive and affective processes. For instance, the amygdala is a brain structure recognized as the main center for the evaluation of emotional stimuli and organization of emotional reactions (Freese & Amaral, 2009; LeDoux, 1989; Phepls, 2006). This brain structure located in the medial temporal lobe is composed of various strongly interconnected nuclei and has extensive connections with other brain structures that underlie cognitive and visceral functions. The amygdala is in charge of processing (i) simple, unimodal, multimodal, and complex sensory information, (ii) contextual, social, and polymodal information about events, (iii) individual's internal motivations and goals, and (iv) information about previous events related to the current perceived stimuli (Lane, Nadel, Allen, & Kaszniak, 2000; LeDoux & Schiller, 2009).

In contemporary CMEs, a variety of factors that influence the emotional evaluation phase are usually taken into account. In fact, some of these factors seem to play an essential role in designing the computational mechanisms underlying *appraisal dimensions*. For instance, to assess appraisal dimensions such as *desirability* and *relevance* of an event, it is necessary to take into account information about agents' current *intentions* and *goals*. Nevertheless, some other factors (such as personality, culture, and motivations) are not seen as indispensable in the design of the computational mechanisms underlying *appraisal dimensions* and therefore they are rarely taken into account. For instance, ALMA (Gebhard, 2005), MAMID (Hudlicka, 2008), and FAtiMA (Dias, Mascarenhas, & Paiva, 2014) are models that take into account personality as an important factor that influences the mechanism underlying the emotion process implemented in CMEs. In addition, although some CMEs take into account this type of factors, the design of most CMEs hardly allows a modification in their architectures without considerable efforts in order to take into consideration factors influencing the emotional evaluation of stimuli, which were not considered in their initial design phase. Moreover, there is a lack of strategies and standards for modeling the complexity of the emotional evaluation phase in a gradual manner.

Modeling emotions in CMEs based on evidence about the functioning of human emotions is critical because a design objective of AAs is to achieve realistic social behaviors that permit natural interactions with humans and other artificial entities. For this reason, we should determine *how to model the influence of internal and external fac-*

tors in the emotional evaluation of perceived stimuli. This is particularly useful in application domains where AAs interact with humans or in the simulation of realistic scenarios. Therefore, as occurs with humans, AAs should incorporate models of emotion capable of evaluating emotional stimuli according to their beliefs, past experiences, current social situation, active motivations, and objectives. In this regard, modeling the influence of internal and external factors in the emotional evaluation of perceived stimuli permits advances in the design of CMEs and ultimately in the design of AAs. However, current CMEs are not designed to be scalable, re-utilizable, or compatible with different agent cognitive architectures.

In this paper we propose a mechanism to model the influence of agents' internal and external factors on the emotional evaluation of stimuli in CMEs. This mechanism adjusts appraisal dimensions (used to emotionally assess the agent's environment) according to influencing factors that may be present in a cognitive agent architecture, and therefore, available to the emotional evaluation phase. In contrast to related literature, our proposal promotes the design of CMEs capable of modeling in a gradual manner the complex emotional evaluation process as occurs in humans. In doing so, our proposal generates synthetic emotions in AAs according to their individuality (i.e., their specific personality, culture, motivations, gender, age, etc.). The paper is structured as follows. In Section 2 we present related work and discuss evidence about internal and external factors that influence the emotional evaluation of stimuli in humans. In Section 3 we introduce the proposed mechanism and in Section 4 we developed a proof of concept to explore the extent to which the mechanism allows the modulation of configurable appraisal dimensions, which ultimately leads to the elicitation of emotions. Finally, we provide some concluding remarks in Section 5.

2. Related work

In this section we discuss how contemporary CMEs have modeled the influence of internal and external factors on the emotional evaluation phase of perceived stimuli in AAs. Particularly, we first present a brief analysis of evidence indicating that a diversity of internal and external factors influence the evaluation of emotional stimuli in humans. We focus on some of the most notable factors associated with people's individuality such as personality, culture, gender, motivations, and social context, which are rarely taken into account in the emotional evaluation process of contemporary CMEs. Then we analyze contemporary CMEs in order to show how they model the influence of these types of internal and external factors in the emotional evaluation phase.

We organize this analysis of CMEs in two parts: *traditional models* and *scalable models*. Traditional models are CMEs designed to model specific aspects of the influence of internal and external factors in the emotional evaluation phase. Scalable models are CMEs whose underlying architecture is designed to model the complexity of the emotional evaluation phase in a gradual manner. In addition, we include a description of the InFra because our proposal is implemented in the context of this integrative framework. Finally, we provide a discussion on the CMEs analyzed.

2.1. Role of influencing factors in the emotional evaluation of stimuli in humans

In this section we analyze the role of influencing factors in the emotional evaluation of stimuli in humans. In particular, we focus on personality, culture, gender, motivations, and social context as those are factors identified in the literature to determine people's individuality but are rarely implemented in contemporary CMEs.

Personality can be defined as a set of characteristics (also called traits) that persist over time and are what distinguish one individual from another. Among these characteristics are thoughts, feelings, attitudes, habits, and behavior. Personality traits shape the way we think, feel, and interpret reality and dictate our behavioral tendencies (Humphreys & Revelle, 1984; Wilson & Dishman, 2015). Rusting (1998) indicates that personality traits lead to individual differences in emotional processing. For instance, neuroticism is a dimension included in several theories to explain personality profiles and is highly associated with individual differences in the propensity for unpleasant emotional experiences (Bolger & Schilling, 1991; Digman, 1990). In this context, personality dimensions such as neuroticism may be associated with negative interpretations of perceived stimuli and an elicitation of negative affect whereas dimensions such as extraversion may be associated with positive interpretations of stimuli and an elicitation of positive affect (Larsen & Buss, 2009; Rusting, 1998). This relationship between personality and the way humans interpret environmental stimuli has led to the design of CMEs that take into account the agent's personality in the emotional evaluation phase (Gebhard, 2005; Hudlicka, 2008).

With respect to mood states, these are also related to individual differences in emotional processing in humans (Larsen & Ketelaar, 1991; Natale & Hantas, 1982; Rusting, 1998). Mood is an internal affective phenomenon that lasts longer than emotions (although not as much as the personality) and has a lower arousal. Mood states represent a predisposition to feel a certain emotion by influencing the way humans evaluate perceived emotional stimuli (Gebhard, 2005; Reisenzein & Weber, 2009). As noted by Rusting (1998), mood states influence emotional information processing. In addition, mood shapes the way people tend to notice and interpret events. For instance, bad mood states lead people to interpret events negatively. Mood states also influence the availability of positive or negative associations in memory, which in turn influence the way emotional stimuli are assessed. For example, negative mood states (such as anxiety) lead to

retrieve negative material from memory that is used in the emotional evaluation of stimuli, leading to a negative influence in the interpretation of events (Rusting, 1998; Vuoskoski & Eerola, 2011). Most CMEs reported in the literature recognize mood states as a crucial aspect to the phase of emotional evaluation (El-Nasr et al., 2000; Marsella & Gratch, 2009; Rodríguez & Ramos, 2014; Velasquez, 1997).

Culture comprises beliefs, values, behaviors, and material objects that constitute a people's way of life. Culture provides structure, guidelines, expectations, and rules that help understand and interpret emotions (Niedenthal & Ric, 2017). According to Mesquita and Karasawa (2002), cultural differences (such as norms and ideals) influence the assessment of a stimulus as pleasant or unpleasant. Also, Kitayama et al. (2006) suggest that culture influences the emotional processing by providing meaning to the individual's context, leading to a systematic variation in emotional experience. Mauro, Sato, and Tucker (1992) demonstrated that some appraisal dimensions (such as control and responsibility) are more susceptible to be influenced by cultural differences than others (such as pleasantness, coping, and goal conduciveness). More importantly, Mesquita and Ellsworth (2001) indicate that although the relationship between appraisal patterns and emotions is universal, the appraisal process is what differs among people with different cultural backgrounds. In contrast to personality and mood, this influencing factor has rarely been taken into account in the computational modeling of emotions (Dias et al., 2014; Mascarenhas, Dias, Prada, & Paiva, 2010).

There are other influencing factors involved in the emotional evaluation of stimuli in humans. We briefly discuss two more instances. Motivations and particularly internal drives such as hunger and thirst are factors that may lead to appraise a stimulus differently. For instance, the consistency of a stimulus in terms of individuals' current drives may lead to a different appraisal of such stimulus, and in turn, to the experience of different emotions (Scherer, Schorr, & Johnstone, 2001). Kismet (Breazeal, 2003) and Cathexis (Velasquez, 1997) are two computational models that take into account motivations in the modeling of emotions. Another factor that shapes the way humans emotionally assess perceived stimuli is gender. Particularly, gender may influence the appraisal of aspects associated with the emotional evaluation of stimuli such as *personal control* in social contexts (Barrett, Robin, Pietromonaco, & Eyssell, 1998). In additional studies, males have been found to be more responsive to positive stimuli whereas females to negative stimuli (Bradley, Codispoti, Cuthbert, & Lang, 2001; Nater, Abbruzzese, Krebs, & Ehlert, 2006). However, to the best of our knowledge, there is no CME whose design takes into account the modeling of the implications of gender differences in the emotional evaluation phase.

2.2. Traditional CMEs

In this section we describe how influencing factors (such as those described in Section 2.1) are taken into account by current CMEs.

In ALMA (Gebhard, 2005), personality traits (based on the five factor model) are utilized to define a default mood for characters, and in this way, to control the calculation of emotion intensity. Furthermore, the personality profile of characters includes appraisal rules determining how such characters appraise environmental stimuli. Similarly, MAMID (Hudlicka, 2005) introduced a methodology for modeling the effects of individual differences in cognitive-affective architectures. In doing so, it takes into account factors that represent individual differences (i.e., personality traits) such as extraversion, stability, aggressiveness, and conscientiousness. These personality traits define personality profiles that in turn modify parameters that control the processing, structure, and content of MAMID's architectural components. In particular, personality traits contribute to emotion elicitation.

Mood states are utilized by most CMEs reported in the literature. In general, mood states are defined as an internal affective state that lasts longer than emotions. In EMA (Marsella & Gratch, 2009), significant events perceived by agents are assessed in terms of a series of appraisal dimensions organized into data structures called *appraisal frames*. These frames are then labeled with a specific type of emotion. In EMA, mood states adjust these appraisal frames in order to determine the agent's affective state, which results from the appraisal frame with the highest intensity. PEACTIDM (Marinier, Laird, & Lewis, 2009) represents mood as an appraisal frame that captures some of the time course and interactions among elicited emotions. Mood states adjust agents' current emotions by influencing *feelings*. Flame (El-Nasr et al., 2000) also utilizes mood states to filter emotions and generate coherent emotional states. In this case, mood represents a modulating factor that can be either positive or negative.

2.3. Scalable CMEs

FAtiMA (Dias et al., 2014) is an agent architecture that utilizes personality, drives, and culture (as modulation factors) to bias emotion intensity. Particularly, FAtiMA implements a *cultural component* that is involved in the evaluation of appraisal dimensions (such as *praiseworthiness*) based on cultural values. More importantly, FAtiMA makes use of a flexible architecture that generalizes the appraisal process (i.e., the emotional evaluation phase). This architecture permits a gradual incorporation of specific appraisal mechanisms that may be based on different appraisal theories. In this manner, the concept of *appraisal frames* is proposed in FAtiMA to represent a series of appraisal dimensions used to assess perceived stimuli and

whose underlying computational mechanisms may model the influence of factors involved in the emotional evaluation of stimuli. It should be noted that although FAtiMA considered the possible influence of different factors in the appraisal process, there is no evidence (e.g., a proof of concept) showing how this influence may occur within the proposed flexible architecture.

FeelMe (Broekens & DeGroot, 2004) is a framework that allows the development of scalable appraisal mechanisms to incrementally model the complexity of the human emotion process. Particularly, this framework incorporates an *appraisal system* that consists of multiple subsystems (called *appraisal banks*), each designed to implement a set of appraisal mechanisms for the emotional evaluation of stimuli. Although the utilization of influencing factors such as personality or culture is not considered in FeelMe, this framework presents a modular and extensible architecture that allows gradual incorporation of appraisal mechanisms.

The Integrative Framework (InFra) (Rodríguez et al., 2016) implements a modular and scalable design to promote the modeling of the interaction between affective and cognitive components implemented by CMEs and cognitive agent architectures, respectively. The InFra incorporates two modules involved in the emotional evaluation of perceived stimuli: *general appraisal* and *emotion filter*. The emotion filter component is designed to facilitate the addition of influencing factors in the emotional evaluation phase by implementing a *modulation fuzzy logic scheme* (see Fig. 2). The main role of such scheme is to serve as an interface between CMEs implemented in the context of the InFra and components in cognitive agent architectures responsible for processing influencing factors (known to be involved in the emotional evaluation of stimuli). The fuzzy logic scheme allows the modulation of the emotional evaluation phase by modifying appraisal dimensions' fuzzy values. The emotion filter amplifies, attenuates or maintains the emotional significance of stimuli perceived by agents. However, as shown in Fig. 2, the fuzzy logic scheme requires determining the effect of each influencing factor on each appraisal dimension. The effect of the influencing factor should indicate what fuzzy sets of appraisal dimensions are favored or disfavored. This effect represents the influence that cognitive components have on agents' affective information. Afterward, a series of fuzzy rules are evaluated to determine the elicited emotion based on the evaluation of perceived stimuli by the different appraisal dimensions.

2.4. Discussion

As seen in the previous subsections, evidence from fields that study human behavior such as psychology and neuroscience indicates that, in humans, the emotional evaluation of stimuli involves a variety of influencing factors, namely personality, culture, gender, among others. However, several of these influencing factors are not usually taken into account in the emotional evaluation phase of CMEs. It is important to note that in addition to the phase of *emotional evaluation of stimuli*, some influencing factors have also been considered by CMEs in the phases of *emotion elicitation* and *generation of emotion-driven behaviors*. In this context, given the theoretical evidence indicating that the evaluation phase is influenced by several internal and external factors, a key question is *why the emotional evaluation of stimuli in contemporary CMEs takes into account only a subset of such internal and external influencing factors?* We believe that a series of challenges should be addressed in order to model the influence in CMEs of all these types of factors. We discuss two of them:

- *Incorporation of CMEs into cognitive agent architectures.* This incorporation requires indicating how the emotional evaluation process must take into account the information projected from modules of cognitive architectures. For instance, developers of CMEs may not know in advance necessary characteristics about influencing factors such as the data structures (used to represent them) and the update frequency of each factor. These types of issues have led CMEs' designers to

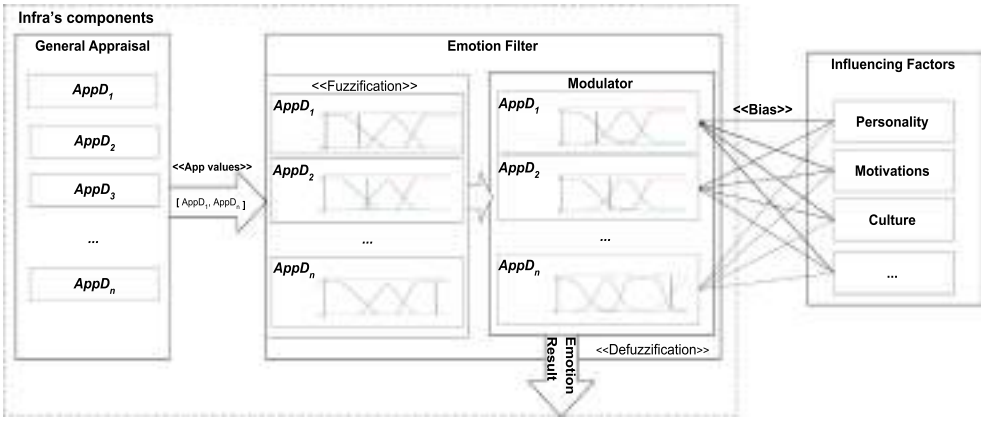

Fig. 2. Fuzzy logic scheme implemented by the InFra for modeling influencing factors.

propose working models that consider only some aspects of the emotion process. In addition, these approaches are not focused on developing scalable frameworks capable of gradually incorporating additional mechanisms to model the influence of diverse factors on the evaluation of emotional stimuli.

- *Theoretical foundations of CMEs*. Although evidence demonstrates that the dynamics of emotions in humans involve a lot of processing of information, there is no clear understanding of this human process. Furthermore, research on human emotion generates a great quantity of evidence explaining this function from diverse perspectives that may be complementary but also contradictory. Particularly, this complexity in the study of human emotions has led to CMEs that model specific facets of the influence of diverse factors such as personality or culture on the emotional evaluation process. This also emphasizes the need for scalable frameworks capable of gradually incorporating new models of influence of any factor on the emotional evaluation process.

Regarding the scalable models reviewed, their main contribution is a structural perspective for modeling the phases of the human emotion process. This type of model usually proposes structural modifications to the underlying architectures of CMEs to achieve flexible and scalable CMEs. In this line of work, they provide explanations as to (i) why the architectural elements are decomposed, (ii) how such elements and decomposition contribute to the scalability, and (iii) how these are interrelated. However, the architectural decomposition proposed by these models is still to be validated in terms of their contribution to the modeling of the human emotion process, and particularly, to the generation of consistent and coherent emotions. It is worth mentioning that these proposals do not present experimental results based on data from human participants.

This present work extends the InFra by providing a mechanism for taking influencing factors into consideration while evaluating emotional stimuli in a gradual manner. Our proposal does not require structural modifications to the underlying architectures of CMEs. In addition, we developed a proof-of-concept system of the proposed mechanism for influencing the emotional evaluation of stimuli. The input of the proof-of-concept system was based on real-world data about emotions, which allowed us to obtain empirical evidence on how our mechanism influences the emotional evaluation of stimuli.

3. A mechanism for influencing the emotional evaluation

In this section, we describe the proposed mechanism to model the influence of agents' external and internal factors on the emotional evaluation phase of CMEs. The proposed mechanism is designed in the context of the InFra (see Section 2 for a description of the InFra). Particularly, the mechanism involves the *general appraisal* module and the *emotion filter* module of the InFra, which are focused on the emotional evaluation of stimuli perceived by agents. Our present proposal extends the InFra by providing a mechanism for modeling the influence of agents' external and internal factors involved in the emotional evaluation of stimuli.

Our mechanism for influencing the emotional evaluation phase is designed to facilitate the modeling of factors that define the individuality of humans, which have a crucial impact on how emotional stimuli are appraised. Among the factors influencing the emotional evaluation are personality, culture, and motivations. It should be noted that these factors are usually left aside in the design of CMEs (as explained in Section 2). Our proposed mechanism is designed to model the influence of any factor implemented in a given cognitive agent architecture. In addition, instead of adopting a monolithic approach that takes into account a number of influencing factors at once (as in ALMA or Flame, to name a few), we propose an approach that allows modeling separately the influence of agents' internal and external factors in a gradual manner. In the remainder of this section, we introduce basic elements associated with the proposed mechanism and then explain the architecture and functionality of such mechanism.

The basic elements of our mechanism for influencing the emotional evaluation are (i) influencing factors, (ii) configurable appraisal dimension, and (iii) influencing models.

- An *influencing factor* is any *internal* and/or *external* phenomenon involved in the emotional evaluation of stimuli in humans. An influencing factor is any information generated and projected from a cognitive or affective component that models a human function or external phenomenon. Instances of influencing factors (known to be involved in the emotional evaluation of stimuli) are motivations, personality, culture, social context, gender, among others.
- A *configurable appraisal dimension* is an appraisal dimension (utilized in emotional evaluation) whose resulting value (obtained from assessing a given agent environment) is modified according to influencing factors. A configurable appraisal dimension can be seen as the parameter that is adjusted to model the effects of influencing factors. In particular, the adjustment of appraisal dimensions depends on the influencing factors available. By adjusting configurable appraisal dimensions, we aim to model how a particular personality profile, cultural feature or any other aspect associated with influencing factors affect the emotional evaluation of stimuli.
- An *influencing model* defines the relationship between a given influencing factor and each configurable appraisal dimension utilized in the emotional evaluation phase. In addition, an influencing model interprets such relationship in terms of fuzzy adjustments. In doing so, we

translate an influencing factor into a fuzzy parameter that can be integrated into the Infra's fuzzy logic scheme. Possible fuzzy logic adjustments are (i) shifts in the limits of fuzzy membership functions of appraisal dimensions and/or (ii) adoption of specific types of membership functions for appraisal dimensions. To determine how much influencing factors should affect configurable appraisal dimensions, the relationship defined by an influencing model may be based on data (collected from studies on emotions) and/or expert knowledge.

Our mechanism for influencing the emotional evaluation can be divided into four phases (Fig. 3): (i) an appraisal phase, (ii) a factor influence calculation phase, (iii) a system adjustment phase, and (iv) a fuzzy calculation phase.

- The *appraisal phase* consists in evaluating agents' perceived stimuli using appraisal dimensions (e.g., dimensions for determining event familiarity and pleasantness) in the general appraisal module. This module assesses perceived stimuli and assigns them a set of numeric values (one for each appraisal dimension) within the continuous range [0, 1].Components involved in the appraisal phase are domain-specific cognitive agent architecture's elements in charge of processing influencing factors. It should be noted that the data structure and format of these influencing factors are highly dependent on the specific component (e.g., a cognitive architecture component modeling personality) that processes this information. It is important to note that the proposed mechanism for influencing emotional evaluation does not require any modification to cognitive agent architecture's elements, which are assumed to be independent from the Infra. Moreover, the mechanism allows the implementation of different appraisal theories.
- The *factor influence calculation phase* consists in computing, by means of influencing models, the relationship between each influencing factor and each appraisal dimension. Based on this relationship value (e.g., a correlation coefficient between an influencing factor and an appraisal dimension), the influencing model determines to what extent the fuzzy logic scheme should be adjusted. In addition, determining how often influencing factors are transmitted from cognitive agent architecture's elements to the adjustment system phase depends on how frequent a given influencing factor should affect agents' emotional evaluation. For instance, the adjustment frequency provoked by an influencing factor such as a personality profile should be very low because agent's personality is assumed to remain relatively stable over a long period of time.
- The *system adjustment phase* consists in modifying the (Infra's) fuzzy logic scheme based on the relationship value between appraisal dimensions and the influencing factors. Possible actions to modify the fuzzy logic scheme are (i) changing the membership function types (for instance, from triangular to trapezoidal) and/or (ii) changing the limits of currently used membership functions. The system adjustment phase is carried out by the (Infra's) emotion filter component. The output of the adjustment phase is a set of adjusted appraisal dimensions.
  It is acknowledged that the influencing models should be designed to receive and process a particular type of influencing factor (e.g., a personality/culture profile) in order to determine the particular type of *fuzzy parameter adjustment* to be made. It is important to mention that for each cognitive agent architecture element influencing agents' emotional evaluation there should be a corresponding influencing model, which determines the adjustment for each configurable appraisal dimension.
- The *fuzzy calculation phase* consists in (de) fuzzifying the values of each appraisal dimension and carrying out the fuzzy logic inference using the adjusted appraisal dimensions. The fuzzy calculation phase is executed by the (Infra's) emotion filter component. It should be noted that the fuzzy inference system should be provided with a set of fuzzy rules to establish the relationship between appraisal dimensions and emotions.

4. A proof of concept based on real-world data about emotions

In this section, we developed a proof of concept of the proposed mechanism for influencing the emotional evalua-

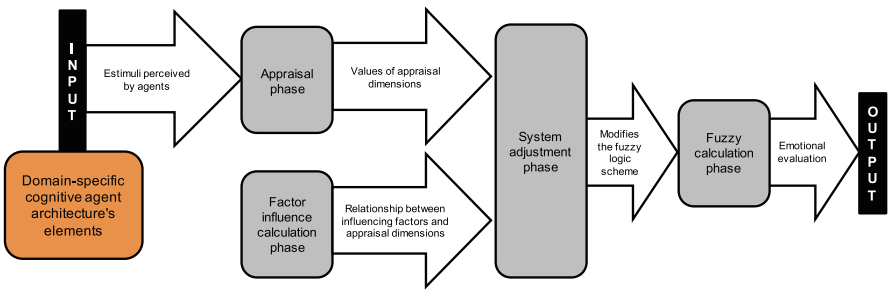

Fig. 3. Phases of the proposed mechanism for influencing emotional evaluation.

tion of stimuli in CMEs (described in Section 3). In particular, we present results from a set of series of emotional evaluations of stimuli perceived by agents (see Figs. 4 and 5). These emotional evaluations were carried out to explore the extent to which an influencing factor modulates the values of configurable appraisal dimensions, which ultimately lead to the elicitation of emotions. The proposed mechanism was implemented using the java programming language and jFuzzyLogic (Cingolani & Alcalá-Fdez, 2013) (a standard-complaint fuzzy logic library), which were also used to implement the modules of the InFra.

The proof of concept presented in this section utilized data about emotions that were extracted from a study reported by Meuleman and Scherer (2013) and Scherer (1993). This study involved 9,102 participants from different countries. Each participant was requested to report an emotionally significant event and to label it with at most two dominant emotions as well as to indicate the corresponding emotion intensity from 1 (the lowest intensity) to 5 (the highest intensity). The available emotions were shame, guilt, sadness, despair, fear, rage, irritation, contempt, anxiety, disgust, joy, pride, and pleasure. In addition to labeling the event with the emotions, the participants were requested to characterize the event using *appraisal dimensions* such as event's relevance, predictability, familiarity, among others. For a complete list of appraisal dimensions utilized see Table 3. The possible values for each appraisal dimension ranged from 0 to 5. For instance, describing an event using the appraisal dimension *familiarity* with a value of 0 indicates that the event was very unfamiliar to a participant and with a value of 5 indicates that the event was very familiar to a participant. Additional data collected about the participants were their language, age, and gender. Please see (Meuleman & Scherer, 2013; Scherer, 1993) for details on the data collection protocol as well as for explanations about the selection and interpretation of the appraisal dimensions.

It is worth mentioning that our proof of concept utilized two out of the thirteen emotions considered in the study: *sadness* and *joy*. We selected these emotions because they were the most commonly reported emotions in the study presented in Meuleman and Scherer (2013) and Scherer (1993). It should be highlighted that in the data set utilized for the proof of concept, each event was labeled by the participants with two emotions, so we created two records (one for each emotion). Moreover, we defined a set of fuzzy rules for these emotions. We utilized the field *gender* of each participant as the influence factor to be implemented in the proof of concept. The influencing model, therefore, was designed to determine the level of influence of this factor on each configurable appraisal dimension (see full list of appraisal dimensions in Table 3). In the proposed proof of concept, we used 100 randomly generated appraisal vectors in order to conduct the analyses. These appraisal vectors consist of a series of values that correspond to each appraisal dimension taken into account (see Table 3). The pseudorandom values were obtained using a uniformly distributed random number generator. The rest of this sec-

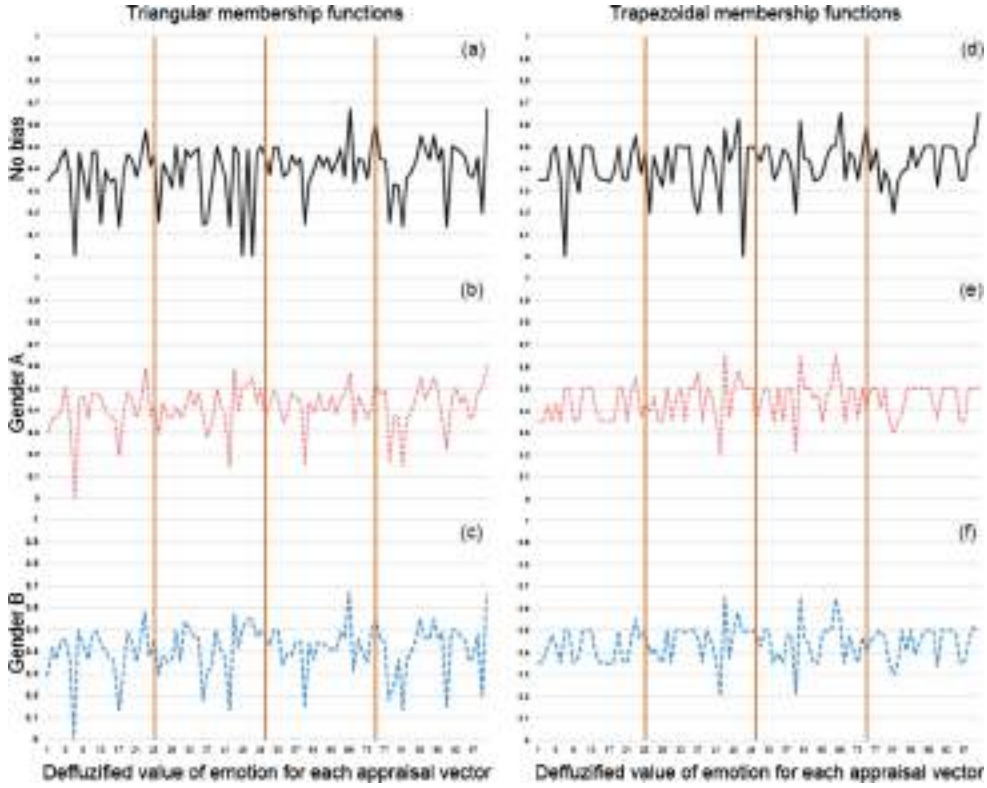

Fig. 4. Outputs of the CME for the joy emotion.

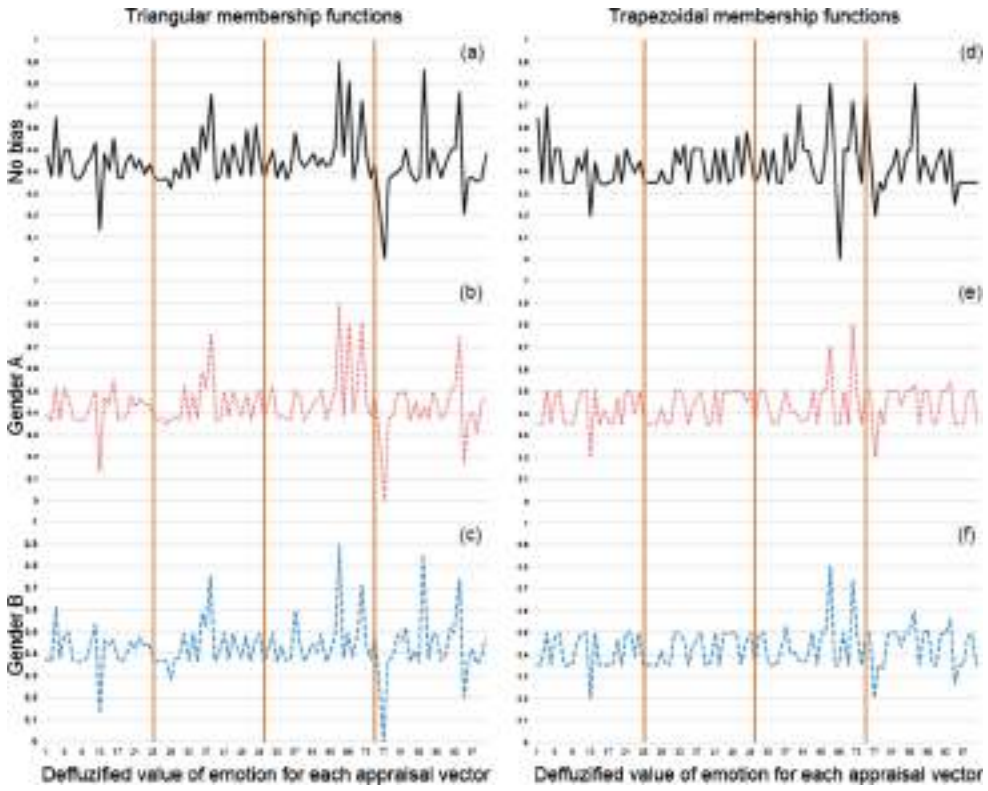

Fig. 5. Outputs of the CME for the sadness emotion.

tion provides further details on how the proposed mechanism was implemented and configured for each of the series of emotional evaluations of stimuli perceived by agents.

We defined a *set of fuzzy rules* to determine the relationship between particular appraisal vectors (representing the assessment of perceived stimuli) and the two emotions (i.e., sadness and joy). In particular, this set of fuzzy rules was created using the PredictiveApriori algorithm (Scheffer, 2005). The PredictiveApriori algorithm mines association rules from data based on how frequently a set of items are connected with a certain class. Please see (Scheffer, 2005) for a detailed description of the PredictiveApriori algorithm. In order to simplify the fuzzy rules, we grouped the values of the appraisal dimensions in the data set into three categories of linguistic variables: *low* for values from 0 to 1, *medium* for values from 2 to 3, and *high* for values from 4 to 5. For instance, an event characterized by the appraisal dimension *familiarity* with a value of 1 indicates that an individual's familiarity with the event is *low*. In a similar manner, we also grouped emotion intensities into the linguistic variables of *low* when the intensity was reported with a value from 1 to 2, *medium* when was reported as 3, and *high* when reported with a value from 4 to 5. We configured the PredictiveApriori algorithm to obtain 50 rules for each emotion category (sadness and joy). However, for the sake of conciseness and completeness of this exemplification, we used only the 5 most representative rules for each emotion category, i.e., the rules containing the most frequently sets of pairs {appraisal dimension $\times$ $\{low, medium, high\}$} connected with the corresponding emotion category $\{\{joy, sadness\} \times \{low, medium, high\}\}$. The resultant fuzzy rules for joy and sadness are reported in Tables 1 and 2, respectively.

It is acknowledged that we could have selected fewer or more rules, however, determining how many rules are sufficient to evaluate emotional stimuli is out of the scope of

Table 1
Fuzzy rules for *joy*.

IF *pleasantness* IS *high* THEN *joy* IS *low*
IF *unpleasantness* IS *low* THEN *joy* IS *low*
IF *suddenness* IS *medium* THEN *joy* IS *low*
IF *normViolation* IS *low* THEN *joy* IS *low*
IF *consequencesExpected* IS *medium* THEN *joy* IS *low*
IF *normViolation* IS *low* THEN *joy* IS *medium*
IF *pleasantness* IS *high* THEN *joy* IS *medium*
IF *moralAcceptability* IS *high* THEN *joy* IS *medium*
IF *unfairness* IS *low* THEN *joy* IS *medium*
IF *conduciveness* IS *high* THEN *joy* IS *medium*
IF *unpleasantness* IS *low* AND *consequencesFelt* IS *low* THEN *joy* IS *high*
IF *pleasantness* IS *high* AND *causedByMyself* IS *low* THEN *joy* IS *high*
IF *unpleasantness* IS *medium* AND *normViolation* IS *low* THEN *joy* IS *high*
IF *suddenness* IS *low* AND *causedByChance* IS *low* THEN *joy* IS *high*
IF *unpleasantness* IS *medium* AND *conduciveness* IS *high* THEN *joy* IS *high*

Table 2
Fuzzy rules for *sadness*.

IF *pleasantness* IS *low* THEN *sadness* IS *low*
IF *unpleasantness* IS *high* THEN *sadness* IS *low*
IF *normViolation* IS *low* THEN *sadness* IS *low*
IF *consequencesExpected* IS *medium* THEN *sadness* IS *low*
IF *intentionalSelf* IS *low* THEN *sadness* IS *low*
IF *intentionalSelf* IS *low* THEN *sadness* IS *medium*
IF *unpleasantness* IS *high* THEN *sadness* IS *medium*
IF *pleasantness* IS *low* THEN *sadness* IS *medium*
IF *consequencesFelt* IS *medium* THEN *sadness* IS *medium*
IF *normViolation* IS *low* THEN *sadness* IS *medium*
IF *predictability* IS *medium* AND *intentionalOther* IS *medium* THEN *sadness* IS *high*
IF *predictability* IS *medium* AND *causedByMyself* IS *high* THEN *sadness* IS *high*
IF *obstructiveness* IS *low* THEN *sadness* IS *high*
IF *unpleasantness* IS *high* AND *intentionalSelf* IS *medium* THEN *sadness* IS *high*
IF *suddenness* IS *high* AND *causedByMyself* IS *high* THEN *sadness* IS *high*

this paper. In addition, it is worth mentioning that there are other algorithms for mining association rules (see Fournier-Viger et al., 2017) and that a set of fuzzy rules may be defined based on theories reported in the literature on emotions. However, our objective is to design a mechanism to bias the emotional evaluation of stimuli, and as a consequence, selecting the best algorithm for mining association rules and validating the resultant rules is out of the scope of this paper. Nevertheless, by using real-world data on emotions and a commonly-used algorithm for mining association rules, we conducted emotional evaluations of stimuli using non-arbitrary fuzzy rules at the same time that we exemplify how fuzzy rules can be obtained.

We selected *gender* as the *influencing factor* because (i) gender has been found to influence the emotional evaluation of stimuli (Barrett et al., 1998; Bradley et al., 2001; Chaplin, 2015; Nater et al., 2006) and (ii) we had data on emotionally significant events and the gender of the participants describing the events. The *influencing model* designed to determine to what extent gender may modulate the emotional evaluation of stimuli was based on computing correlation coefficients between the values of emotion intensity and the appraisal dimensions grouped by emotion and gender. The correlation coefficients ranged from −0.1368 to 0.3376. This suggests that there is no a strong linear relationship between a single appraisal dimension and the intensity of an emotion, however, the relationship exists as reported in Chaplin (2015), Barrett et al. (1998), Nater et al. (2006), and Bradley et al. (2001) and as indicated by the nonzero correlation coefficients. For this reason, to exemplify the effects of gender as an influencing factor, we normalized the correlation coefficients with respect to the maximum correlation coefficient. The normalized correlation coefficients between emotion intensity and the appraisal dimensions (grouped by emotion and gender) are reported in Table 3.

The influencing model utilizes six fuzzy logic scheme configurations to represent the bias produced by the influence factor (i.e., gender) according to the calculated correlations: *high negative* (from −1.00 to −0.75), *medium negative* (from −0.75 to −0.25), *low negative* (from −0.25 to −0.1), *low positive* (from 0.1 to 0.25), *medium positive* (from 0.25 to 0.75), and *high positive* (from 0.75 to 1.00). We considered normalized correlation coefficients between −0.1 and 0.1 to be negligible, and as a consequence, we did not take them taken into account to influence the evaluation of emotional stimuli. In particular, the influencing model explores to what extent the different types of membership functions available in the fuzzy logic scheme of the InFra help to represent the influence of diverse factors in the emotional evaluation phase. We selected triangular and trapezoidal membership functions because they are among the most frequently used (Barua, Mudunuri, & Kosheleva, 2014) (the defuzzification method was center of gravity). By using real-world data on emotions and a commonly-used statistical measure to indicate the strength of a relationship, we aim to exemplify how influencing factors may be characterized. Nonetheless, we acknowledge that other measures may be used to judge the effect of influencing factors and that many other influencing factors (such as age You, Ju, Wang, Zhang, & Liu, 2017) may be used. In this regard, determining how many and which influencing factors should be taken into account as well as selecting the best measure is out of the scope of this exemplification.

Results. Figs. 4–6 show results about the emotional evaluation of stimuli taken into account the influencing factor, influencing model, configurable appraisal dimensions, and fuzzy rules described above (for the joy and sadness emotions). As mentioned above, the influencing model translated the influencing factor (i.e., gender) to different configurations in the fuzzy logic scheme considering two types of fuzzy membership functions: triangular and trapezoidal membership functions. From the results obtained using these configurations, we draw three observations.

- *Observation 1: On the use of gender as an influencing factor for biasing the evaluation of emotional stimuli.Analysis*. As shown in Figs. 4 and 5, the bias introduced by gender caused relatively small changes in the CMEs' outputs for both joy and sadness. However, these changes were not drastic even though the correlation coefficients between emotion intensity and the appraisal dimensions were scaled. In addition, it is worth mentioning that the overall tendencies of the defuzzified values taking into account all the 100 appraisal vectors remained relatively unchanged (see Figs. 4 and 5). In this regard, we conducted independent two-tailed t-tests for each pair of series of experiments grouped by emotion and membership function type, the results indicate that (in spite of the small changes) the means are not statistically different ($p > 0.05$). This suggests that our proposed bias process influenced the evaluation of

Table 3
Normalized correlation coefficients of appraisal dimensions with respect to gender.

	Emotion: Joy		Emotion: Sadness	
	Gender A	Gender B	Gender A	Gender B
Adjustment	0.142	0.260	−0.318	−0.362
Avoidability	−0.114	−0.183	0.169	0.052
Caused by chance	0.240	0.319	0.410	0.125
Caused by other	0.317	0.132	0.075	0.072
Caused by myself	0.355	0.077	−0.053	−0.045
Conduciveness	0.651	0.462	0.067	−0.233
Consequences expected	−0.011	0.009	−0.135	−0.119
Consequences far future	−0.005	0.038	−0.021	0.033
Consequences felt	−0.118	0.091	0.290	−0.078
Consequences near future	−0.171	0.189	−0.117	−0.182
Familiarity	−0.339	−0.230	−0.405	−0.265
Intentional-other	0.248	0.086	−0.051	0.088
Intentional-self	0.479	0.008	−0.365	−0.139
Modifiability	0.005	−0.295	0.069	−0.119
Moral acceptability	0.146	0.117	−0.215	−0.383
Norm violation	−0.296	−0.179	−0.204	0.071
Obstructiveness	−0.269	−0.239	0.694	0.509
Pleasantness	1.000	0.408	−0.144	−0.354
Predictability	0.111	0.120	−0.126	−0.144
Relevance	0.640	0.556	0.697	0.639
Self-image compatibility	0.361	0.079	−0.096	−0.166
Suddenness	0.239	0.275	0.301	0.511
Unfairness	−0.270	−0.399	0.409	0.343
Unpleasantness	−0.356	0.079	0.865	0.667
Urgency	0.270	0.290	0.353	0.357

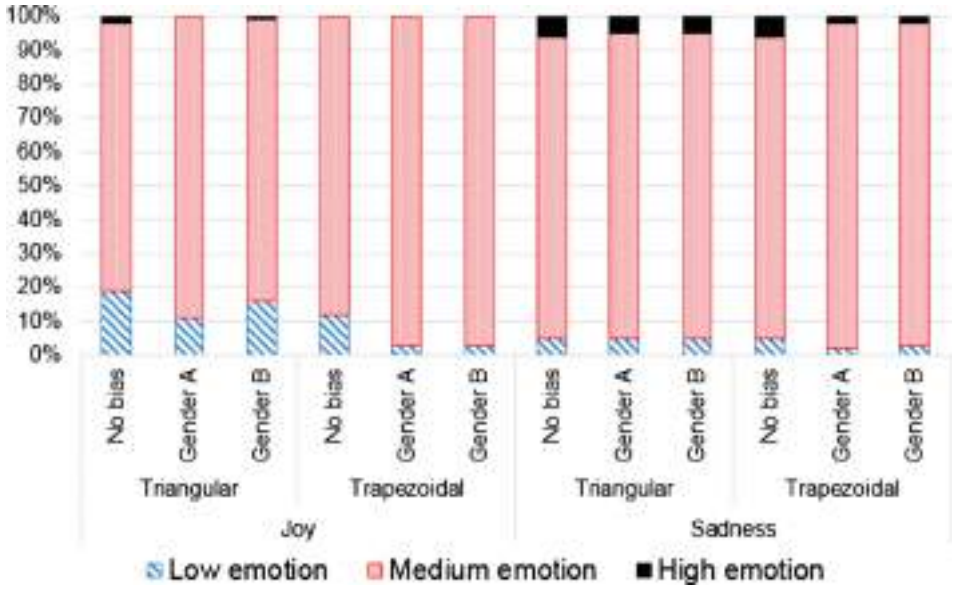

Fig. 6. Proportion of low, medium, and high emotions.

emotional stimuli while preserving the overall features of the CMEs. However, increasing the magnitude of an influencing factor and/or adding other influencing factors may result in drastic changes in the CMEs' outputs as expected.

- *Observation 2: On the effects of the membership function type on the evaluation of emotional stimuli.Analysis*. As depicted in Figs. 4 and 5, in general, the ranges of the deffuzified values (obtained from our inference engine) for both emotions were wider when using triangular membership than when using trapezoidal membership functions. Moreover, on average, the standard deviation of the defuzzified values when using triangular membership functions was approximately 20% higher than when using trapezoidal membership functions. This suggests that triangular membership functions may help to

evaluate emotional stimuli in a more sensitive manner (than trapezoidal membership functions), i.e., triangular membership functions may be able to react to small changes in the values of the appraisal dimensions. Nevertheless, we acknowledge that membership functions should be based on expert opinions (as indicated by Barua et al. (2014)), and as a consequence, the type of membership function should be selected based on the domain in which the CMEs will be used.

- *Observation 3: Fuzzy rules and the proportion of low, medium, and high emotions.Analysis.* For both emotions, the least predominant emotional level was high, followed by low and lastly medium (see Fig. 6). Taking into account that the fuzzy rules were mined from real-world data and regardless of the fact that the input appraisal vectors were randomly generated, this result suggests that highly intense emotions are less frequent (as indicated by Bless (2001)) and may require very specific combinations of values of appraisal dimensions. Indeed, the fuzzy rules corresponding to high sadness and high joy, in general, involve two appraisal dimensions, unlike the fuzzy rules for low and medium emotions, which involve only one appraisal dimension (see Tables 1 and 2). In addition, the most predominant emotional level was medium because the set of fuzzy rules for low emotions intersected with the set of fuzzy rules for medium emotions and when the rules (within the intersection) were triggered, the resultant emotional level was medium due to aggregation.

5. Conclusions

The contributions of our present work are threefold. Firstly, we incorporate influencing factors into a mechanism for emotional evaluation of stimuli supported by a fuzzy logic inference engine. Secondly, we introduce and define configurable appraisal dimensions (into the emotional evaluation phase), which can be adjusted based on internal and/or external factors in order to bias the evaluation of emotional stimuli accordingly. Thirdly, to the best of our knowledge, we are the first to provide experimental results of a CME on the effects of influencing factors for emotional evaluation of stimuli based on real-world data about emotions. It should be mentioned that our framework is domain-independent and allows for the incorporation of influencing models defining the relationship between a given influencing factor and a given set of configurable appraisal dimensions. Our contributions allow us to emulate the evaluation of complex sensory information that is carried out by the amygdala.

Based on the experimental results obtained from our proof-of-concept CME, we can conclude that influencing models (expressing the relationship between influencing factors and appraisal variables) can properly affect the emotional evaluation of stimuli while preserving the overall features of CMEs. In addition, we found consistent differences in the emotional evaluation depending on what kind of membership function was utilized, which shed light on the selection of the membership function types in fuzzy-logic based CMEs.

Our future work will focus on (i) exploring the effects of taking into account several influencing factors concurrently as occurs in the brain structures underlying emotional functions (such as the amygdala) and (ii) comparing the emotional outcomes derived from different metrics (e.g., information gain) to implement influencing models.

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Propuesta de rediseño de proceso en centros geriátricos mediante la implementación de tecnologías para el monitoreo del paciente

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***Abstract*— En México existen diferentes centros diurnos orientados al cuidado del paciente con Alzheimer. Usualmente, este tipo de centros carecen de un aprovechamiento de tecnología. Un re-diseño de procesos podría ayudar al utilizar tecnología y mejorar la efectividad de los empleados, así como mejorar la atención y monitoreo hacia los pacientes. El presente proyecto propone una reingeniería en el proceso de intervención terapéutica, tomando como caso de estudio un centro diurno ubicado en Cd. Obregón, Sonora, basada en la metodología de Davenport. En la propuesta, se diseña un método de monitoreo cualitativo, el cual incluye una aplicación móvil para el registro diario de los comportamientos, actitudes, y desempeño del paciente; así como el uso de sensores para un monitoreo en tiempo real. Esto, para la prevención de accidentes y una mejor toma de decisiones a largo plazo.**

Palabras clave: rediseño de procesos, alzheimer, monitoreo, toma de decisiones.

I. INTRODUCCIÓN

El Alzheimer es una enfermedad degenerativa y principal causa de [3]. Esta enfermedad tiene como síntomas problemas de memoria, de habla, de resolución de problemas y de otras habilidades cognitivas que dificultan la realización de actividades diarias [4]. Esta enfermedad se va desarrollando en tres distintas fases (leve, moderada y severa) [5] cada una más grave que la otra. En México existen centros diurnos que apoyan a los familiares en el cuidado del paciente, así como a favorecer la desaceleración de la enfermedad, logrando una mejor calidad de vida para el paciente y una reducción de la carga de trabajo del cuidador. En este tipo de centros, se realizan distintas actividades como talleres ocupacionales y recreativos[1], además de contar con distintas terapias tanto cognitivas, como físicas [6].

En estos centros se genera información útil acerca de los pacientes, sin embargo, no siempre es registrada y analizada adecuadamente [7]. En general, en México este tipo de centros no cuenta con la tecnología necesaria o los procesos adecuados para sacar el mejor provecho a estos datos. Por ello, es importante realizar un rediseño en los procesos en los cuales se interactúa con el paciente, para poder recabar la información necesaria para en un futuro, poderla aprovechar ya sea para la toma de decisiones a corto, mediano y largo plazo, así como para la realización de predicciones con respecto al deterioro de cada paciente.

En el presente trabajo se propone el rediseño de un proceso en un centro geriátrico. En particular, se presentan los resultados de la observación, análisis y medición del proceso actual así como la propuesta del nuevo proceso.

II. TRABAJOS RELACIONADOS

Jansen-Vullers y Reijers [8], proponen un rediseño de proceso en una institución de salud mental cuyo principal objetivo es una simplificación del proceso de ingreso de tratamiento. En su situación inicial, el proceso duraba un poco más de 10 días laborales. Jansen-Vullers y Reijers tomaron siete escenarios de rediseño que evaluaron para identificar cuál es el más favorable en términos de servicio y tiempo. El escenario más favorable fue el soportado en trabajo basado en caso y no teniendo ninguna mejora en el escenario basado en la integración de tecnología.

Khodambashi [9] afirma que las tecnologías de información mejoran el rediseño de procesos, ya que éstas permiten al equipo a recolectar, analizar, almacenar y distribuir información más efectivamente, además de incrementar la colaboración y la comunicación. En el presente trabajo se propone la implementación de tecnología en un centro geriátrico utilizando *weareables* y mejorando la calidad de los datos registrados para la mejora de toma de decisiones dentro del centro.

III. METODOLOGÍA

A. Objetivos.

Con el objetivo de facilitar el procesamiento y análisis de información del proceso de intervención terapéutica, se busca alcanzar los siguientes objetivos específicos:

- Analizar el funcionamiento del proceso actual de intervención terapéutica mediante observaciones y mediciones y describirlo en un documento formal.
- Rediseñar el proceso de intervención terapéutica, con el fin de disminuir tiempos en actividades innecesarias, recopilar

[1] http://www.alzheimermexico.org.mx/index.php/quehacemos/programa_centro

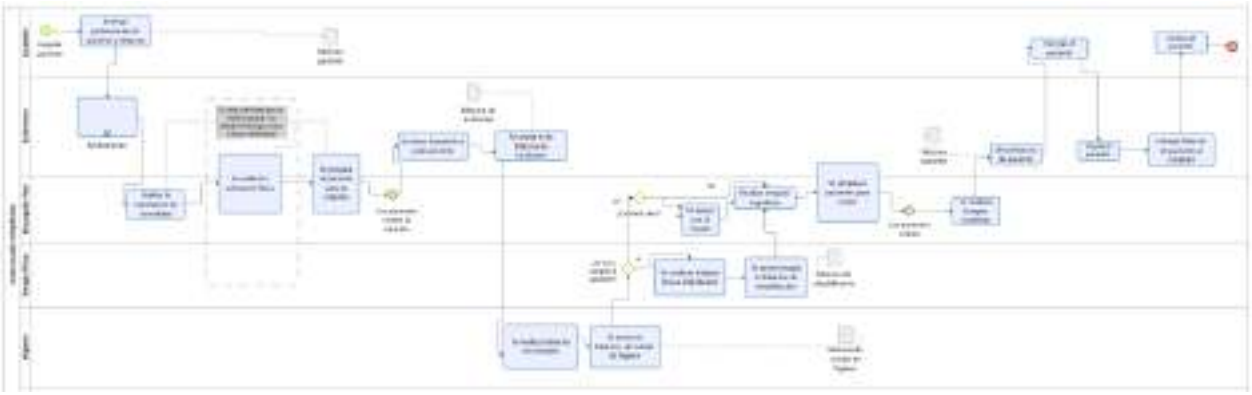

Figura 1: Representación BPMN del proceso actual

información útil acerca del paciente, sin restarle la atención del personal, mediante el apoyo de distintas tecnologías.

B. Pregunta de investigación.

¿De qué manera se puede mejorar la calidad de los datos con los que se toman las decisiones de los cambios de fase en una estancia geriátrica?

C. Proceso.

El rediseño propuesto se basa en la metodología de reingeniería de Davenport descrita en Mohapatra [10], la cual describe los siguientes pasos:

*1) Visión y planteamiento de objetivos. S*e definen los problemas que quieren ser solucionados con el rediseño del proceso de acuerdo a la visión de la compañía y los objetivos de los procesos.

2) Identificación de los procesos de negocio. Se identifica el proceso que va a ser sometido a la reingeniería.

3) Entendimiento y medición de procesos. Se estudia el funcionamiento y desempeño exacto de los procesos seleccionados. Se realizaron actividades de observación y distintas entrevistas sobre el proceso actual. Posteriormente, se realiza un modelado BPMN[2] (Business Process Model and Notation) del proceso además de diagramas de rol-actividad.

4) Identificar tecnologías de información

En este paso se estudia la aplicabilidad de herramientas de tecnologías de información para los procesos rediseñados.

5) Prototipo de proceso.

Se diseña un prototipo funcional del nuevo proceso de negocio. Las personas en la empresa estudian el prototipo y desarrollan ideas para las mejoras hasta que quedan conformes con el rediseño del proceso de trabajo.

IV. Resultados parciales

Al momento se han logrado los siguientes resultados parciales en el rediseño del proceso de intervención terapéutica, siguiendo la metodología de Davenport.

1) Visión y planteamiento de objetivos.

Mediante reuniones con los directivos del centro y el coordinador de las áreas de terapia, se revisó la organización, sus funciones, quiénes eran sus clientes o beneficiarios, cómo surgió la organización, la misión y visión de la misma. Se revisó un manual de perfiles y procesos de la estancia, donde se describen las actividades de cada puesto, así como el perfil profesional que lo debe de desarrollar. Finalmente se definió la actual cadena de valor de la organización.

El problema detectado fue que actualmente toda la documentación con respecto al paciente se realiza de manera manual. Respecto a observaciones, no existe un registro diario sobre el comportamiento o desempeño en la terapia de cada paciente. Además, las bitácoras diarias que se utilizan, no generan ningún tipo de conocimiento o impacto con respecto al avance de cada paciente.

2) Identificación del proceso de negocio.

Se eligió el proceso de "Intervención terapéutica" para aplicar la reingeniería, en el cual se interactúa directamente con el paciente, además de que impacta sobre las decisiones de cambio de fase del paciente, así como en su progreso o deterioro tanto físico como cognitivo.

3) Entendimiento y medición de procesos.

Se definió la información que se registra diariamente de los pacientes mediante observación y entrevistas semiestructuradas. Asimismo, se observaron jornadas completas de trabajo durante dos semanas, y de media jornada alternando entre la mañana y la tarde durante dos semanas más, midiendo el tiempo que les tomaban a los empleados la realización de las distintas tareas. Se generó un diagrama BPMN del proceso actual (Figura 1).

a) Descripción de roles.

Se realizó una descripción de los actores que participan en este, con sus nombres y responsabilidades, plasmados a continuación:

- Cuidador: Es el familiar o encargado del paciente en casa.
- Enfermera: Da seguimiento clínico al paciente, lo recibe en la entrada, le toma la presión y registra los incidentes que ocurren a lo largo del día.
- Psicólogo o encargado de fase: Brinda terapia cognitiva al paciente según la fase a la que pertenezca.

[2] http://www.bpmn.org/

- Encargado de terapia física o fisioterapeuta: Brinda rehabilitación física a los pacientes.
- Encargado de higiene: Revisa la higiene del paciente, llevarlos al baño, verificar evacuaciones, informar si existe alguna infección. Si el paciente requiere un baño, también es la encargada de brindarlo.
- Coordinador de intervención terapéutica: Supervisa que cada una de las áreas realicen adecuadamente su labor.

b) Descripción de proceso actual.

El proceso de intervención terapéutica inicia con el recibimiento de los pacientes a partir de las 8:00 horas. El cuidador entrega al paciente con su respectiva bitácora que contiene información sobre el comportamiento del paciente en casa, tal como sueño y si sucedió algún incidente. Posteriormente la enfermera registra la hora de llegada del paciente a mano en la lista de asistencia. Las bitácoras se acomodan en la entrada categorizándolas por fase. Cada paciente es llevado al área de intervención por una enfermera. Cuando llegan a su área, los psicólogos se encuentran realizando la orientación de la realidad, donde se les lee el periódico a los adultos y se comenta al respecto.

Después, se inicia con la reactivación física grupal donde se realizan movimientos de extremidades repetitivos acompañados de música, que se realizan sentados. La reactivación física dura de 40 a 60 min y en este momento los adultos se encuentran divididos en tres grupos de acuerdo a su nivel de deterioro. Se tiene un descanso a los 15 min para que los pacientes tomen agua, y se continúa con juegos físicos que incluyen habilidades cognitivas, como atrapar una pelota. Al finalizar la reactivación física, se les da un pequeño receso a los pacientes de aproximadamente 15 minutos donde tienen música y éstos pueden bailar y platicar con sus compañeros. Transcurrido este tiempo, se preparan a los pacientes para la merienda y el consumo de la misma (esta actividad dura alrededor de 15 minutos). Al finalizar, se acomodan los pacientes en las distintas fases. Hasta este momento, la única información que ha sido registrada es la entrada del paciente y la bitácora recibida por la enfermera.

Una vez ubicados todos los pacientes en su respectivo grupo, se procede con actividades planeadas para cada miembro. Simultáneamente, los enfermeros toman la presión de cada paciente y se anota en la bitácora de incidentes. Asimismo, cada paciente recibe terapia física tres veces por semana. La fisioterapeuta se enfoca en las necesidades específicas de cada persona, con una duración de entre 15 y 25 minutos según la disposición del adulto mayor. Como parte de esta actividad, se anotan en la bitácora de rehabilitación física las áreas que se trabajan.

Las enfermeras se encargan de llenar las bitácoras por cada paciente, donde se indica qué comió el paciente y si hubo algún comportamiento que destacar del día. Alrededor de las 12:45 horas se comienza la preparación de los pacientes para la hora de comida. Posteriormente se sirve la comida y los pacientes comen, esto dura aproximadamente 30 min. Cuando finaliza la hora de la comida, se reacomodan los pacientes para continuar con sus terapias psicológicas. Cuando el cuidador pasa por el paciente la enfermera va por él y se lo entrega junto con su bitácora.

4) Identificar tecnologías de información

Se propone el uso de distintas tecnologías para agilizar el proceso de ingreso de información.

a) Aplicación móvil.

Se propone la implementación de una aplicación móvil en dónde se registren todos los datos relacionados con el paciente, pudiendo unificar a todas las áreas en un solo sistema. La aplicación móvil permitiría la integración y resguardo seguro de la información que se obtiene en la estancia, así como la posibilidad de poder obtener conocimiento esencial acerca de cada paciente para otros procesos.

b) Weareables

Se propone el uso de pulseras para el monitoreo de señales fisiológicas del paciente. Además de la adquisición de DFree [3], un dispositivo basado en ultrasonido que monitorea la vejiga del adulto mayor, mandando una alerta cuando éste requiere ir al baño, y que registra sus actividades en línea.

5) Prototipo de proceso.

La Figura 2 muestra el diagrama BPMN de la propuesta, donde se simuló el funcionamiento del nuevo proceso.

a) Descripción del proceso propuesto

El proceso empieza con la llegada del paciente a la estancia, quién tendrá un código QR colocado en una tarjeta brindada por el cuidador, el cual se escaneará para pasar asistencia mediante una aplicación móvil. Al llegar se le colocará a cada paciente una pulsera para medir sus pulsos. Posteriormente, la enfermera revisará la aplicación para verificar que se hayan introducido datos en casa y preguntará si existió algún incidente que no haya sido capturado; de ser así, se captura en la aplicación, para después llevar al paciente a su lugar. Al finalizar, otra enfermera le tomará la presión arterial para anotarlo en la aplicación. Un encargado de fase estará realizando la orientación de la realidad a los pacientes que hayan llegado.

A las 9:00 horas se iniciará la reactivación física grupal de la misma manera que el proceso actual. Después se preparará a los pacientes para su merienda. Al finalizar, las enfermeras capturarán en la aplicación si el paciente comió adecuadamente la colación.

Al finalizar la reactivación física, la encargada de fisioterapia anotará en la aplicación observaciones extraordinarias ocurridas. Posteriormente, se hará la rutina común de terapias físicas. Al ingresar el paciente, se indicará en la aplicación el inicio de la terapia. Cuando la terapia

[3] https://www.dfreeus.biz/

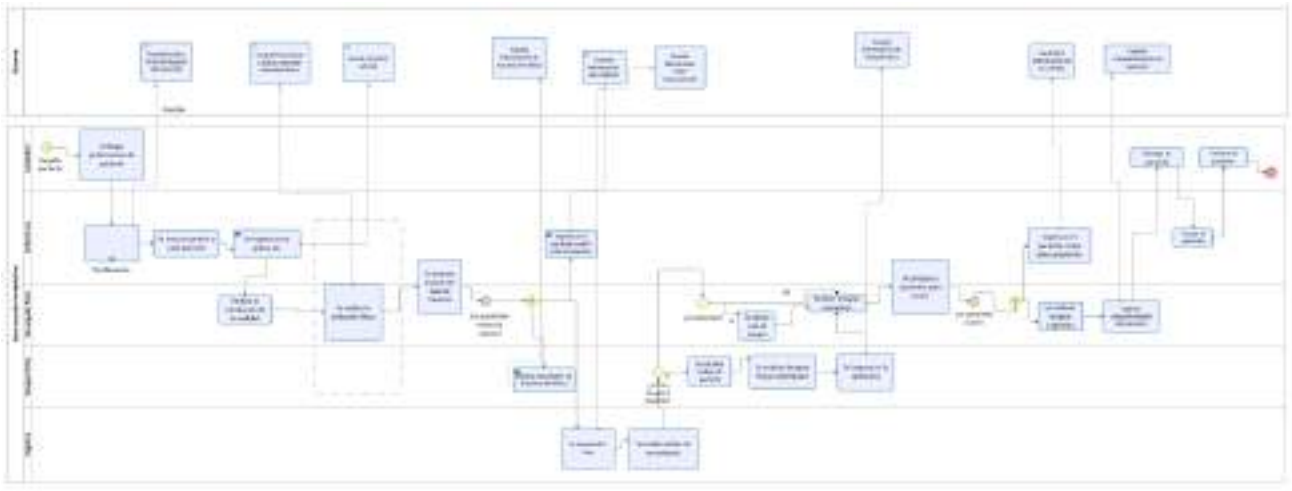

Figura 2: Modelado de propuesta de proceso.

termine, la fisioterapeuta lo indicará en la aplicación e ingresará el resumen de su terapia, evaluando el desempeño del paciente y su estado de ánimo inicial y final.

Mientras tanto, los demás pacientes estarán recibiendo sus respectivas terapias cognitivas. Cuando llegue la hora de comida, aproximadamente a las 12:45, se iniciará el acomodo para la comida, al igual que en el proceso actual. Al finalizar la comida, la enfermera anotará en la aplicación si el paciente comió debidamente. Posteriormente, se reanudarán las terapias cognitivas, y el encargado de fase ingresará el comportamiento del día del paciente en la aplicación, así como una evaluación del paciente en las actividades realizadas en el día. Cuando el cuidador llegue por el paciente, la enfermera irá por él y registrará su salida en la aplicación y retirará la pulsera.

V. CONCLUSIONES

La presente propuesta de rediseño permitirá mejorar la atención hacia los pacientes, además de habilitar el análisis de los casos de cambio de fase, así como predecir el deterioro de los pacientes y así poder tomar acciones al respecto; se pueden crear perfiles de pacientes, identificar cuáles terapias son más efectivas, así como prever las crisis mediante los signos vitales del paciente.

La utilización de tecnología permite asegurar la calidad de los datos registrados teniendo un formato definido y su tratamiento será más sencillo. Además, la aplicación móvil permitirá tener la menor cantidad de datos no estructurados para un análisis más sencillo.

El trabajo futuro incluye el diseño e implementación de la aplicación móvil propuesta, así como el desarrollo de un tablero de control como soporte a la toma de decisiones del paciente que permita la categorización de los pacientes según sus actitudes y desempeño en las terapias.

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Reengineering of the software development process in a technology services company

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Abstract

Purpose – The purpose of this paper is to address the need of a reengineering of the software development process in a Mexican technology services company. In general, the main risk faced by small- and medium-sized software developers (SMEs) is the inability to meet delivery times or to adjust to project requirements, whether through lack of follow-up on the critical activities of the development process or through an inadequate distribution of workloads among members of the project team.

Design/methodology/approach – The methodology used to carry out the reengineering of the software development process is Hammer and Champy, which consists of six stages: introduction to the current situation of the company and the need for change; identification of the business processes; selection of the business process to be redesigned; understanding of the process selected; proposal for reengineering the business process selected; and the results of the comparison between the current situation of the process and the proposed reengineering of the process through the use of Business Process Model and Notation (BPMN 2.0).

Findings – Based on the results, the paper shows the importance of the analysis and implementation of the reengineering in a software development company. It describes step-by-step how to apply the methodology of Hammer and Champy in a business process through simulated scenarios, using BPMN 2.0. By carrying out the implementation of the proposed reengineering, the company would therefore save 45.12 percent of costs, 41.17 percent of time, and a better distribution of resources, at the same time guaranteeing the satisfaction of its clients.

Originality/value – The study addresses the current needs of small- and medium-sized software developers, providing a step-by-step guide to the implementation of a process reengineering methodology, performing an analysis and modeling of processes in BPMN 2.0 and providing results through a simulation of the critical process, with the aim to observe the flow of activities and the significant improvements that would be achieved by implementing the reengineering proposal. This simulation schema allows business owners to observe the potential of the changes and to verify the positive impact they would have on the company before beginning to make operational changes in the organization.

Keywords Business process, Software development, Process analysis, Software engineering, BPMN, Business process reengineering, Process reengineering

Paper type Case study

Introduction

The information technology industry, currently one of the most dynamic and fast-growing industries in the global economy, is undergoing a major transformation at the Industry 4.0 (Lasi *et al.*, 2014; Wan *et al.*, 2016; Zhou *et al.*, 2015). The cause of the industry's remarkable global growth is that it is recognized as a generator of competitive advantages as a

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knowledge industry identified with the rapid acceptance of change and the modernization of productive processes that integrates technological and administrative innovations in response to constant changes in the context. It offers competitive advantages by giving added value to its products and services. As a result, it has caused changes in the business environment, bringing about new challenges that demand greater managerial skills. The increase of competition in the technology sector itself has emphasized the need for these skills for companies that strive to keep up with their competitors (Zhou *et al.*, 2015). The software industry confronts a serious challenge due to competition, because of the constant emergence of small- and medium-sized software companies which are standing up to more established enterprises. These companies must make great efforts to improve their competitiveness and make them even more efficient. In order to strengthen these kinds of companies, efficient practices need to be adapted to their size and business type and processes need to be improved for increasing the quality and productivity of their services (Huang *et al.*, 2015; Fayad *et al.*, 2000).

The process for determining the quality of the product or services is one of the most important activities in the administration of a company; thus, it is advisable that all the company's processes are connected with the generation of products and service be aligned to a well-defined objective, and be constantly subject to review in response to changes, with the aim to improve internal processes and/or reduce defects in the products or services (Huang *et al.*, 2015). Hence, business processes reengineering (BPR) has helped companies to adapt to the highly competitive and rapidly changing market environments by incrementally or radically improving their processes. BPR involves a radical change in the company's manner of acting and it is defined as "fundamental reconsideration and radical redesign of organizational processes, in order to achieve dramatic improvements of current performance in cost, speed, and quality of service" (Hammer and Champy, 2009). However, BPR has also been considered as a process improvement approach in many projects over the years (Anand *et al.*, 2014; Attaran, 2003; Bertolini *et al.*, 2015; Bevilacqua *et al.*, 2009). According to Zellner (2011) since BPR were considered as an essential part of the business improvement, it could be found in the literature in many different ways such as business process redesign (Reijers and Mansar, 2005; Davenport and Short, 1990), business reengineering (Hammer and Champy, 1993), continuous improvement process (Deming, 2000), among others. BPR as a radical change is considered a high level of risk (Goksoy *et al.*, 2012) where about 70 percent of the projects failed (Omidi and Khoshtinat, 2016; Seethamraju and Marjanovic, 2009). In this case study, BPR is considered as a process improvement using the Hammer and Champy (1993) methodology.

Reengineering became popular in the early of 1990s when Hammer and Champy (1993) introduced this approach in their book titled *Reengineering the Corporation: A Manifesto for Business Revolution*. Hence, in order to respond to changes, increase profits, reduce costs, reduce process times, improve the quality of products and services or simply to improve productivity, the reengineering of company's processes has become an option since the 1990s (Attaran, 2003). However, according to Radhakrishnan and Balasubramanian (2010), the approach was not completely understood or appreciated at the beginning because of the poorly planned and executed improvement projects. In addition, it is well known that regardless of the application of reengineering as a radical change or process improvement, addressing the human factor is crucial to the success of any reengineering project. Thus, the explanation and persuasion of employees to understand and accept the changes within the company, especially the way they do their daily activities is necessary to obtain the expected results because they are the vehicle for change who will either embrace or resist change (Goksoy *et al.*, 2012; Anand *et al.*, 2014). In the last decade, many companies continue embracing reengineering with the aim to be more competitive and efficient integrating business websites, enterprise systems as well

as business intelligence systems where today's businesses demand the use of technology in the process redesign to obtain more information about their customers, suppliers, products, competitors, etc. According to Attaran (2003), the redesign of the processes will be between the company and its customers, suppliers and partners, this is known as process X-engineering proposed by James Champy (2002) where Cisco, Dell, Intel and Solectron have successfully implemented X-engineering.

Also, Tka and Ghannouchi (2014) considered that BPR is one of the existing methods in the literature that leads to evolutionary changes and adjustments that have become a necessity in today's business process improvement. According to Chan and Peel (1998), organizations carry out a reengineering project for external and internal reasons or factors. Internal factors occur within a company such as the need to improve technology, increase efficiency, reduce cost and define or redefine strategic goals. Otherwise, external factors are related to the pressures exerted by customers, competitors, market conditions and governmental regulations or political pressures. Thus, companies that aim to improve their competitiveness and increase profits decide to implement a reengineering but, since they often fear radical change, they choose for incremental improvement of their processes. For this, a business process model is a fundamental stage in the reengineering, which helps the organization to better understand its current processes and to plan the transition to the redesigned processes. Petrillo *et al.* (2018) propose a model as a valuable tool to facilitate a successful design of business process reengineering in project management which is intended to help companies to operate projects for transfer and optimization of production lines. It is expected that using Agile Reengineering Performance Model tools will facilitate to modify the evolution of the project, with the possibility of expanding or improving the application if necessary. In this way, case studies provide guidelines for BPR projects in different sectors such as financial institutions (Shin and Jemella, 2002), public administrations (Hesson *et al.*, 2007; Rinaldi *et al.*, 2015), agri-food sector (Bevilacqua *et al.*, 2009), seaport sector (Islam *et al.*, 2013), pharmaceutical industry (Bertolini *et al.*, 2015), among others. In the same way, contemporary companies responsible for software development are under enormous pressure to deliver their software products quickly, within the prescribed timeframe, and with the highest quality and lowest cost, which implies more dynamism, invisibility and exclusivity (Anand *et al.*, 2014).

In this regard, Mexican software companies are innovating in their internal processes to remain competitive and offer better products and services to their clients. In this paper, a case study is conducted to address a BPR project in a Mexican Technology Services Company, whose core activity is custom and commercial software development. Although the company is relatively new, its products are present in about 19 countries, reflecting the high commitment to hard work and teamwork. To improve its competitiveness, the company was interested in carrying out a reengineering project to redesign some of the company processes to better support the company's mission, strategic goals and customer needs. Mainly, the biggest concern was to reduce the delay time of software development, since it is the main business activity of the company. In addition, the reengineering project could help them align the mission and vision, standardize the processes, redefine the responsibilities of each role of the team members, among other aspects related to the organizational situation.

This study provides detailed information about a BPR process through the Hammer and Champy methodology for a Mexican technology-based company. Some of the actions that took place in the redesign are related to a better distribution of resources, while at the same time ensuring the quality of work and customer satisfaction. Even more, the benefits of the proposed approach are presented through simulation results where the company would save 45.12 percent in cost and the development time would be reduced by 41.17 percent.

Business process reengineering methodology

In the last years, there have been technological innovations, new business models, rapidly changing market place and increasingly demanding customers, which has led companies to face difficult conditions in their daily operations, late deliveries and a continuously increasing competition. Hence, a business reengineering project is often a solution to improve companies' profit, customer satisfaction, costs reduction, respond better to competitive pressures, among others. Several methodologies have been proposed to support a business reengineering process, such as the Hammer and Champy, Davenport, Manganelli and Klein and Kodak (Radhakrishnan and Balasubramanian, 2010). Usually, each methodology shares three phases such as an analysis phase, a design phase and an implementation phase which shows similarities and differences. For example, in the analysis phase each approach differs in the scope of project preparation. Hammer and Champy (1993) focus on analyzing the company situation and the project preparation for a successful implementation. Davenport methodology emphasizes on information technology for innovating business processes. Manganelli and Klein's methodology suggests concentrating on those businesses that directly support the strategic goals focusing on a social and technical design which include organizational and personnel development plans. Finally, Kodak methodology is influenced by Hammer and Champy methodology, nevertheless, in the final step related to the change management, this is performed parallelly to the first four steps (project initiation, process understanding, new process design and business transition). Hammer and Champy (1993) describe the BPR as the radical change of business processes to obtain improvements related to cost, quality, service and quickness. However, Radhakrishnan and Balasubramanian (2010) point out that BPR could be a significant improvement to a business process or a radical change depending on the company needs. Michael Hammer proposed the Business Reengineering concept in the Harvard Business Review titled "Reengineering Work: Don't Automate, Obliterate." Hammer and Champy argue that the main problems of a fail project of process reengineering are the lack of efficient management, unclear objectives and resistance to change. Thus, they proposed a methodology for a successful reengineering project known as the Hammer and Champy methodology. Radhakrishnan and Balasubramanian (2010) synthesized this methodology in six steps: introduction to the reengineering of business processes; identifying business processes; selection of the business process to be redesigned; understanding of the selected business process; redesign of the selected business process; and implementation of the redesigned business process. In this regard, the selection of a methodology for the BPR project is according to the particular situation of the company taking into account strategic goals, economic situation and competitive requirements. On the other hand, other approaches, such as capability maturity model, capability maturity model integration, SPICE (ISO/IEC 15504), among others (Khan *et al.*, 2019), have been proposed for technology-based companies where the focus is the software process improvement. Those approaches are used when the company needs a maturity model to improve the activities carried out exclusively for software development, thus, this maturity model does not consider the mission and strategic objectives of the company during its transformation. Therefore, a reengineering methodology is more suitable for the company in this case study, since, the critical problems were at a strategic level and not in the software development itself. In this regard, Hammer and Champy methodology was used to conduct the reengineering project for the software development process because of the project preparation step for redesigning processes (Table I).

Case study

This research was carried out on a software development company located in the southern part of the state of Sonora, in Mexico. The company was created in 2013 out of an

Step No.	Project steps	Objectives
1.	Introduction to the Reengineering of Business Processes	The CEO of the company begins the project. He describes briefly and programmatically the current situation of the business in order to initiate the necessary actions
2.	Identifying business processes	Examination of the general panorama of how processes interact within the company and in relation to the outside world. A deliverable of this process is a diagrammatic representation of all the processes
3.	Selection of the business process to be redesigned	Selection of one or more processes to be redesigned. All those are selected that provide significant value to the company's clients, as well as those which, by their nature, are easy to redesign
4.	Understanding of the selected business process	This is not limited to a detailed analysis of the functioning of the business process selected. It focuses rather on the performance of current processes in comparison to how they are expected to function in the future
5.	Redesign of the selected business process	According to Hammer and Champy, this is the most creative step, characterized by imagination, lateral thinking, and a touch of madness
6.	Implementation of the redesigned business process	This step covers the implementation phase of the business process reengineering project. Hammer and Champy do not say as much about implementation as they do about project planning. They believe in the success of the implementation once the five previous steps have been adequately carried out

Source: Radhakrishnan and Balasubramanian (2010)

Table I.
Steps for the Hammer/ Champy methodology

entrepreneurial idea that consisted of developing a system for administering the educational resources of a university. After a couple of years, several academic institutions in the region decided to try it out, and they were pleased with the results. Over time, what began as school software became a management system for human resources in transnational companies. Currently, the company is one of the best-known software companies in northwestern Mexico, with more than 15,000 clients in 19 countries. The company offers solutions and services through the use of successful and innovate agile methodologies and tools. Among the services offered by the company are warehouse and transport management systems, as well as systems for payroll, accounting and billing. The company also offers custom software development, contributing business value to its clients with speed and quality. The organizational structure of the company is without a strict hierarchy, with a focus on decentralization, few management levels, and horizontal communications, oriented toward multifunctional work and flexible limits between positions, and with an emphasis on teamwork and great interest in the client. Hence, the company offers technological solutions through the application of processes, models and standards. It is focused on satisfying client's needs in the areas of software development, software deployment and support in any business sector. Every two weeks, the company carries out a series of critical activities connected with the software development process, which must be completed within a timeframe agreed on with the client, by contractual obligation. It is currently difficult to maintain adequate control of these activities in order to ensure the delivery of the final product at the end of the two weeks. It is very common that, for the smaller projects, they keep the delivery date in mind, with all the necessary precautions taken. Nevertheless, it is more common for the larger projects to be delivered late, as requirements are constantly changing and there is no definite follow-up of the most important metrics in the process. This is because of the roles of various members of the work team are not well established. One of the main risks of continuing with the current workflow is, therefore, the possibility that the software not be published on time and the dissatisfaction of the client.

Research design

The research design for the case study consisted of multiple visits to the company where a CEO and two software developers mainly participated in seven formal interviews. However, the authors had the opportunity to discuss with other developers about their activities during the software development process, either to clarify or explain and thereby informally collect data. For this purpose, there are about 15 developers who have different roles and responsibilities in the company, not only in the software development process. Moreover, multiple visits to the company were made in a period of eight months in order to collect data from various sources such as direct observation, directed questions, e-mail exchanges, document records and group discussions. First, a situational analysis of the company was carried out for the first four months where the mission and business vision were reformulated, the strategic objectives were redefined, and a value chain was designed, see Figures 1–3. In addition, the reengineering project was carried out for the following four months using the Hammer and Champy methodology.

Reengineering of the software development process

The software development process is redesigned following the Hammer and Champy methodology, described in Radhakrishnan and Balasubramanian (2010). In this manner, this methodology involves executing six steps: introduction to the reengineering, identify the main business processes, selection and understanding the selected business process, redesign and implementation. Therefore, an analysis of the organizational situation was made to know about the strategic planning of the company in order to redesign the critical process aligned with the company's objectives. A description of these steps is presented as follows.

Step 1: introduction to the reengineering of business processes. First, a situational analysis of the company was carried out in order to diagnose the situation and operation of the company, as well as, the identification of the opportunities and threats offered by the different factors in the environment and recognize the strengths and weaknesses of each of the elements that compose the organization. Furthermore, the reengineering project is

Figure 1.
Vision, mission and values of the company

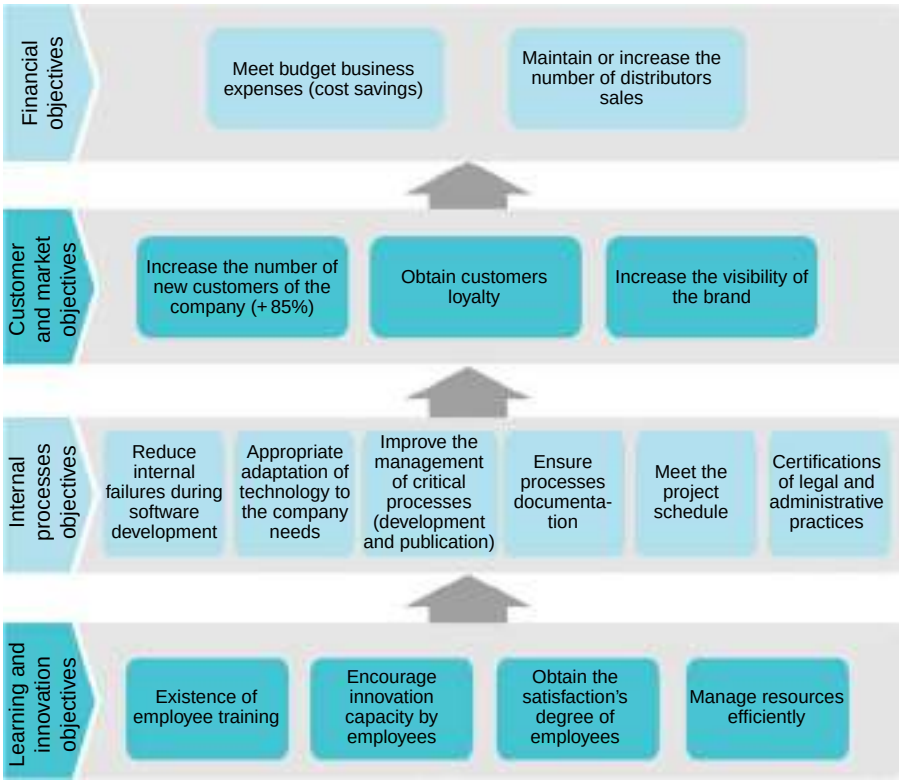

Figure 2.
Company's strategic objectives

delimited to a period of four months. For this purpose, the mission, vision and strategic objectives of the company were reformulated and the value chain was designed, see Figures 1–3. As can be seen in Figure 2, one of the objectives of the internal processes is to improve the management of critical processes, being the software development process, the main critical process for the company. The other strategic objective related to the internal processes is to reduce internal failures during the software development process; for example, adapt technology to the specific needs of the projects, ensure the availability of information about the process and meet the deadlines established when launching new projects or delivering advances on existing projects. The company therefore has a clear need of carrying out a reengineering of its software development process, since this is a critical process to which attention must be paid if the company wants to improve its competitiveness, increase its new client base, reinforce the loyalty and satisfaction of its existing clients and heighten the visibility of its brand.

Step 2: identifying business processes. After, the situational analysis, eight main processes were identified for accomplishing the company's daily activities, such as the software development process, marketing and sales, client support, recruitment and selection hiring process, human resources planning, finance and accounting, supply planning and maintenance services, see Table II. The company's business processes were identified and analyzed in a general way in order to select the critical one based on their needs. For this purpose, a list of priorities was established where the software development process was selected as the critical process to be redesigned.

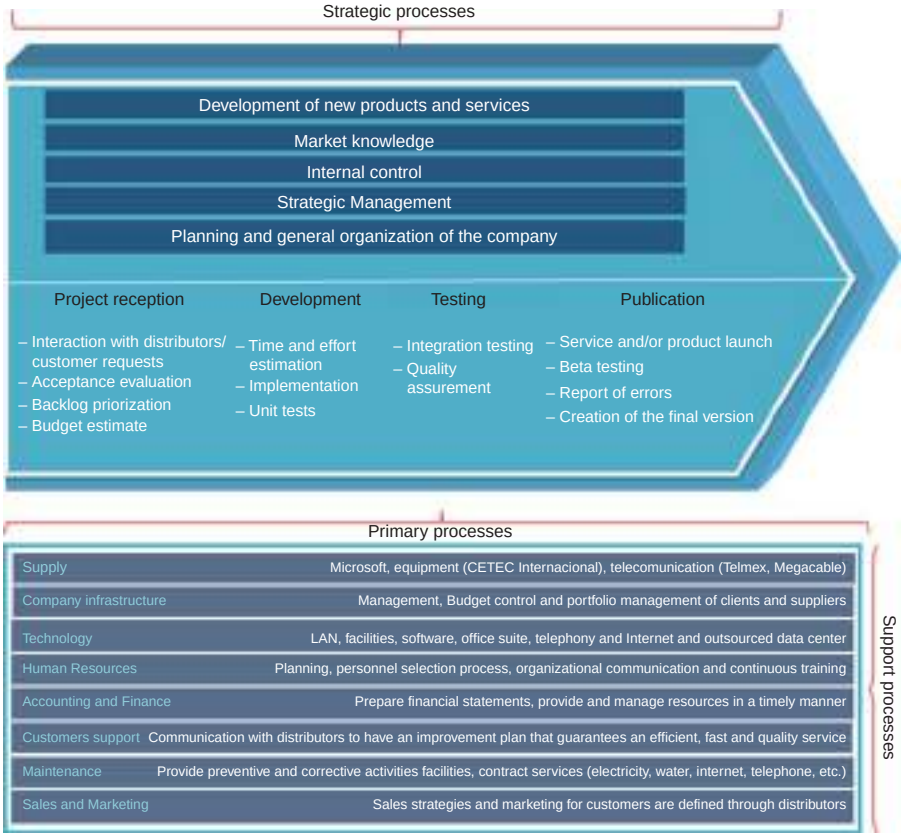

Figure 3.
Value chain of the company

Step 3: selection of the business process for reengineering. The selection of the critical business process for the reengineering project was the software development process due to the time-consuming of some activities represented thereby for the company money that could be invested in another project; additionally, some roles have a higher workload than others. The following criteria were used for the selection of the critical business process:

- state: identifying the processes that are ineffective or where problems have been detected in the activities such as time-consuming, work overload, lack of communication, among others;
- relevance: comparing the relative importance of each process, prioritizing those processes where there is a greater influence of the client and considering the objectives and strategic business plan of the company; and
- feasibility: considering the feasibility of the reengineering process by identifying the factors that determine the probability of success of the process changes in a period of time.

In other words, the critical processes for reengineering, in general, are those considered as inefficient or delayed, with a great impact on clients that contribute to the fulfillment the strategic objectives of the company. Thus, the selected process for this case study is the software development process, as it is the most relevant process for the company with a significant impact on the clients.

No.	Area	Process	Description	Process owner
1	Software development	Software development process	This process begins when a request is registered by a client and continues with a series of activities involved in the development and final publication of software	Project management and software developer
2	Sales	Marketing and sales	Sales and marketing strategies are defined through distributors for increasing sales	Sales manager
3	Sales	Client support	The communication is established with the distributors in order to have an improvement plan for an efficient, fast and quality service	Sales manager
4	Human resources	Recruitment and selection hiring process	Recruitment of high-skilled professionals is crucial for the company success	Human resources manager
5	Human resources	Human resources planning	Growth planning, organizational communication and continuous training	Human resources manager
6	Finance	Finance and accounting	Prepare financial statements, provide and control resources with opportunity	CEO
7	Finance	Supply planning	Guarantee the necessary software, hardware and telecommunications equipment to perform daily activities	Project management
8	Finance	Maintenance service	Provide preventive and corrective activities of the facilities (electricity, water, internet, telephone)	CEO

Table II.
Company's main processes

Step 4: understanding the selected business process. The aim of this step of the Hammer and Champy methodology is to provide a high level view of the performance of the selected process in order to have the necessary knowledge and insight to create a totally new design that improves the current conditions of the process. Thus, four roles are involved in the selected software development process: the client, the analyst, the developer and the quality assurance, see Figure 4. In this respect, the client is the one in charge of requesting the service; the analyst is responsible for requesting the requirements and is responsible for

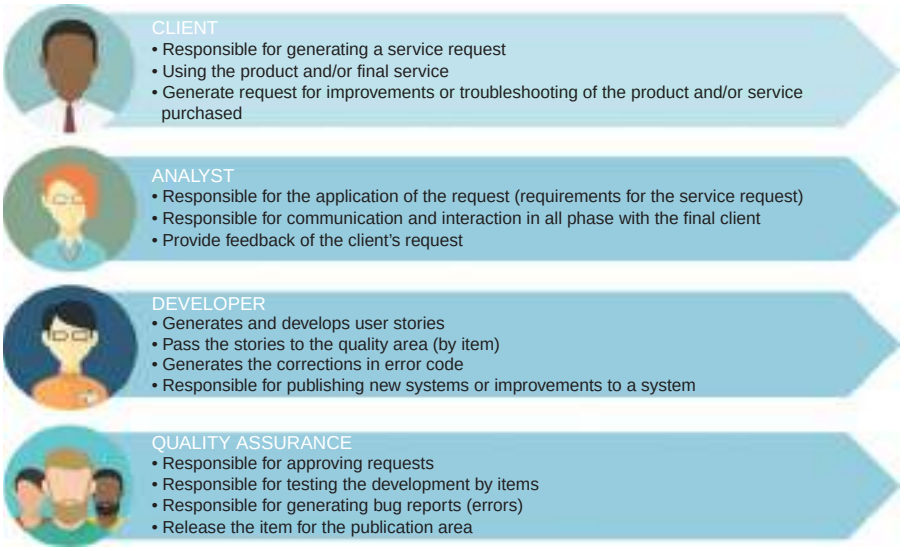

Figure 4.
Roles involved in the process of developing software

maintaining the communication and interaction with the client; the developer is responsible for generating and developing the user's stories as well as correcting code errors and modifications related to the project; finally, the quality assurance is responsible for testing the item, generating error reports and deciding when to send the item to the publication area. In this way, the interaction of each of these roles and their activities can be seen in Figures 4 and 5. In addition, Figures 6 and 7 show in detail the activities and artifacts involved in this process. On the other hand, the artifacts are referred to the input/output item indicated by an arrow; for example, in Figure 7 the client's request a document, user stories,

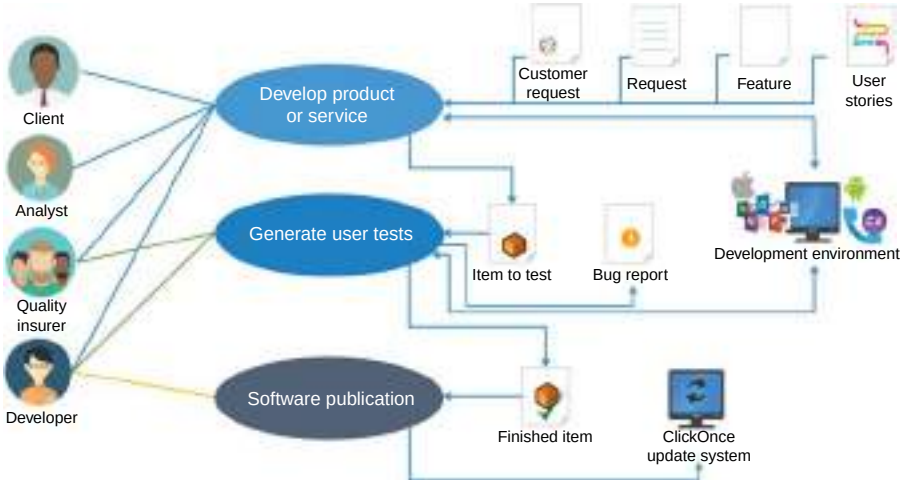

Figure 5.
General vision of the current software development process

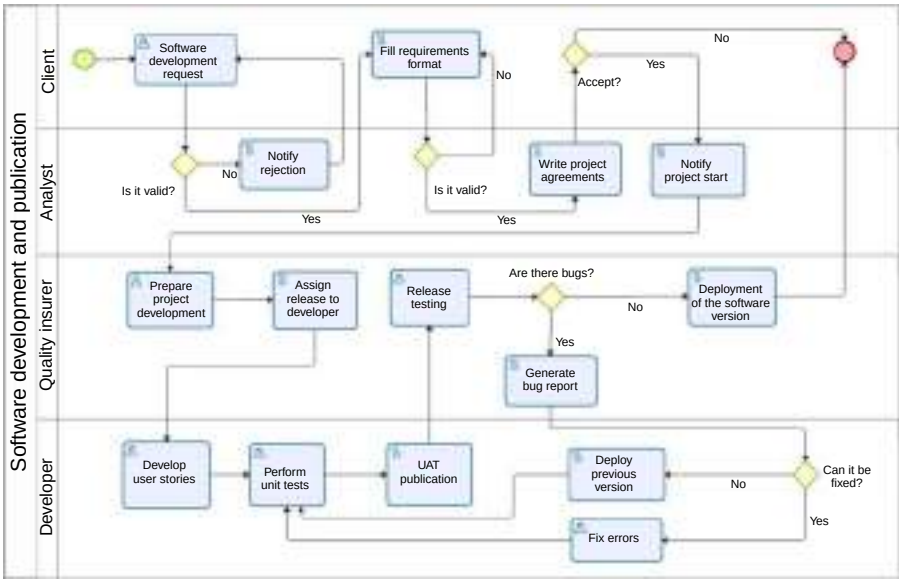

Figure 6.
BPMN diagram of the current software development process

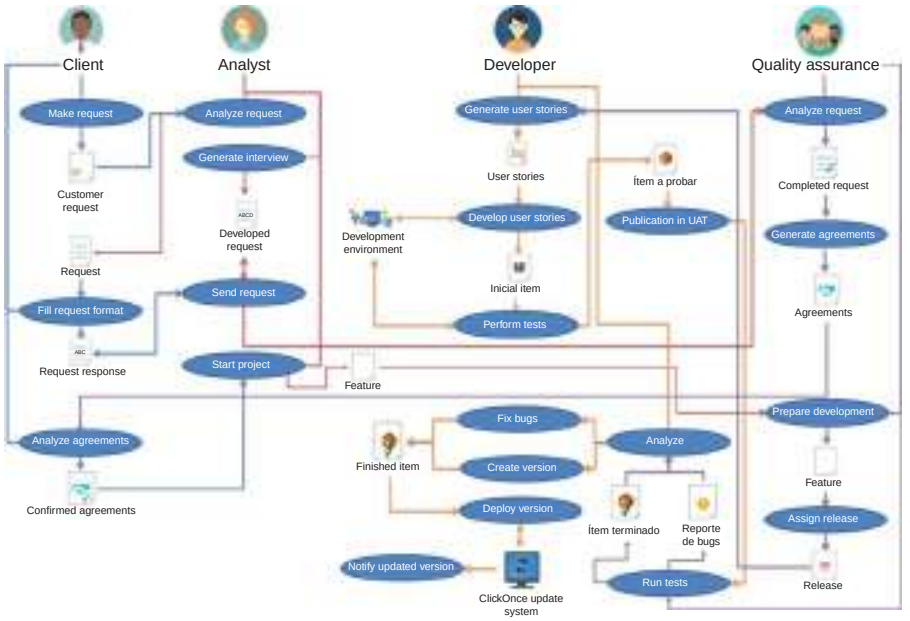

Figure 7.
Rich picture of the current process of developing software

bugs reports, among others. Figure 6 shows the current workflow through a BPMN diagram (Allweyer, 2016) indicating the detail activities carried out by each role.

This process requires the fulfillment of four stages: project reception, construction, testing and publication, see Figure 3. Hence, when the projects are received, it is common to observe that the work team is stressed to meet the deadlines of the project delivery. The principal reason is because in this process there are activities carried out by people who have other assignments and chores, so it is difficult to comply within the established date. Sometimes, the employees forget the responsibilities of their role in the company, either due to the lack of documentation of the process and lack to communication. Also, through the interviews with the managers and the work team, it was found that the software development process has many areas of opportunity and improvement.

Step 5: redesign of the selected business process. In order to redesign, the selected business process is mandatory to understand the current process and identify the activities that must be improved. Hence, we propose the redesign of the software development process through the process modeling represented by a rich picture and BPMN 2.0. The Business Process Model and Notation (BPMN) is a language that has been developed on a solid mathematical foundation provided by the theory of process calculus, an essential requirement for automating execution and easily providing proofs of general consistency properties. In order to describe a workflow, BPMN provides a diagram of business process with a large set of elements and attributes (Cimino *et al.*, 2017). Thus, the notation allows the people involved in the business processes to understand how the flow of activities is carried out within a given process, and to observe the interactions among roles, activities and artifacts.

The activities identified as critical in the software development process actually are assigned to people who have other roles within the company, see the activities presented in Figure 7. On the other hand, Figure 9 presents the rich picture of the reengineered process where the role of project manager is included as well as the corresponding activities. In this respect, a list of the most important changes carried out in the redesigned process is

presented in Table III, where the activities are simplified and the roles are clearly defined along with their responsibilities for a better flow of the process. Moreover, during the visits to the company, a lack of process documentation was found, as well as, a lack of a clear definition of roles and responsibilities. It is therefore, we propose to include a new role named Project Manager, see Figure 8. The project manager will be responsible for the project preparation and team assignments, as well as, schedule the deliveries. Thus, some tasks were simplified to reduce time and costs, see Figures 7 and 9. The redesigned process in BPMN is presented in Figure 10 where the role of project manager is included improving the organization of the software project.

Step 6: implementation of the redesigned business process. This step consists the implementation of the redesigned business process according to the Hammer and Champy methodology. However, this case study presents simulation results for the redesigned process as well as the current process in order to quantitatively know about the benefits that the company could obtain by applying the proposed changes. According to Goksoy *et al.* (2012), the simulation of the reengineering process through a technological tool has proven

Table III.
Main modified activities in the software development process

No.	Proposed activities
1	The client requests are now automatically approved when the requests are related to an existing system
2	The quality assurance activities are now limited to the generation of quality tests, detection of bugs, provide error reports and the deployment of updated versions
3	The role of project manage is now included in the process, as well as, their corresponding activities and responsibilities. These activities correspond to time and costs estimation, preparation of the project, team and member assignments, as well as, schedule the deliveries
4	Specific activities were established for each role, see Figure 8
5	Some tasks were simplified to reduce time and costs, see Figures 6 and 8
6	Some activities were eliminated and improved for a better process performance, see Figures 6 and 8

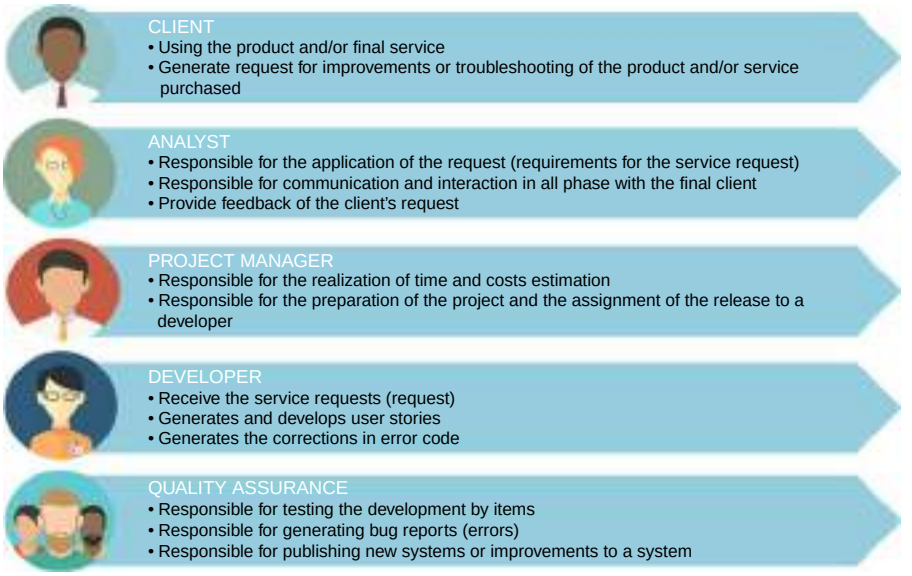

Figure 8.
Proposed roles for the software development process

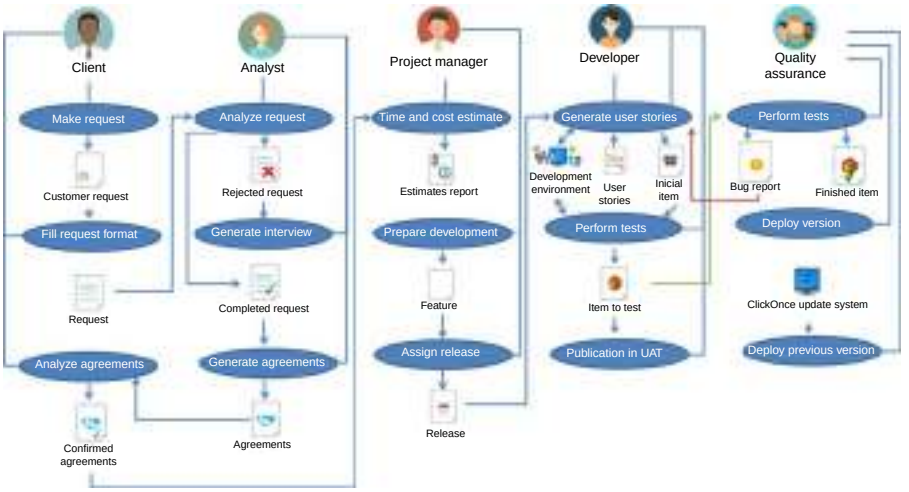

Figure 9.
Rich picture of the reengineering software development process

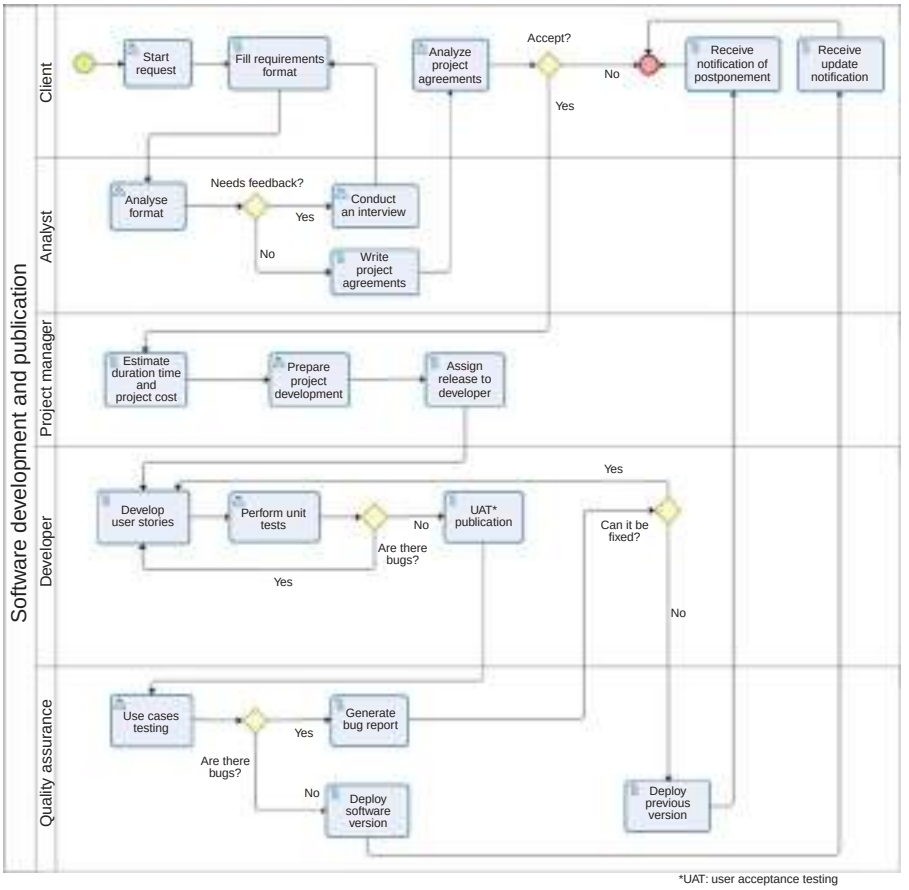

Figure 10.
Proposed BPMN modeling for the redesign of the software development process

to be an effective to determine before applying the changes to know the productive impact and also, clarify the problems presented in the process.

The simulation of the software development process, both, current process (as-is) and the redesigned process (to-be) was presented to the company in order to implement the proposed changes. The CEOs as well as the team were very satisfied with the proposal, therefore, they were interested in redesigning other company processes. In this way, they will decide when to implement the changes in the company in order to reduce the publishing time of the software development process, save costs in the company and increase customer satisfaction.

BPMN simulation results

The feasibility of the proposed redesign process is presented through two simulated scenarios using the software Bizagi (www.bizagi.com/) modeling the as-is and to-be processes in BPMN. A simulation is a useful tool, not only for identifying the activities that are causing delays and misuse of resources, but also, for obtaining comparisons between the processes and how the activities are carried out taking to account the required time to accomplish all the activities. Moreover, if bottlenecks are presented in the process, then, they could be localized in the simulation. In this regard, the data such as time and costs of each activity were collected for the simulation scenarios. The costs of the activities per hour in both scenarios were calculated based on the employee's monthly payment and the hours worked in a month. Thus, the cost per hour of the activities is the same in both models due to the number of working hours and the employee's monthly payment remains the same in the to-be model. Tables IV and V present the results in both scenarios where the reduction of time, cost and effort is noticeable. This reduction is mainly because some activities were simplified, improved and some others eliminated, setting clear and specific activities for each role. Moreover, the addition of the project manager as a role in the to-be model was indispensable since his activities and responsibilities were doing by the quality assurance and developer. In this sense, the workload of the roles in the to-be was better distributed.

Scenario

The software company has two principal business services, the first is the development of software projects (new project to be implemented) and the second is the improvement of an

Table IV. Simulation results of the current process

Resource	Use (%)	Total cost ($)
Developer	44.03	7,951.42
Analyst	2.98	538.40
Quality assurance	50.91	9,140.19
Client	2.08	0.00

Table V. Simulation results of the redesign process

Resource	Use (%)	Total cost ($)
Developer	39.83	3,950.63
Analyst	4.34	430.00
Quality assurance	39.56	3,923.75
Client	2.45	0.00
Project manager	13.82	1,370.63

existing system (modification of functionality and/or fixing bugs). For this case study, the most frequent situation faced by the company is the improvement of an existing system. Hence, we present comparisons of time, cost and effort measured in man-hours of the current and the proposed process using the same initial conditions. The parameters for the simulation scenario are the following.

Scenario parameters

Activities duration: 14 days
Currency: MXN – Mexican Peso
Initial time: 08.00
Duration of the working day: 8 h
Resources: analyst, quality assurance, project manager, developer, client.
Cost: proportional to the hourly wage and the duration of each activity.

Time, cost and effort comparisons

The activities causing a delay in the delivery of the software will cause an additional cost for the company along with the client dissatisfaction. For example, the activities carried out by the quality assurance represent 50.91 percent of all the activities in the current software development process, see Table IV, while in the redesigned process represent 39.56 percent, see Table V, meaning a reduction of $5,216.44MXN only for the quality assurance during the software development process. Consequently, a reduction of 45.12 percent of the costs in the overall process could be save the company implementing the redesigned process, see Table VI for an overall costs comparison. In this way, the savings are mostly due to the modification of the sequence of activities in order to reduce the cycle cost, the elimination of unnecessary activities and, the reduction of some tasks, see Figure 11.

Resource	Cost of current process ($)	Cost of proposed process ($)
Developer	7,951.42	3,950.63
Analyst	538.40	430.00
Quality assurance	9,140.19	3,923.75
Client	0.00	0.00
Project manager	0.00	1,370.63
Total cost	17,630	9,675

Table VI.
Costs comparison

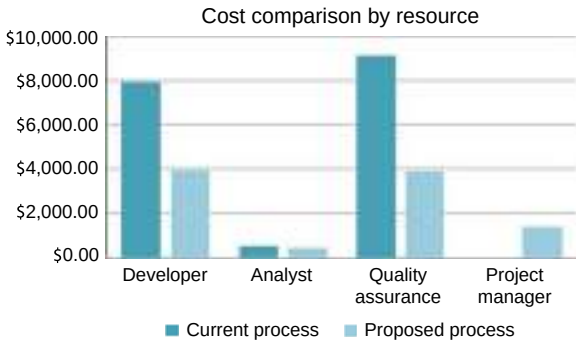

Figure 11.
Cost comparison by resource between the current and proposed

According to the simulation scenario, the current process requires 313:34:00 h to accomplish all the activities and deliver the software project, meanwhile, the proposed process would take 184:31:00 h, saving 129:03:00 h. This is a reduction of 41.17 percent of the total time required to finish the project, see Figure 12. The reduction in time is mainly due to the optimization of tasks and the new role added (project manager) in the redesigned process, see Figures 6, 7, 9 and 10, where the sequence of activities was modified to reduce the cycle time, unnecessary waiting times were reduced and activities corresponding to each role were reassigned.

According to the results, an inefficient process flow was found in the current process presenting an overload of activities in the quality area, with a 50.91 percent use of resources in order to complete all the activities of the process and deliver the development project, see Figure 13. Furthermore, an overload of activities and responsibilities of the quality assurance were detected in the current process. Finally, the lack of the project manager role was detected, who is responsible of the project planning, project cost and time estimation to mention but a few; thus, this role is included in the reengineering proposal since the project manager already work in the company, which means that there are no additional payments for this person.

Conclusions

This paper presents a case study of a reengineering process for a Mexican Software Development Company. According to the company mission and strategic goals, they are interested in creating high-quality solutions and services that exceed the expectations of its clients, thereby earning their loyalty and increasing the visibility of its brand. Currently, the company faces a challenge related to its software development process due to their constant concern about to meet deadlines agreed with the client and the continuing changes on the requirements. The methodology of Hammer and Champy was used to carry out the

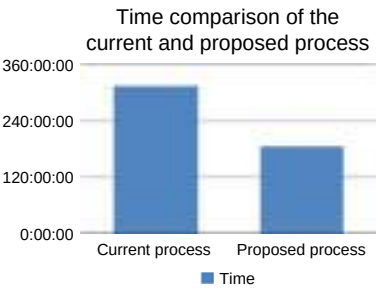

Figure 12.
Total time comparison of the current and proposed process

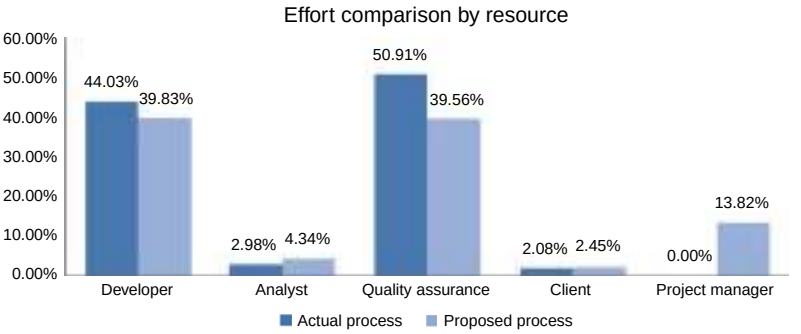

Figure 13.
Effort comparison by resource for current and proposed process

reengineering project where the process modeling with the interactions of roles, activities and artifacts was represented through the BPMN diagram. Furthermore, two scenarios with the same initial conditions were formulated using Bizagi simulation software. One scenario simulates the current process and another simulates the reengineered process; as a result, the redesigned process presented a significant improvement in times and costs. Moreover, according to the results of the redesigned process, resources are redistributed in a balanced manner, in accord with the responsibilities of each role within the company allowing the optimization of task flows where:

- it is proposed that the activities of the quality assurance role correspond only to the generation of quality tests and detection of errors in the developed items, in addition to generating the error reports and the display of updated versions; and
- the set of activities that corresponds to the new role of project manager are established. It involves mainly those related to the project preparation and the assignment of the project release to a developer.

According to the results obtained from the analysis of the company's software development process, the reengineering proposal is a simple and a viable solution which would not require the company to invest in technology or human resources, but merely to make better use of the resources that already possesses. The reengineering of the software development process would have a positive impact reducing costs, times and effort in addition to guaranteeing quality and client satisfaction through development of projects that ensure an optimal flow of activities.

Future directions

In order to accomplish a good performance of the software development process in the implementation of the reengineering proposal, it is suggested that the following actions are to be taken into account to obtain greater benefits:

- access to project information: allow the access to the project progress registry platform to all roles involved in a given ongoing project;
- follow-up and control of activities: the project manager should follow-up on employee activities in real time in order to maintain control of the employees' performance and so be able to detect delays before they become critical to the delivery of the project;
- use of data and data availability for new analyses: perform periodic reports showing the performance of the software development process in order to diagnose being able to make effective decisions; and
- design a mechanism for estimating costs and time: determine and document the estimated duration and cost of the all the activities required to carry out the process, which will make for more effective follow-up of the indicators as the project progresses.

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Evolving behaviors for bounded-flow tracking control of second-order dynamical systems

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ABSTRACT

A two-stage methodology for the development of nonlinear analytical controllers for tracking control in second-order dynamical systems subject to flow variable constraints is proposed. It extends the concepts of behavior-based control to describe the system as the summation of its *unforced*, *forced*, and *learned* behaviors. While the *unforced* behavior is characterized by its analytical dynamical model, the *forced* and *learned* behaviors are introduced in the system by means of a Control-Theory-based controller and an evolutionary learning process based in the Genetic Programming paradigm. The integration of both approaches in a unified framework allows the system to exhibit a good tracking performance while keeping the flow variable bounded to a desired value, parametrized as a boundary interval. A set of 180993 *learned* behaviors, which preserves asymptotic convergence to the desired behavior while achieving a bounded flow variable, were discovered by the evolutionary process. Simulation results show the effectiveness of the found nonlinear tracking controllers with the highest fitness value, as well as the one with the lower structural complexity. A performance comparison between numerical simulations and real-time experiments for a mechatronic prototype is also provided to illustrate the feasibility of the proposed method in real-world applications.

1. Introduction

Second-Order Dynamical Systems (SODS) are widely used in engineering to describe the dynamic behavior of mechanical, electrical, pneumatic, and hydraulic systems, among others (see e.g. Ogata, 2003; Fabien, 2009; Ogata, 2010; Khalil, 2002). The general form of these systems is described by the ordinary differential equation

$$a\ddot{q}(t) + b\dot{q}(t) + cq(t) = du(t), \tag{1}$$

where $q(t), u(t) \in \mathbb{R}$ is the output and the input, respectively, while $\dot{q}(t)$ and $\ddot{q}(t)$ denote the first and second time-derivative of the output. The coefficients a, b, c, and d denote the system parameters. In systems dynamics theory, $\dot{q}(t)$ is the so-called *flow variable* while $u(t)$ is the *effort variable* (Ogata, 2003; Fabien, 2009).

The significance of (1) can be extended to a broad range of applications. For instance, the Double-Integrator System (DIS) is described from (1) by taking b and c equal to zero while a and d equal to one. DIS have been commonly used in robotics to describe the motion of a rigid body of a single Degree-Of-Freedom (DOF) with unit moment of inertia (see e.g. Knoll and Röbenack, 2011; Serpelloni et al., 2016), and to model nodes in networked multi-agent systems (Pettersen et al., 2006; Olfati-Saber et al., 2007; Garcia et al., 2016). Other applications of (1) include, among others, modeling of armature-controlled DC motors (neglecting the armature inductance), connectivity in wireless communication and cooperative motion in swarm robotics, in the form of a *virtual* spring–damper system (Naruse, 2015; Urcola et al., 2008; Tardioli et al., 2010).

The dynamics (1) is indeed an Euler–Lagrange system for which many control strategies can be applied with the aim to make the system output to reach a given reference. If the reference is constant, the control problem is known as set-point regulation while if it is variable is known as (trajectory) tracking. Despite different successful control strategies for these problems have been proposed in Khalil (2002), Kelly et al. (2005) and Spong et al. (2006), their designs do not consider explicitly the physical capabilities of the system, like the maximal efforts that can be demanded from the actuators or the maximal flow that can be developed by the system. In practice, the different variables and signals are physically limited, so these controllers must carefully be implemented since they could easily cause the system to operate under saturated conditions when the limits are overtaken. It has been proved that, under saturation, the system performance is severely deteriorated

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and could fastly lead to instability (Alvarez-Ramírez et al., 2008). The design of control strategies that take into account these physical limitations is not an easy task since the more constraints are considered, the more complex the controller design will result.

In mechanical systems, the flow variable of a SODS corresponds to the linear or angular velocity. Control of mechanical systems subject to velocity constraints has been an interesting topic of research in robotics and some Control Theory (CT) based solution have been proposed (see e.g. Ngo and Mahony, 2006; Omrcen et al., 2007; Garelli et al., 2011; Hu et al., 2013; Salinas et al., 2016). In Ngo and Mahony (2006), a modified proportional–derivative (PD) controller is proposed for solving the regulation problem in robot manipulators subject to joint velocity constraints. Since the controller includes some damping terms, asymptotic convergence to the reference is slow. In Omrcen et al. (2007), a method for compensating velocity saturation is designed for redundant manipulators. It is based on the robot kinematics, the null-space approach, and the pseudo-inverse Jacobian. The method is restrictive as it is no longer valid in singular configurations. In this sense, Garelli et al. (2011) handles robot singularities and speed constraints in its control solution based on sliding modes; however, the proposal allows the control signals to exhibit chattering which is not suitable for practical implementations in mechanical systems. In Hu et al. (2013), the velocity constraints problem is considered for the attitude control of a spacecraft. Among these results, a common characteristic is that the system is subject to different operating conditions and the performance is deteriorated when the signals are saturated, although stability is preserved. In consequence, the developed controllers are not valid if any initial velocity is out of the specified bound (the results remain limited as the velocity bound cannot be changed online to a lower value to modify the system performance). Furthermore, these contributions mainly deal with the set-point regulation problem (constant reference). Different from these works, in Peñaloza-Mejía et al. (2015), a novel solution has been proposed for trajectory tracking in an omnidirectional mobile robot subject to velocity constraints. The proposal consists of an inverse-dynamics control with an additive excess-of-energy dissipation term that allows the system to fastly converge to the trajectory while keeping the velocities bounded to desired values set by the user.

Some other proposals introduce the use of Soft Computing techniques as an optimization tuning tool to modify the performance of CT-based controllers (Kim and Park, 2005; Chiang and Chen, 2017; Sedghizadeh and Beheshti, 2018). For this scheme, the controller is derived by applying the CT approach and the aim is to find a better performance by testing constant values (either for the system parameters or the controller gains) using Soft Computing techniques, such as Fuzzy Logic, NNs (Neural Networks), PSO (Particle Swarm Optimization), GA (Genetic Algorithms) and GP (Genetic Programming), among others. The optimized parameters aim to increase the convergence rate to the desired behavior as well as fulfill desired features in the response of the system, such as bounded variables or signals demanded by the controller. Nevertheless, most Soft Computing techniques are unable to provide a rigorous analysis of the system response as CT approach does.

The design of the different solutions, either for set-point regulation or trajectory tracking, has been a real challenge. These have led to different fixed control strategies which strongly impose the closed-loop system behavior. Considering (Peñaloza-Mejía et al., 2015), the controller is more flexible as it consists of two terms: one for the tracking task and one for the bounded velocity task. This is one of the keys which allows the system to fastly track the reference while keeping the velocities within their limits. Just to mention, in Peñaloza-Mejía et al. (2015), the bounding-velocity term solely acts to slow down the motion when the velocity has reached the specified limits (the velocity no longer increases), while it has no effect while the velocities are below these limits. Since the design of the bounding-velocity term in Peñaloza-Mejía et al. (2015) was done by hand and it really took its time, an interesting question that arises here is if it is possible to automatically synthesize another (better) controller, but by using computational methods, such that the system achieves asymptotic tracking of the reference with bounded flow variable. Some state-of-the-art proposals in evolutionary robotics have shown that it is possible to automatically synthesize controllers for some problems in robotics (see e.g. Lee and Hallam, 1999; Abdessemed and Benmahammed, 2001; Ng and Johansson, 2002; Nelson et al., 2009; Song et al., 2011; Fukunaga et al., 2012; Lamini et al., 2018).

In this work, an analytic behavior-based framework has been applied for the automatic synthesis of controllers to fulfill physical constraints while achieving the desired task. It takes the flexibility of designing nonlinear controllers for a SODS (1) as the sum of partial control laws to simultaneously accomplish the tracking of the desired reference while keeping bounded the flow variable of the controlled system. Taking advantage of the GP paradigm, the search for behaviors fulfilling both objectives is implemented, where a set of 180993 fittest solutions is obtained.

1.1. An analytic behavior-based framework

Mataric (1994) and Matarić and Michaud (2008) developed the idea of behavior-based systems by introducing *basis* behaviors that lead the system to achieve a goal. Each *basis* behavior is defined as a minimal set of actions used for decision-making and action–execution processes. Behavior-based control was brought in by Arkin (1998) to endow intelligence into robots through the analysis of behaviors of biological systems and by taking advantage of the interaction of the system with the environment. This approach was developed given a situatedness property of the system to adapt its dynamics to real-world environments via mutual interaction.

In contrast to the traditional approach, our framework extends the concepts of behavior-based control to introduce two essential properties: an analytical representation of the system–environment interaction and the inclusion of the internal dynamics. Both properties are generated by the introduction of CT approach to provide an structure to represent behaviors analytically, and it allows to formulate the feedback in the automation of a learning process for the system. On the other hand, Genetic Programming (GP) has been highly successful as a technique for getting computers to automatically solve problems without having to tell them explicitly (Langdon and Poli, 2010). GP technique suggests a syntactical tree form to represent a solution, where their elements are program instructions or mathematical operators and operands. The novelty of the applied framework in this work is the integration of CT and GP techniques, to derive a scheme for the construction of analytic solutions, in the automation of the synthesis of nonlinear controllers. Specifically, it has been developed to address the tracking problem in a SODS where a bounded flow variable is required. It takes advantage of the analytic representation of the control problem and stability properties of the controlled system, provided by the CT approach, to guarantee a behavior that converge to the desired reference. Then, a GP-based process is implemented for the automatic search of behavior modifiers to keep a bounded flow variable without compromising the achievement of the previous desired behavior.

An overview of the key aspects of the proposed framework is shown in Fig. 1. The entire behavior of the system is characterized by its *natural* behavior, which is composed of three *basis* behaviors plus the unknown and unmodeled dynamics, the parametric uncertainties due to normal wear and tear, and the external disturbances from the environment. The *basis* behaviors are composed of analytic functions and the behavior synthesis is performed by a learning process given a previous CT-based design. The first *basis* behavior denoted as the *unforced* behavior is the dynamic model of the system which depends on initial conditions without applying any input or excitation signal. As for the aforementioned control problem addressed in this work, the *unforced* behavior is the SODS given in (1) with the effort variable $u(t)$ equal to zero. Such definition can be related to the free response of (1) within the CT approach. Whereas the *unforced* behavior is given by

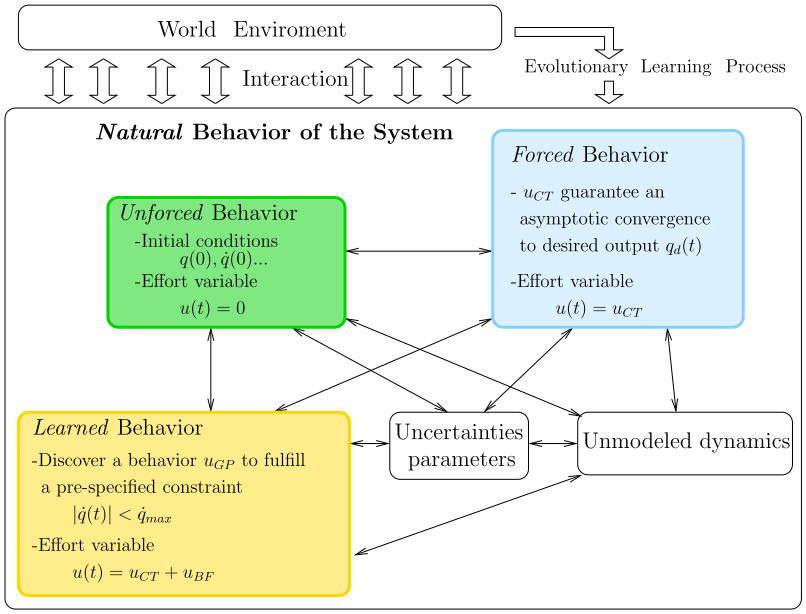


Fig. 1. A conceptual framework of the learning process of a SODS towards the development of analytic nonlinear tracking controllers with constrained variables. The *natural* behavior of the system is given by the interaction of *unforced*, *forced*, and *learned* behaviors in addition to its unmodeled dynamics and parametric uncertainties. While the *unforced* and *forced* behaviors are described by a well-defined procedure, the *learned* behaviors are suitable modifiers to adaptively change the *natural* behavior to perform under restrictions, either from its physical specifications or from the world environment.

its modeled internal dynamics, the second *basis behavior* (called *forced* behavior) is induced by the action of a CT-based controller denoted as u_{CT}. The advantage of applying a CT-based controller is its property of guaranteeing the performance of the system through the concept of stability of equilibrium points. In this case, the equilibrium points of the SODS are those initial conditions that, whenever the system starts at them, it will remain in that equilibrium points for all future time. The *forced* behavior proposed for the SODS is the fulfilling of control objective given in (2); that is, it must guarantee the convergence of the system to a desired reference $q_d(t)$. Then, the consistency of this induced behavior is analyzed by applying one of the most important criteria within CT denominated the Lyapunov stability.

The *forced* behavior of the system is an innate behavior; i.e., once the stability of the system applying this controller is verified, fulfillment of the specified objective is guaranteed. This behavior is a general solution considering changes in the environment and the initial conditions of the system since the problem setup is based in the CT approach. Finally, the third *basis* behavior is the *learned* behavior generated by applying nonlinear controllers derived from a learning process. The *learned* behaviors act as an adaptive mechanism of the system either to change the environment or to modify its conduct to exhibit desired features. In our approach, the CT-based representation of the control problem is useful to describe the behavior of the system through a multivariable mathematical function, where each part of this function accomplishes an specific goal. Specifically, GP allows the implementation of a learning process where the system acquires the ability to perform under flow variable restrictions while exhibiting the desired response. This new acquired ability is generated by each GP fitted discovered solution denoted as u_{BF} plus the CT-based controller u_{CT}. Here, subscript BF stands for *bounded flow* since the generated *learned* behavior aims to limit the flow variable of the SODS within a pre-specified interval. Thus, the *natural* behavior of the system, defined as the closed-loop dynamics within the CT terminology, is computed as the solution of the SODS (1) while applying the full control input $u(t) = u_{CT} + u_{BF}$.

1.2. Contribution

In this work, an analytic behavior-based control framework is applied, for the automatic development of a set of output tracking controllers with constrained flow variable for a SODS. To the best of the author's knowledge, the trajectory tracking problem with desired bounded flow variable had not been studied under this framework, only recently in the work of Peñaloza Mejía et al. (2017), where the problem was particularly addressed for the double-integrator system. In the current work, the synthesis of nonlinear controllers is extended to a wider class of systems modeled by SODS described by (1).

A summary of the main contributions of this paper is listed as follows.

- The formulation of a learning process for the synthesis of nonlinear controllers in a SODS to solve the tracking problem while exhibiting a bounded flow variable. The implementation of an analytic behavior-based framework allows the definition of the behavior of the system as the sum of three *basis* behaviors, and the discovery of desired behaviors of the system where a constrained variable is considered.
- CT approach is applied to provide an analytical representation of the behaviors, and an automation structure to generate new behaviors in the SODS. It has been also used as feedback for the learning process of the system aiming to acquire new features.
- A traditional CT-based controller is introduced to generate a *forced* behavior in the SODS which is characterized by the property of guaranteeing the performance of the system through the concept of Lyapunov stability.
- The GP paradigm allows to implement a learning process in the SODS to find solutions for the flow variable restriction without an explicit programming. This work takes advantage of the properties of the GP to build analytical solutions, and to automate the synthesis of nonlinear controllers for the stated control problems.
- For the SODS given by the dynamics (1), the learning process must fulfill two main requirements: (a) it must not affect the *forced* behavior of the system to converge to a desired (twice continuously differentiable) output $q_d(t) \in C^2$, and (b) its entire performance (i.e., its *natural* behavior) must be measurable within an index of suitability.
- The developed methodology based on the framework described in this work, can be redesigned where the system is able to learn new features, and embed them as part of its *natural* behavior. More terms can be added to the *effort* variable of the system where each one of them aims to fulfill a desirable trait in the behavior of the system without inhibiting each other.

- The *learning* process was implemented in a SODS, where all the parameters of the system are the unit. Nevertheless, the discovered nonlinear controllers are flexible since an experimental study was carried out in a mechatronic prototype (modeled by a SODS) where velocity constraints must be met.

The rest of the paper is organized as follows. In Section 2, the synthesis of a tracking CT-based controller is presented, and the description of the layout for the search of evolved behaviors is introduced. The proposed methodology, applied to the design of analytical nonlinear controllers using the GP paradigm, is described in Section 3. In addition, the set of fittest *learned* behaviors which solve the tracking control problem of a SODS while imposing a bounded flow variable, is also presented. Section 4 provides the results of numerical simulations and real-time experiments in a mechatronic prototype, modeled by a SODS, applying a selected controller from the discovered *learned* behaviors. Finally, the conclusions are given in Section 5.

2. Synthesis of tracking controllers

In the following, the formulation upon which the proposed framework for the evolutionary learning process of a SODS towards the development of a set of nonlinear controllers enforcing constrained variables, is presented.

2.1. Problem statement

Consider the SODS whose dynamics was given in (1). Assume that there is a desired C^2 reference $q_d(t) \in \mathbb{R}$ to be tracked. Our control objective can be described as the design of an effort variable $u(t)$, such that the following two performance conditions are achieved by the controlled system,

1. the output $q(t)$ asymptotically converges to the desired reference $q_d(t)$, that is,

$$\lim_{t\to\infty} |q_d(t) - q(t)| = 0, \tag{2}$$

2. the flow variable $\dot{q}(t)$ is kept within a constant boundary interval; that is,

$$|\dot{q}(t)| \leq \dot{q}_{max}, \quad \forall \quad t \geq 0, \tag{3}$$

where $\dot{q}_{max}$ is a positive constant corresponding to maximum value of bound on flow variable for the SODS, freely set accordingly to meet the physical constraint.

2.2. Controller design

The proposed effort variable for the SODS (1) is a combination of two controllers given by

$$u(t) = u_{CT} + u_{BF}, \tag{4}$$

where u_{CT} is used to achieve asymptotic tracking of the reference, while u_{BF} is used to keep the flow variable within the desired suitable limits defined by the value of $\dot{q}_{max}$.

The tracking controller applied is a traditional CT-based strategy consisting in a PD (Proportional–Derivative) with inverse dynamics. We propose an approach for designing the bounding flow variable controller u_{BF} by means of evolutionary algorithms based on GP. Furthermore, the tracking performance and the maximal allowed flow variable, can be considered simultaneously using this framework.

2.2.1. CT-based output tracking controller

Let us define the tracking errors as

$$\tilde{q}(t) = q_d(t) - q(t), \quad \dot{\tilde{q}}(t) = \dot{q}_d(t) - \dot{q}(t), \quad \ddot{\tilde{q}}(t) = \ddot{q}_d(t) - \ddot{q}(t), \tag{5}$$

and consider for (1), the traditional CT-based PD controller with inverse dynamics (Spong et al., 2006)

$$u_{CT} = \frac{1}{d}\left(az + b\dot{q}(t) + cq(t)\right), \tag{6}$$

where

$$z = \ddot{q}_d(t) + k_D\dot{\tilde{q}}(t) + k_P\tilde{q}(t). \tag{7}$$

Assuming there is no bounding controller present (i.e. $u_{BF} = 0$), the closed-loop dynamics obtained by substituting (6) and (7) into (1), is described by the second-order linear system

$$\ddot{\tilde{q}}(t) + k_D\dot{\tilde{q}}(t) + k_P\tilde{q}(t) = 0, \tag{8}$$

which ensures asymptotic tracking of the reference provided that the control gains k_P and k_D be positive. Closed-loop stability of the controlled system has been thoroughly proven in the state-of-the-art, and values of the control gains must be properly chosen in accordance with the desired tracking performance (for further details, see e.g. Spong et al., 2006). The resulting dynamics (8) models the *forced* behavior of the SODS, as formulated in the proposed conceptual framework, previously shown in Fig. 1. Backed up by the CT approach, asymptotic tracking property only guarantees convergence of the SODS (1) to the desired reference $q_d(t)$; that is, fulfillment of the first control objective defined in (2). Let us recall that posing the control problem using the CT approach and the integration of a PD with inverse dynamics controller allows the reduction of the search space for the GP. Now, an additional term for the effort variable given as u_{BF} must be developed to fulfill the bounding condition for the flow variable as stated in (3), using the GP approach.

3. Evolved behavior modifiers for bounded flow variable in a SODS

In this section, a methodology towards the development of nonlinear controllers, joining the CT-based tracking controller built up previously and a GP-based set of *learned* behaviors, to achieve simultaneously control objectives stated in (2) and (3), is presented.

As proposed, let us set the effort variable (4) as the sum of two control inputs given as u_{CT} and u_{BF}. Then, let u_{BF} (known as the bounding flow variable controller) be defined as a set of GP-based control laws generically denoted as u_{GP}. Thus, a set of L *learned* fittest behavior modifiers is discovered through the form of u_{GP_j}, $j = 1, \ldots, L$, as bounding flow variable controllers u_{BF_j}. These controllers are local optimum solutions producing *learned* behaviors acting together with the *unforced* and *forced* behaviors of the SODS.

As follows, the full closed-loop dynamics, obtained by substituting (4) into (1), where u_{CT} is given in (6) and (7), while $u_{BF} = a/d\, u_{GP_j}$, is defined as

$$\ddot{\tilde{q}}(t) + k_D\dot{\tilde{q}}(t) + k_P\tilde{q}(t) = u_{GP_j}, \tag{9}$$

where the control input u_{GP_j}, denoting the *learned* behaviors, takes the place of u_{BF} as the bounding flow variable controllers.

As established by our proposed framework, the search of fitted evolved behavior modifiers u_{GP_j} aims to the fulfillment of physical constraints without affecting the *forced* behavior of the system to reach the desired output $q_d(t)$; i.e., convergence of the error dynamics to zero in the absence of u_{GP_j}. Furthermore, note that the dynamics of the SODS, described by its physical parameters a, b, c, and d, have been compensated by the inverse dynamics terms in u_{CT}. Hence, setting values of a, b, and c, for the evolutionary process is not required since the *forced* behavior, related to the CT-based controller, will algebraically compensate it with the inverse dynamics control terms. Taking into account the general case, we have selected a unitary value for the effort variable gain, denoted as d, for the SODS.

The overview of the applied adaptive process leading the SODS to *learn* how-to achieve a bounded flow variable is given as a flowchart in Fig. 2. First, the parameters of the system are initialized, and the selected pairs of starting velocities and positions are established; this set up defines the *unforced* behavior. Second, the *forced* behavior is generated by the controller u_{CT} as described by the Eqs. (6) and (7).

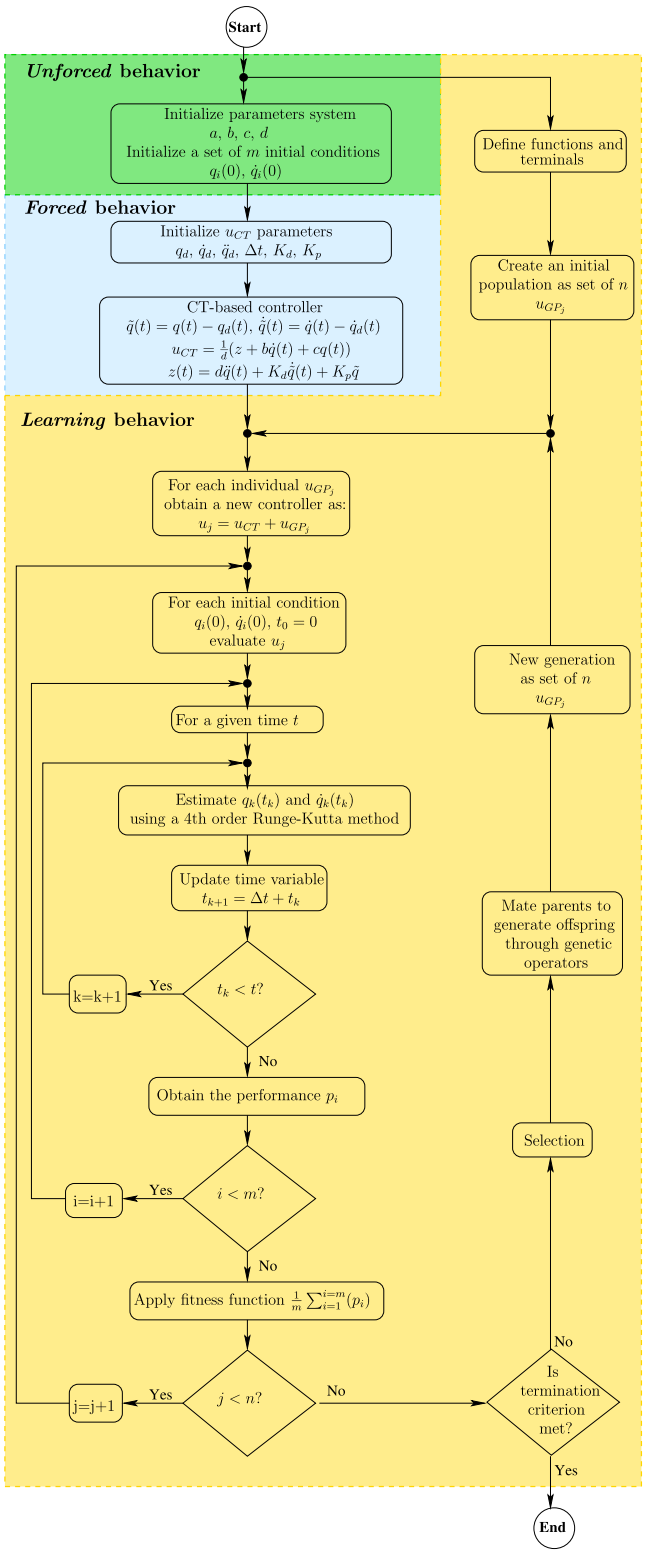


Fig. 2. Computational outline of the GP process to generate the *learned* behaviors for a SODS. The performance evaluation is done by a numerical simulation of the Second-Order Dynamical System for each discovered solution in the form $u_{CT} + u_{BF}$.

Third, the *learned* behaviors for the system are discovered with the GP process by the solutions in the form of the controller u_{GP}. The performance of the system is done by evaluating the *natural* behavior of the system given as the sum of its three basis behaviors: *unforced*, *force* and *learned*. If the performance of the behavior is suitable for each initial condition and accomplishes the required restrictions, this possible solution is selected to apply the genetic operators and build a new generation. This procedure continues until the defined number of generations is reached.

Table 1
Set of terminals to generate *learned* behaviors by the GP aiming to achieve bounded flow variable in the SODS. Flow variable of the SODS, errors against the desired behavior, as well as some constant values, are considered.

ID	Term	Description	ID	Term	Description
1	$\dot{q}(t)$	Flow variable	5	$\dot{\tilde{q}}(t)$	Flow variable error
2	$\dot{q}_{max}$	Flow variable limit	6	$-\dot{\tilde{q}}(t)$	Negative flow variable error
3	$\dot{q}_d(t)$	Desired flow variable	7	0.5	Constant value
4	ϵ	Constant value	8	1	Constant value

Table 2
Functions used in the evolutionary process to find *learned* behaviors achieving bounded flow variable in the SODS.

ID	Expression	Description	ID	Expression	Description
1	$(\cdot)^2$	Square	17	asin(·)	Inverse sine
2	$(\cdot)^3$	Cubic	18	acos(·)	Inverse cosine
3	$\sqrt{\lvert\cdot\rvert}$	Square root of the function absolute value	19	atan(·)	Inverse tangent
4	asinh(·)	Inverse hyperbolic sine	20	$e^{(\cdot)}$	Exponential
5	sinh(·)	Hyperbolic sine	21	ln(·)	Natural logarithm
6	cosh(·)	Hyperbolic cosine	22	Re(·)	Real part
7	tanh(·)	Hyperbolic tangent	23	$\lVert\cdot\rVert$	Euclidean norm
8	csch(·)	Hyperbolic cosecant	24	$\lvert\cdot\rvert$	Absolute value
9	sech(·)	Hyperbolic secant	25	sgn(·)	Signum function
10	coth(·)	Hyperbolic cotangent	26	+	Addition
11	cos(·)	Cosine	27	−	Subtraction
12	sin(·)	Sine	28	/	Division
13	tan(·)	Tangent	29	∗	Multiplication
14	csc(·)	Cosecant	30	$(\cdot)^{(\cdot)}$	Exponentiation
15	sec(·)	Cosine	31	max(·, ·)	Maximum
16	cot(·)	Cotangent	32	min(·, ·)	Minimum

An adequate selection of terminals and functions allows to define the search space of feasible solutions. The terminals set is based on expressions related to the flow variable $\dot{q}(t)$, the selected constant value of the desired boundary limits $\dot{q}_{max}$, the tracking controller u_{CT}, and the flow variable error of the SODS with respect to the desired behavior denoted as $\dot{\tilde{q}}(t)$. In addition, some proposed constant values are included. The functions set is composed of simple arithmetic, trigonometric and some special mathematical functions which were chosen due to its property of continuity. Note the inclusion of the hyperbolic tangent (*tanh*) and signum function (*sgn*), frequently used as saturating functions within state-of-the-art proposals, among the selected functions. Some non-differentiable functions, such as minimum (*min*) and maximum (*max*) functions, were also included to expand the search space of the GP. Both sets of terminals and functions are shown in Tables 1 and 2, respectively.

3.1. Fitness function design

The search of solutions is guided by an objective function, called fitness function, defined as a performance metric of the controlled SODS. The fitness function is applied for each generated bounding flow controller u_{GP_j} and it must be evaluated simultaneously, along the total simulation time t_f. Hence, the performance of the SODS is evaluated for each particular set i of initial conditions, $q_i(0)$ and $\dot{q}_i(0)$, within the numerical simulation of the full closed-loop dynamics of the system (9), as

$$performance_i = \sqrt{\frac{T}{t_f}\sum_{k=0}^{n}\tilde{q}_i^2(kT)} + \sqrt{\frac{T}{t_f}\sum_{k=0}^{n}\dot{\tilde{q}}_i^2(kT)} + N_{oc_i}, \tag{10}$$

$$N_{oc_i} = \sum_{k=0}^{n} OC_k, \tag{11}$$

$$OC_k = \begin{cases} 1, & |\dot{q}_i(kT)| \geq \dot{q}_{max} \\ 0, & \text{Other} \end{cases} \tag{12}$$

where n is the total number of iterations required to compute the whole simulation time given the step size T (i.e. $n = \frac{t_f}{T}$), and N_{oc_i} is given by the number of sample times where the flow variable of the system is out of the established constant bound $\pm\dot{q}_{max}$.

The performance of the system is given by the performance index computed as in Eqs. (10)–(12), where the following three criteria have been considered.

1. *Convergence of the output variable error $\tilde{q}$ to zero is preserved.* This condition ensures that the desired output $q_d(t)$ is reached by the SODS despite the influence of the bounding controller u_{GP_j}. The suitability of the possible solution is evaluated in the first term of Eq. (10) as the Root Mean Square Error (RMSE) of the sampled output variable error $\tilde{q}_i(kT)$.
2. *Convergence of the flow variable $\dot{q}(t)$ to the computed first time-derivative of desired output denoted as $\dot{q}_d(t)$.* RMSE is also applied to the sampled flow variable error $\tilde{\dot{q}}_i(kT)$ to numerically evaluate that desired flow variable $\dot{q}_d(t)$ is also reached. This characteristic is evaluated in the second term of Eq. (10).
3. *The flow variable of the SODS lies in the interval defined by $\pm\dot{q}_{max}$.* The bounding controller must swiftly take the flow variable to that interval and keep it there for all future instants of time. We have defined a parameter N_{oc} to heavily penalize the number of times where the boundary interval $\pm\dot{q}_{max}$ is exceeded by the controlled system. This penalization is denoted as the third term of Eq. (10) and computed according to Eqs. (11) and (12).

Finally, the fitness function is calculated, for each jth behavior modifier, as the average performance of the set of selected M initial conditions through the whole execution time of its corresponding simulation; that is,

$$fitness_j = \frac{1}{M}\sum_{i=1}^{M} performance_i. \tag{13}$$

Remark 3.1. The fitness value of each discovered possible solution is computed as an average of the addition of the three evaluated criteria for all the selected sceneries of the GP process. The fitness value of each solution can be characterized by the N_{OC} parameter given the structure of the evaluation for each case given by Eqs. (10) – (12); i.e, any proposed solution with fitness value equal or above 1 means that the flow variable of the SODS breach the bound interval defined by $\pm\dot{q}_{max}$ at some instant kT of the simulation. In consequence, a solution with a fitness value lower than the unit, implies that, in average, it is a suitable solution.

3.2. Genetic programming setup

The preliminary stage for the implementation of the GP procedure is the definition setup given by the *forced* behavior. Three settings are required to define the *forced* behavior generated by the CT-based tracking controller u_{CT}. Firstly, the desired reference $q_d(t)$, as well as its first and second time-derivatives, are considered as

$$q_d(t) = \cos\left(\frac{2\pi}{5}t\right), \tag{14}$$

$$\dot{q}_d(t) = -\frac{2\pi}{5}\sin\left(\frac{2\pi}{5}t\right), \tag{15}$$

$$\ddot{q}_d(t) = -\frac{4\pi^2}{25}\cos\left(\frac{2\pi}{5}t\right). \tag{16}$$

Performance testing is done by implementing a numerical simulation of the full closed-loop dynamics given by the solution of its ordinary differential equations (9). A 4th-order Runge–Kutta method with fixed-step size T is used. Thus, the second required parameter selection is set as $T = 1\times10^{-3}$ [s] with a total simulation time of $t_f = 10$ [s]. The third and last required setting for the *forced* behavior is the tuning step for the CT-based controller (i.e., the selection of the values for the constant gains), which were chosen as $k_P = 20.34$ and $k_D = 5.33$, to achieve convergence around the desired reference with a maximum overshoot of 10% (see e.g. Ogata, 2003 to know how to choose the gains with respect to the desired specifications of the system output response).

Table 3
Settings for the parameters used by the evolutionary process.

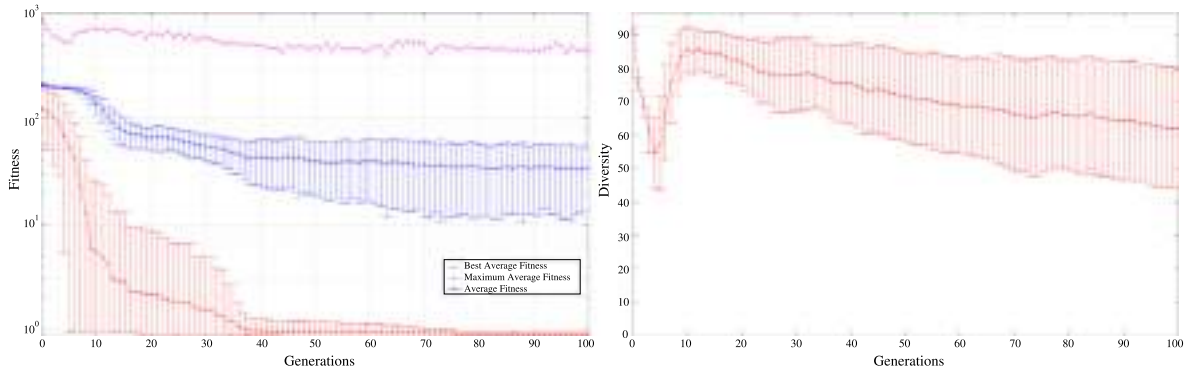
Parameter	Value
Number of generations	100
Population size	400
Crossover rate	80%
Mutation rate	20%
Maximum tree depth	11
Sampling	Lexicographic
Elitism	Keep best

The value of the bound $\dot{q}_{max}$ for the flow variable of the system is defined as ±2 [units]. In addition, a set of 8 pair of values given as $M = \{(0,0), (0,\pi/5), (\pi/2,0), (\pi/2,\pi/5), (\pi,0), (\pi,\pi/5), (3\pi/2,0), (3\pi/2,\pi/5)\}$ has been chosen as initial conditions for output and flow variables $(q(0), \dot{q}(0))$. The selection of this initial conditions depends on the values of $q_d(t)$, $\dot{q}_d(t)$, and the constant bound $\dot{q}_{max}$. In addition, the total number of defined sceneries must consider the impact in computation time for the GP, and also the cases where the initial conditions in the output variable, without the *learned* behavior induced by u_{GP}, lead the system to violate the sought restriction in flow variable. All proposed initial conditions in flow variable are inside the boundary limits established for $\pm\dot{q}_{max}$ assuming that this is the maximum reachable value for the system.

The aforementioned parameters describe the testing sceneries devoted to evaluate the *learned* behaviors. After a tuning step, the evolutionary process was executed for 100 generations with a population size of 400 individuals. The ramped half-and-half method is applied as initialization heuristic, as proposed by Koza et al. (2000). This approach builds half of the initial population with unbalanced syntactical trees allowing branches of different lengths, while the other half of the population is generated applying the full-method, making balanced syntactical trees. The syntactical tree depth has been user-defined to avoid uncontrolled growth of the trees in order to prevent bloat. After the initial population is created and evaluated with the fitness function, the next step is the selection. The probability of selection for each individual is proportional with the fitness value; in this case, the roulette wheel selection method was employed. Once the individuals are selected, a crossover and mutation probability is defined over each solution. Since the crossover operator performs a local search and the mutation operator avoid an early convergence to a local minimum, there is a compromise between both operators. In this work, the crossover operator is proposed with a higher probability than the mutation operator. In addition, lexicographic parsimony pressure was implemented to prefer smaller syntactical trees only when fitnesses values, between two or more individuals, are equal. Finally, with the aim to improve convergence, the elitism method was adopted to keep the best individual over each generation. These parameters are summarized in Table 3.

3.3. Evolution statistics

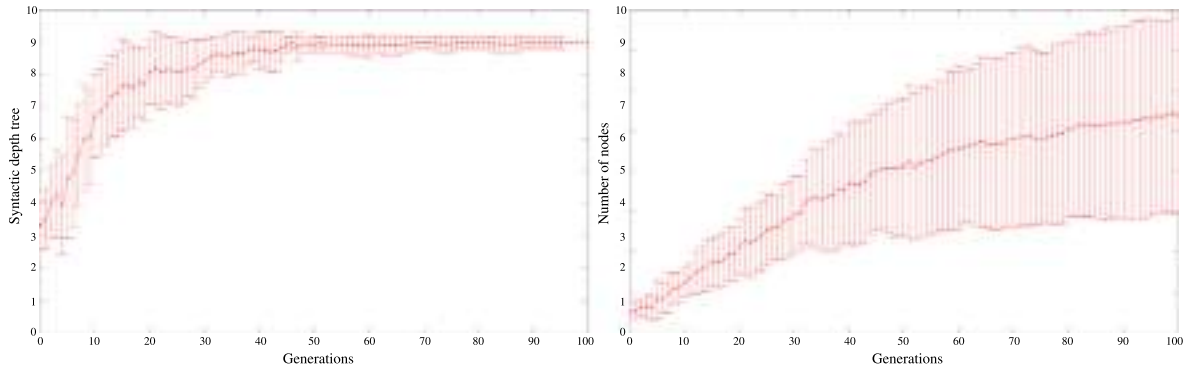
Typical statistics about the evolutionary process are provided, where the discovered solutions are given as nonlinear controllers in the form of Eq. (4). These solutions are applied in order to achieve a bounded flow variable within $\pm\dot{q}_{max}$, as well as convergence to the desired output variable $q_d(t)$. Fig. 3(a) shows the history of the average fitness, the average of best fitness, and average maximum fitness, of all the solutions along all runs. A semi-logarithmic scale is used for the fitness axis and out-layered values are discarded to highlight its evolution history. All graphs are plotted, with respect to the number of generations, as the



(a) Best, average and worst fitness

(b) Diversity average

Fig. 3. Statistics of the evolution performed by the GP process in the fitness and diversity of the *learned* behaviors, see Table 3.



(a) Average depth of best solutions

(b) Average nodes of best solutions

Fig. 4. Statistics of the evolution performed by the GP process in the average complexity of the *learned* behaviors, see Table 3.

averages over the total number of runs. Notice that there is a high performance after the 10th generation and the evolutionary process converges to a local optimum solution around the 40th generation. Furthermore, the diversity of the population is above the 50% up till the last generation, as shown in Fig. 3(b). Thus, a broad exploration of the search space, preventing from a prematurely convergence to a local optima, is concluded.

The average complexity of the fittest solutions, measured by the depth and number of nodes accordingly to its syntactical tree representation, is shown by Figs. 4(a) and 4(b), respectively. Notice that the improvement in performance is not significant in the latest generations of the evolutionary process whereas an increase in the structural complexity of the solutions is observed. This monotonic increase of complexity in the solutions is exhibited through the averages of the evolution while it reaches the maximum number of generations.

Summing up the results about the average on fitness and the evolution of the structural complexity of the solutions, shown in Figs. 3 and 4, the evolutionary process discovers solutions with a high performance and lower complexity in early generations. This feature is very important since the found solutions not only achieve the desired behavior; in addition, they can also be easily implemented in real-world systems due to their simple syntactical structure.

3.4. Discovered behaviors and numerical performance comparison

From a solution analysis standpoint, suited behaviors fulfilling all the established control objectives within a suitable fitted index (i.e., bounded flow variable and convergence to the desired output variable) are obtained when the fitness value of the solution is less than the unit. The evolutionary process found a set of 180993 nonlinear controllers u_{GP} with fitness value less than the unit at the end of the 30 runs. Five solutions with the highest performance as well as five solutions with lowest structural complexity and fitness value less than the unit, are selected and presented in Table 4. Notice that the top three solutions, u_{GP_1} to u_{GP_3}, and solution u_{GP_8} with lower structural complexity, are discontinuous functions since they include *max* and *min* functions. This property gives them the disadvantage of being complex to analyze stability applying CT approach; however, better performance is observed in comparison with other solutions. Solution u_{GP_4} is consistent with many stat-of-the-art proposals where a bounded function such as the hyperbolic tangential function (*tanh*) appears.

Finally, solutions u_{GP_7} and $u_{GP_{10}}$ have the lowest structural complexity among all the fittest solutions. In these, the hyperbolic sine function (*sinh*) is proposed by the GP process as a bounding flow variable function, instead of the frequently used hyperbolic tangential function (*tanh*).

A performance comparison of discovered nonlinear controllers given as (4) against to the state-of-the-art controller proposed in Peñaloza-Mejía et al. (2015), is presented. This controller is defined as u_{BV}, and its computed fitness value is shown in the last row of Table 4. It has been applied to solve the tracking problem in an omnidirectional mobile robot where desired bounds for the developed Cartesian velocities is enforced. The robot is modeled as a SODS where the flow variable corresponds to the velocity.

Behavior modifiers u_{GP_1} and u_{GP_7} have been selected for the performance comparison. Solution u_{GP_1} holds the highest fitness value and u_{GP_7} is selected due to its highest fitness value among the solutions with lowest structural complexity without exponentiation. Fig. 5 shows the behavior of SODS applying the nonlinear controllers of the form (4) with evolved behavior modifiers u_{GP_1} and u_{GP_7}. The selected initial

Table 4
The set of fittest *learned* behaviors u_{GP_j}, $j = 1, \ldots, 10$, discovered by the Genetic Programming process where bounded flow variable is accomplished. In addition, proposed controller by Peñaloza-Mejía et al. (2015) (denoted as u_{BV}) with its computed fitness value is provided for comparison purposes.

Name	Expression	Fitness
u_{GP_1}	$-13\hat{\tilde{q}} - 2[\min(\hat{\tilde{q}}(t) + \hat{\dot{q}}_d(t), 0)]^3 - \min(\hat{\tilde{q}}(t) + \hat{\dot{q}}_d(t), \hat{\tilde{q}}(t))$ $-2\min(\hat{\dot{q}}_d(t), \hat{\tilde{q}}(t)) + [\min(\hat{\tilde{q}}(t) + \hat{\dot{q}}_d(t), \hat{\tilde{q}}(t))]^6$ $+[\min(\hat{\tilde{q}}(t) + \hat{\dot{q}}_d(t), -\hat{\tilde{q}}(t))]^3 - \|[\min(\hat{\tilde{q}}(t) + \hat{\dot{q}}_d(t), \text{sech}(\hat{\tilde{q}}(t)))]^3\|$	0.8860
u_{GP_2}	$\text{Re}[\max(-\hat{\tilde{q}}(t)\epsilon^{\hat{\tilde{q}}(t)+\hat{\dot{q}}_d(t)}, 2\epsilon^{\epsilon}, \hat{\tilde{q}}(t)(\epsilon - 13)) - \hat{\tilde{q}}(t)]$ $-\text{asinh}(\max(-\hat{\tilde{q}}(t)\epsilon^{\hat{\tilde{q}}(t)+\hat{\dot{q}}_d(t)+1}, 2\epsilon)^{-\hat{\tilde{q}}(t)(\epsilon+6)})$	0.8871
u_{GP_3}	$\max\{\cosh(\max[-2\hat{\tilde{q}}\cosh(\cosh(\hat{\dot{q}}_d(t))), \text{acos}(\cosh(\text{acos}(\hat{\dot{q}}_d(t)))), -\hat{\tilde{q}}^2(t)]),$ $\hat{\tilde{q}}(t)[(\text{acos}(\cosh(\cot(\epsilon))) - 2\cot(\epsilon)) - \cosh(\hat{\tilde{q}})(-\hat{\tilde{q}} - \text{acos}(\cosh(\cot(\epsilon))))]\}$	0.8872
u_{GP_4}	$-6\hat{\tilde{q}}(t) + \epsilon + \tan(\tanh(-3\hat{\tilde{q}}(t))) + \tanh(-2\hat{\tilde{q}}(t)) + 3\tanh(\tan(\dot{q}_{\max}))$ $+\tanh(-5\hat{\dot{\tilde{q}}}(t)) + \cosh(\tan(\tanh(\tanh(-\hat{\dot{\tilde{q}}}(t)))))$ $-\cos(\hat{\tilde{q}}(t) + \hat{\dot{q}}_d(t))) + \tanh(\tan(\tanh(\tan(\cosh(\hat{\tilde{q}}(t) + \hat{\dot{q}}_d(t))))))$	0.8883
u_{GP_5}	$-\hat{\dot{\tilde{q}}}[\sinh(\dot{q}_{\max}) + \dot{q}_{\max}[\sinh(\hat{\dot{\tilde{q}}} + \hat{\dot{q}}_d) + \cosh(\dot{q}_{\max}(\hat{\dot{\tilde{q}}} + \hat{\dot{q}}_d)^2)]]$	0.8889
u_{GP_6}	$\left[2\hat{\tilde{q}}(t)\cosh^2(\hat{\dot{q}}_d(t))\right]^3$	0.9304
u_{GP_7}	$10\hat{\tilde{q}}(t) + \sinh(\sinh(3\hat{\tilde{q}}(t)))$	0.9478
u_{GP_8}	$\left[\min(\hat{\dot{q}}_d(t) - \hat{\tilde{q}}(t), 0.5)\right]^6 + \hat{\tilde{q}}(t)$	0.9552
u_{GP_9}	$\hat{\tilde{q}}(t) + \cosh(\hat{\dot{\tilde{q}}}(t) + \cosh(\hat{\dot{q}}_d(t) - \hat{\dot{\tilde{q}}}(t)))$	0.9604
$u_{GP_{10}}$	$\hat{\dot{q}}_d(t) - \hat{\tilde{q}}(t) + \sinh(\hat{\tilde{q}}(t))$	0.9748
u_{BV} (Peñaloza-Mejía et al., 2015)	$\frac{a}{d}(\lambda + \lvert z\rvert)f(\dot{q}, \dot{q}_{max})$, where $\lambda > 0$, z is given in (7), and $f(\dot{q}, \dot{q}_{max}) = \begin{cases} 1, & \dot{q}(t) < \dot{q}_{max} \\ \frac{1-\cos(\frac{\pi}{\Delta}(\dot{q}(t)-\dot{q}_{max}))}{2}, & -\dot{q}_{max} \le \dot{q}(t) < -\dot{q}_{max} + \Delta \\ 0, & -\dot{q}_{max} + \Delta \le \dot{q}(t) \le \dot{q}_{max} - \Delta \\ \frac{-1+\cos(\frac{\pi}{\Delta}(\dot{q}(t)+\dot{q}_{max}))}{2}, & \dot{q}_{max} - \Delta < \dot{q}(t) \le \dot{q}_{max} \\ -1, & \dot{q}(t) > \dot{q}_{max} \end{cases}$	0.9600

conditions were defined as $q(0) = 3\pi/2$ and $\dot{q}(0) = \pi/5$. In addition, the behavior obtained with the piecewise bounding controller u_{BV} proposed in Peñaloza-Mejía et al. (2015) is also presented. For illustration purposes, numerical results applying solely the inverse dynamics controller u_{CT} are also plotted in Fig. 5. The main advantage of the controller u_{CT} is given by its speed to attain the output variable of the SODS to the desired reference but reaching very high values (above the defined restriction given by $\pm\dot{q}_{max}$) in its flow variable.

As expected, all controllers lead the SODS to converge to the desired behaviors $q_d(t)$ and $\dot{q}_d(t)$, defined by Eqs. (14) and (15). Only evolved behavior modifiers u_{GP_1}, u_{GP_7}, and bounding controller u_{BV}, comply with the bounded flow variable policy, established as ± 2 units. Notice that the behavior of the system with evolved behavior modifiers u_{GP_1} and u_{GP_7} is a smoother motion towards the desired behavior $q_d(t)$. Nonlinear controller with u_{GP_1} has a similar behavior than u_{BV}, nevertheless it operates in saturated mode in a shorter time and their response is smother than u_{BV}, avoiding the overshoots.

In order to provide a straightforward performance comparison of the applied controllers for each control objective defined in (2) and (3), graphs of errors in output and flow variables ($\tilde{q}(t)$ and $\dot{\tilde{q}}(t)$) of the SODS are presented in Fig. 6.

The first condition, referring to control objective in (2), relates the performance of the controlled system with its effectiveness in converging to the desired trajectory regardless the presence of the bounding flow variable controllers. As shown by top in Fig. 6, all controllers fulfill this objective in view of the fact that the errors in the output variable, defined as $\tilde{q}(t)$, settle at zero. As stated in the problem description, control objective in (3) refers to the ability of the flow variable of the system to operate between the pre-specified boundary limits defined by $\dot{q}_{max}$. As shown by the middle row of Fig. 5, controllers with bounding function u_{BV} and evolved behavior modifiers u_{GP_1} and u_{GP_7}, comply with the bounded flow policy defined in (3) since they constrain its flow variable to perform inside the limits established by $\dot{q}_{max}$. Nevertheless, note that controller with u_{BV} attach the flow variable of the system to the bounding limits of the interval defined by $\pm\dot{q}_{max}$ (i.e., it performs in saturation mode). Saturation is an undesirable phenomena since it could lead to instability of the controlled system or even degrade its performance in real world implementations. Observe that *learned* behaviors induced with u_{GP_1} and u_{GP_7} avoid the undesirable saturation phenomena keeping the flow variable smoothly operating inside the bounding interval. As expected, the exerted effort variable upon the SODS for the nonlinear controllers with u_{BV}, u_{GP_1}, and u_{GP_7} is also lower than solely applying the inverse dynamics controller u_{CT}. Obtained results let us conclude that the evolutionary process, performed by the GP, has discovered suited behavior modifiers that fits the trade-off between structural complexity and good performance.

From the analysis of the elements used by the solution set, incidence ratios of the proposed terminals and functions, emerging in the discovered behaviors of the evolutionary process, are shown in Fig. 7 where the number of function and terminal corresponds to those assigned in Tables 1 and 2, respectively. The most used functions are the arithmetic functions, exponentiation, maximum, minimum, square function, hyperbolic cosine and hyperbolic tangent. As for the terminals, the negative flow variable error $-\hat{\tilde{q}}(t)$ and the flow variable of the SODS $\dot{q}(t)$, are the most used within the discovered solutions.

One meaningful feature of the discovered behaviors is that most used terminals are the negative flow variable error $-\hat{\dot{\tilde{q}}}(t)$ and the flow variable $\dot{q}(t)$. Instead of being attached to the specific values of the selected sceneries, the nonlinear controllers take into account the error dynamics of the SODS against the desired behavior. This means that its performance is not affected by the initial conditions of the sceneries, given by the *unforced* behavior of the SODS, while applying the discovered nonlinear controllers, suggesting a possible generalization of these solutions.

3.5. Discussion

Among the solutions shown in Table 4, the u_{GP7} has the simplest structure. Remember that it has been obtained by evolving the closed-loop system for the trajectory tracking task, and at this point, one could think that it is only valid for the particular conditions given in simulations, but it is not the case. To illustrate this point, note that $\hat{\dot{\tilde{q}}}\, u_{GP_7} = \hat{\dot{\tilde{q}}}\left(10\hat{\tilde{q}} + \sinh\left(\sinh(3\hat{\tilde{q}})\right)\right) \ge 0$ for all t. This means that u_{GP_7}, similar to u_{BV} in Peñaloza-Mejía et al. (2015), is passive (Khalil, 2002) and dissipates the excess of energy in the system to keep the velocities withing the desired limits. The coefficients determine the rate of dissipation which modifies in turn the system behavior. So, replace the coefficients by positive gains k_G and k_S to obtain $u_{GP_7} = k_G\hat{\tilde{q}}(t) + \sinh(\sinh(k_S\hat{\dot{\tilde{q}}}(t)))$. Now consider a set-point regulation task (it is a particular case of the tracking task) for system (1). Note that there is no need to evolve the system to find a new solution for this case: the u_{GP_7} is still valid and only the gains need to be adjusted in accordance to the desired behavior. This shows the flexibility of the solution found by the GP.

Consider the system (1) with unitary coefficients and suppose that the output is required to be regulated at the constant value of one unit in no longer than two seconds with a maximal overshoot of 10%. Also, consider that the maximal value to be developed by the flow variable is one unit. For these specifications, the gains can be chosen as $k_P = 20.34$, $k_D = 5.33$, $k_G = 2$, and $k_S = 2$. A comparison of the system performance under the action of the computed-torque controller (6)–(7), u_{CT}, the controller given in Peñaloza-Mejía et al. (2015), u_{CT+BV}, the evolved controller u_{CT+GP_7} and the nonlinear controller given in Ngo and Mahony (2006), u_{Ngo}, is shown in Figs. 8 and 9. In the graphics, it can be seen that the output is regulated at the desired value in the specified settling time in almost all controllers, the slowest response is obtained with the controller u_{Ngo} while the fastest response is obtained with the u_{CT}. The flow variable is kept within the desired limits with the controllers u_{CT+BV} (Peñaloza-Mejía et al., 2015), u_{CT+GP_7}, and u_{Ngo} (Ngo and Mahony, 2006).

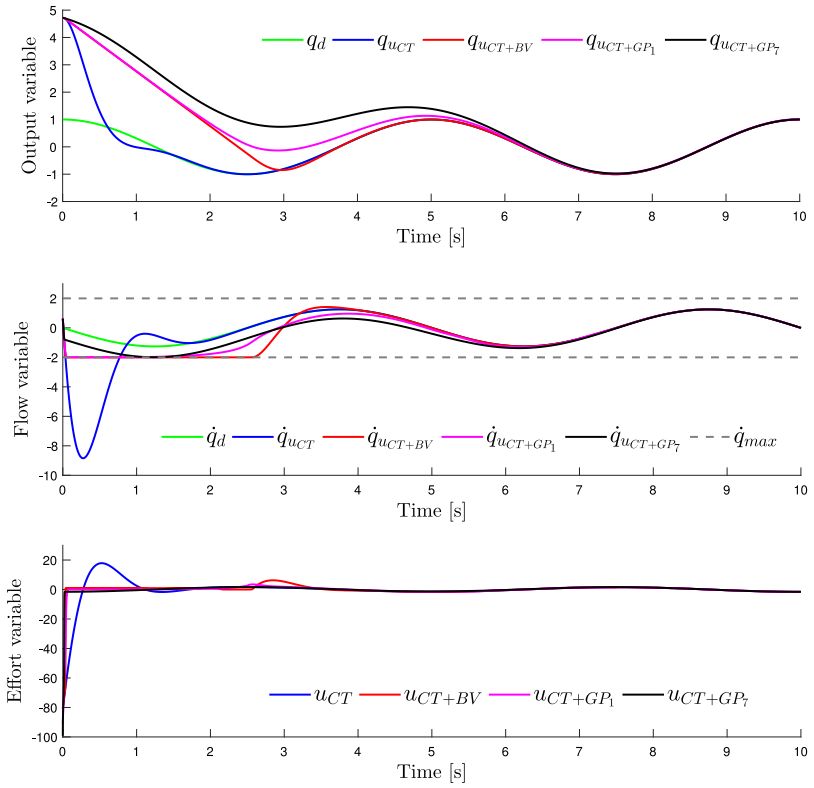


Fig. 5. Simulation results applying evolved behavior modifiers u_{GP_1} and u_{GP_7} against the bounding piecewise function u_{BV} proposed in Peñaloza-Mejía et al. (2015), and the inverse dynamics controller u_{CT}. Output and flow variables exhibited by the SODS are depicted in top and middle rows, respectively, while applied effort variable is presented in bottom row. Note that the u_{GP_1} has a similar behavior than u_{BV}, but its response is smother avoiding the overshoots. On the other hand, the saturation mode response is not present in the u_{GP_7} behavior, in consequence there is a slower convergence and lower effort to the system.

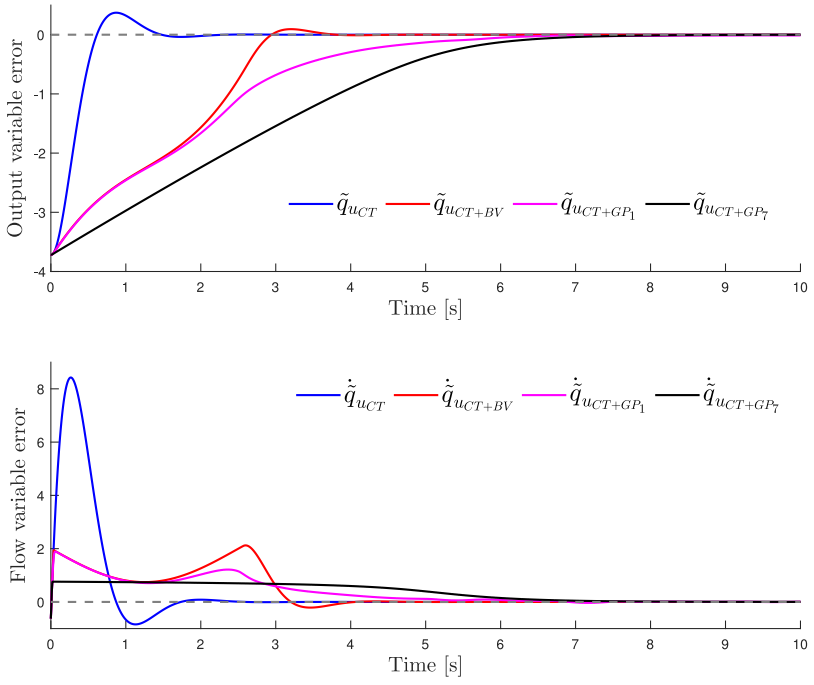


Fig. 6. Exhibited errors in output and flow variables obtained from simulation results applying evolved behavior modifier u_{GP_1} against the bounding piecewise function u_{BV} proposed in Peñaloza-Mejía et al. (2015), as well as the inverse dynamics controller u_{CT}. Note that all controllers converge to zero, nevertheless the transient state for u_{GP_1} and u_{GP_7} is longer due to their smother response. In particular, the error for u_{GP_7} is almost constant in the flow variable, and a consequence of this behavior is a lower effort for the system.

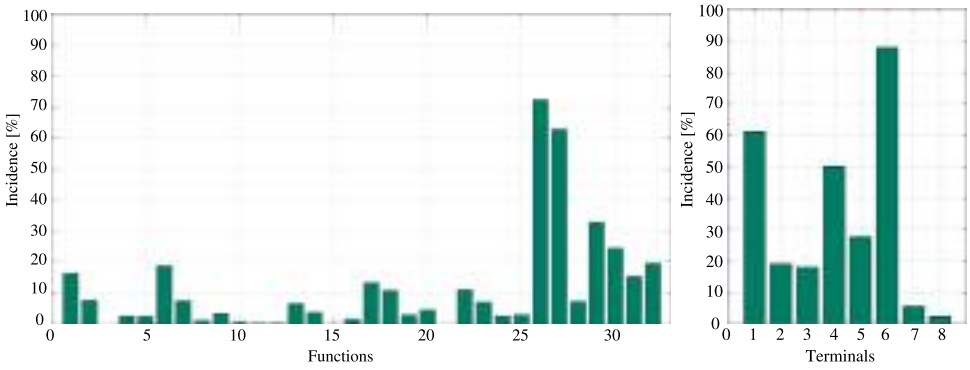


Fig. 7. Incidence ratio of the appearance of functions and terminals, within the discovered *learned* behaviors, with good performance and bounded flow variable of the SODS. Index values in x-axes are defined as shown in Tables 1 and 2, respectively.

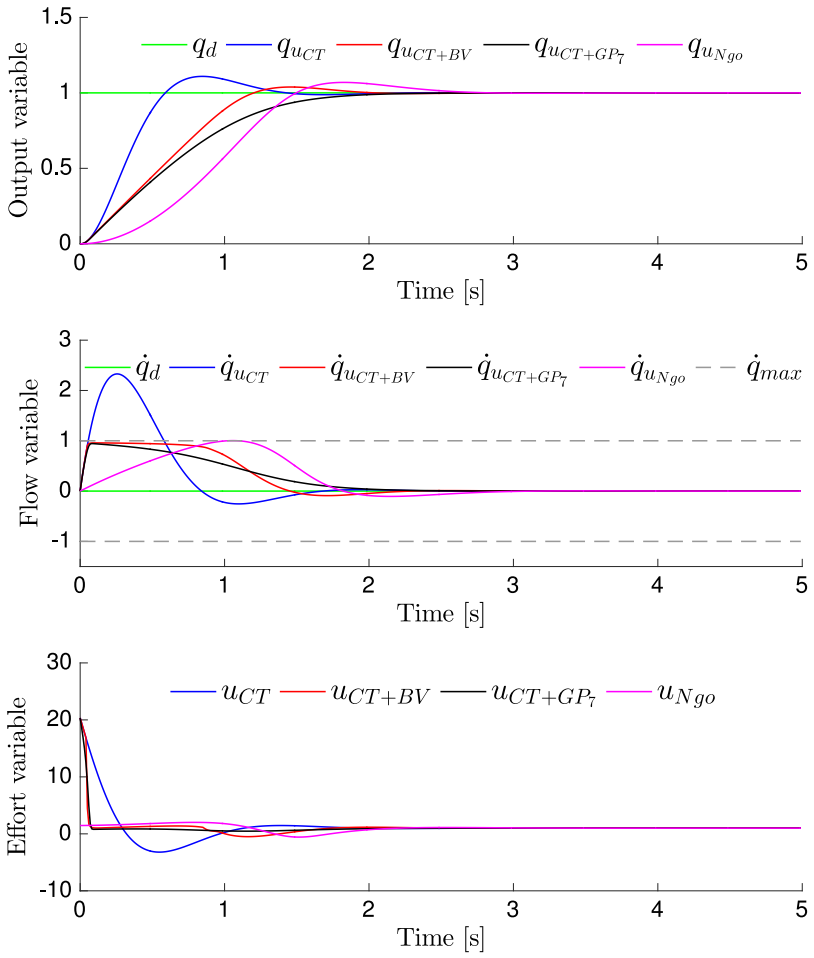


Fig. 8. Comparison of output, flow, and effort variables in a set-point regulation task for the SODS under the action of different controllers: u_{CT} is the computed-torque controller given in (6) and (7), u_{CT+BV} is the controller given in Peñaloza-Mejía et al. (2015), u_{CT+GP_7} is the evolved controller, and u_{Ngo} is the controller given in Ngo and Mahony (2006).

A quantitative evaluation of the performance of the controllers has been made through the index given by the norm $\mathcal{L}_2$, which measures in a time trip T the average of the root mean square of a signal like $\mathcal{L}_2(f(t)) = \sqrt{\frac{1}{T}\int_0^T \|f(t)\|^2 dt}$. A discrete implementation of the criterion $\mathcal{L}_2$ leads to $\mathcal{L}_2(f(kh)) = \sqrt{\frac{h}{T}\sum_{k=0}^{N}\|f(kh)\|^2}$, where h is the sampling period. The Table 5 shows the indexes $\mathcal{L}_2$-norm for adjustment of the set point. There, you can see that the lowest value for the output error is obtained under the action of the u_{CT} controller, but note that the flow variable is not constrained. When taking into account the limits of the flow variable, the controller u_{CT+BV} and u_{Ngo} (Ngo and Mahony, 2006) have the lowest and largest values, respectively, for the output error and the effort. In the middle, the proposed controller u_{CT+GP_7} has a good performance: it exhibits the smallest index of the flow variable and with less input effort than the controllers u_{CT} and u_{CT+BV} (Peñaloza-Mejía et al., 2015). Note that there is a trade-off between the response time of the system, the effort required and the flow developed. The faster the response, the greater the required effort and the greater the developed flow. The less the developed flow, the less the required effort, but the greater response time.

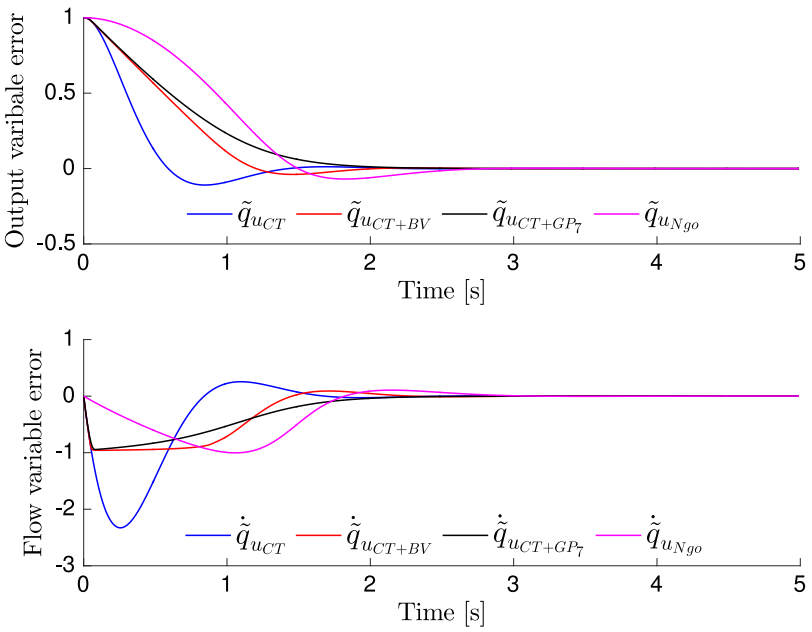


Fig. 9. Comparison of output and flow variable errors in a set-point regulation task for the SODS under the action of different controllers: u_{CT} is the computed-torque controller given in (6) and (7), u_{CT+BV} is the controller given in Peñaloza-Mejía et al. (2015), u_{CT+GP_7} is the evolved controller, and u_{Ngo} is the controller given in Ngo and Mahony (2006).

Table 5
$\mathcal{L}_2$-norm indexes for set-point regulation.

Index	CT	$CT+BV$ (Peñaloza-Mejía et al., 2015)	$CT+GP_7$	Ngo (Ngo and Mahony, 2006)
$\mathcal{L}_2(\tilde{q})$	0.2152	0.2787	0.2918	0.3744
$\mathcal{L}_2(\dot{\tilde{q}})$	0.6306	0.4214	0.3707	0.4058
$\mathcal{L}_2(u)$	2.9941	2.1221	1.9660	1.1736

In the next section is performed an evaluation in a real mechanical system, in this context, due to the characteristics of the evolved controller u_{CT+GP7}, makes it ideal to the implementation. Nevertheless, this analysis could be done for any other of the evolved controllers.

4. Application to a mechatronic plant

The aim of this section is to illustrate the effectiveness of applying the *learned* behavior in a physical system: the Quanser IP02 linear motion plant (Manual, 2012). To this end, numerical simulations and real-time experiments were carried out in this mechatronic plant, considering the trajectory tracking problem with desired bounded velocity, and under the action of the evolved controller. Fig. 10 shows the mechatronic plant, which consists of an aluminum cart sliding along a stainless steel shaft (using linear bearings) and driven by a DC motor equipped with a planetary gearbox and a rack and pinion mechanism. The plant operation involves real-time rapid control prototyping software for Matlab/Simulink, where the controller is programmed and then uploaded in a DSP board where it runs in hard real-time with a sampling frequency of 1 kHz. The input/output data acquisition device (DAQ) is also used to read the cart linear displacement (via an optical encoder) and to send the computed control voltage to a power amplifier. A connection diagram is shown in Fig. 11. See Manual (2012) for further details on the experimental set-up description.

4.1. Dynamic model

Applying Newton's second law, a relationship between the force applied to the cart by the DC motor and the resultant linear motion is derived. Then the system dynamics is described by the second-order differential equation

$$\tau\ddot{q}(t) + \dot{q}(t) = ku(t), \tag{17}$$

where $q(t)$ is the linear displacement (the output variable), $\dot{q}(t)$ is the linear velocity (the flow variable), $\ddot{q}(t)$ is the acceleration (the second time-derivative of the output variable), and $u(t)$ is the applied voltage (the effort variable). The system parameters are lumped in the coefficients τ and k, which are defined as $\tau = \frac{M}{B_{\text{eq}}}$ [s] and $k = \frac{A_{\text{m}}}{B_{\text{eq}}}\left[\frac{\text{m}}{\text{V s}}\right]$, where $B_{\text{eq}} = \frac{\eta_g\eta_m K_g^2 K_m K_t + B R_m r_p^2}{R_m r_p^2}\left[\frac{\text{N s}}{\text{m}}\right]$ and $A_{\text{m}} = \frac{\eta_g\eta_m K_g K_t}{R_m r_p}\left[\frac{\text{N}}{\text{V}}\right]$. Using Table 6, their values are computed as $\tau = 0.0584$ [s] and $k = 0.1433$ [m/V s]. Note that the dynamics (17) is in the form of the SODS (1) by taking $a = \tau$, $b = 1$, $c = 0$, and $d = k$. Hereinafter, we will omit the time variable t from notation for purposes of clarity and ease.

Table 6
Parameters of the IP02 linear motion plant (Manual, 2012).

Parameter	Description	Value	Units
M	Mass of cart	0.38	kg
B	Viscous damping coefficient	4.3	N ms/rad
η_g	Planetary gearbox efficiency	0.9 ± 10%	
η_m	Motor efficiency	0.69 ± 5%	
K_g	Planetary gearbox gear ratio	3.71	
K_t	Motor current-torque constant	0.00768	N m/A
K_m	Motor back-emf constant	0.00768	V s/rad
R_m	Motor armature resistance	2.6	Ω
r_p	Motor pinion radius	6.35×10^{-3}	m

4.2. Control implementation

Three different controllers have been considered for carrying out numerical simulations and real-time experiments: the inverse dynamics controller u_{CT} (Spong et al., 2006), given in (6) and (7), the inverse dynamics controller plus a bounding-velocity term u_{CT+BV} (Peñaloza-Mejía et al., 2015), and the evolved nonlinear controller u_{CT+GP_7}. The idea to include the controllers u_{CT} and u_{CT+BV} is to give a reference to better illustrate the performance of the proposed evolved controller u_{CT+GP_7}.

Fig. 10. The IP02 linear motion plant (Manual, 2012).

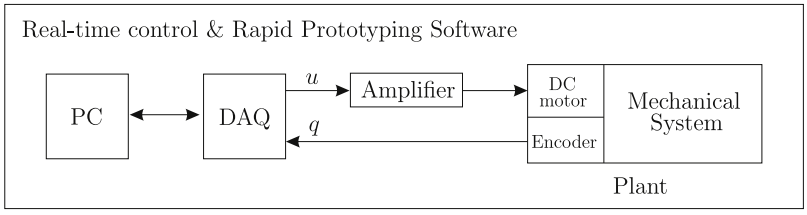


Fig. 11. Diagram of the real-time setup.

The first controller, u_{CT}, is given by (6) and (7), and for the system (17) has the form

$$u_{CT} = \frac{\tau}{k} z + \frac{1}{k}\dot{q}, \tag{18}$$

where z is given in (7). This controller ensures asymptotic tracking of the reference whenever the gains k_P and k_D be positive (these are chosen in accordance with the desired tracking performance); however, the velocity can reach any value.

The second controller, u_{CT+BV}, has been proposed in Peñaloza-Mejía et al. (2015). It is defined for this system by the same inverse-dynamics term (18) plus the bounding-velocity term u_{BV} given in Table 4. So,

$$u_{CT+BV} = \underbrace{\frac{\tau}{k} z + \frac{1}{k}\dot{q}(t)}_{u_{CT}} + \underbrace{\frac{\tau}{k}(\lambda + |z|) f(\dot{q}, \dot{q}_{\max})}_{u_{BV}}. \tag{19}$$

This controller achieves asymptotic tracking of the reference with desired bounded velocity $\dot{q}_{\max}$.

The third controller, u_{CT+GP_7}, has been found by the evolutionary process and is described by

$$u_{CT+GP_7} = \underbrace{\frac{\tau}{k} z + \frac{1}{k}\dot{q}}_{u_{CT}} + \underbrace{\frac{\tau}{k}\left(k_G \ddot{\tilde{q}} + \sinh\left(\sinh(k_S \dot{\tilde{q}})\right)\right)}_{u_{GP_7}}, \tag{20}$$

where k_G and k_S are positive constants to be chosen to meet the desired bound $\dot{q}_{\max}$ of the Quanser IP02 linear motion plant (17).

4.3. Numerical simulations

Considering the above controllers (18)–(20) for the dynamics (17), numerical simulations were carried out in Matlab/Simulink using a fixed-step Euler integration method at 1×10^{-3} [s]. The desired reference to be tracked was $q_d = A\cos(\omega t)$, with $A = 0.05$ [m] and $\omega = 4/5\pi$; the control gains k_P and k_D were chosen to have the system response to converge around the reference in about 0.5 [s] with a maximum overshoot of 10% (i.e. $k_P = 20$ and $k_D = 8$). The velocity bound $\dot{q}_{\max}$ was set to 0.18 [m/s], and the initial conditions were $q(0) = 0$ [m] and $\dot{q} = 0$ [m/s]. The values of the other gains were set as $\lambda = 0.35$, $\delta = 0.005$, $k_G = 10$, and $k_S = 3$.

Table 7
$\mathcal{L}_2$-norm indexes for the IP02 simulation results.

Index	CT	$CT + BV$ (Peñaloza-Mejía et al., 2015)	$CT + GP_7$
$\mathcal{L}_2(\tilde{q})$	0.4716	0.5366	0.6327
$\mathcal{L}_2(\dot{\tilde{q}})$	4.1472	3.3781	2.5414
$\mathcal{L}_2(u)$	0.7214	0.6848	0.6374

Figs. 12 and 13 show the simulation results. As described, the subscripts u_{CT}, u_{CT+BV}, and u_{CT+GP_7} were used in the signals to distinguish the system performance under the action of the controllers (18)–(20). In the graphics, it can be shown that the system output asymptotically tracks the reference q_d with all controllers. However, only the controllers u_{CT+BV} and u_{CT+GP_7} allow the system to keep the velocity within the desired limits. Furthermore, for the evolved controller u_{CT+GP_7}, the velocity is not saturated and it has a smooth time evolution; also, the required voltage is smooth and exhibits the least effort.

According to Fig. 13, the position and velocity errors converge to zero. As expected, the u_{CT} controller allows the system to exhibit the fastest converge to the reference since the velocity is not constrained. When the velocity is bounded, the controllers u_{CT+BV} and u_{CT+GP_7} produce a slightly slower convergence, but the velocity errors, as well as the required efforts to be applied (voltages), are lower. In particular, the u_{CT+GP_7} controller produces the lowest values, as shown in the $\mathcal{L}_2$-norm indexes shown in Table 7.

4.4. Real-time experiments

Real-time experiments were carried out in the IP02 linear motion plant considering the controllers (18)–(20). For the developed experiments, the desired reference to be tracked, the selected control parameters, and the initial conditions chosen were all the same as those described in simulations.

The real-time results of the positions, velocities, and applied voltages are shown in Fig. 14, while the tracking errors are shown in Fig. 15.

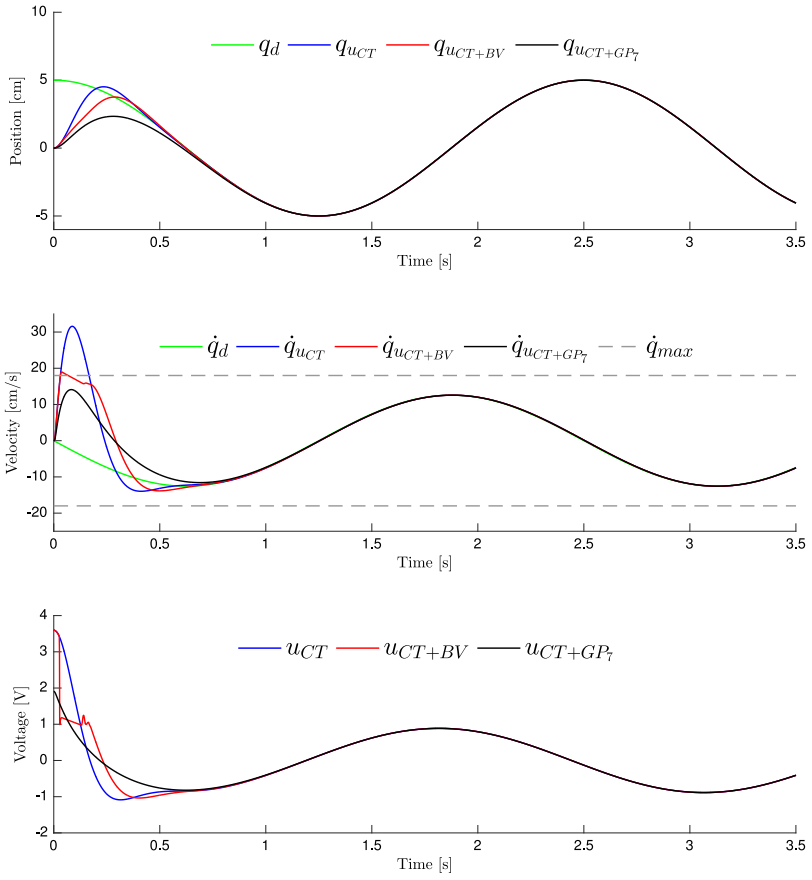


Fig. 12. Simulation results of the IP02 plant under the action of u_{CT}, u_{CT+BV}, and u_{CT+GP_7}: positions, velocity, and applied voltages.

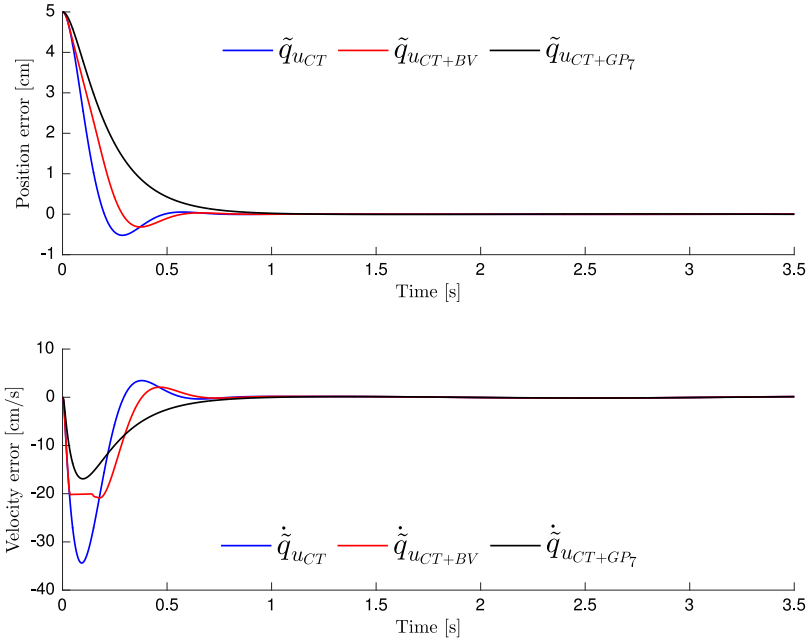


Fig. 13. Simulation results of the IP02 plant under the action of u_{CT}, u_{CT+BV}, and u_{CT+GP_7}: position and velocity errors.

In the figures, it is shown that the three compared controllers achieve tracking of the desired trajectory, but only the u_{CT+GP_7} allows the system to perform with a smooth velocity behavior away from saturation. As shown in the $\mathcal{L}_2$-norm indexes in Table 8, the u_{CT+GP_7} controller produces the lowest values for the velocity error and the applied voltage.

4.5. Discussion

The real-time results are similar to the ones obtained in simulations. The slight discrepancies between them are due to unmodeled dynamics, parameter uncertainties, and undesirable effects such as backlash and

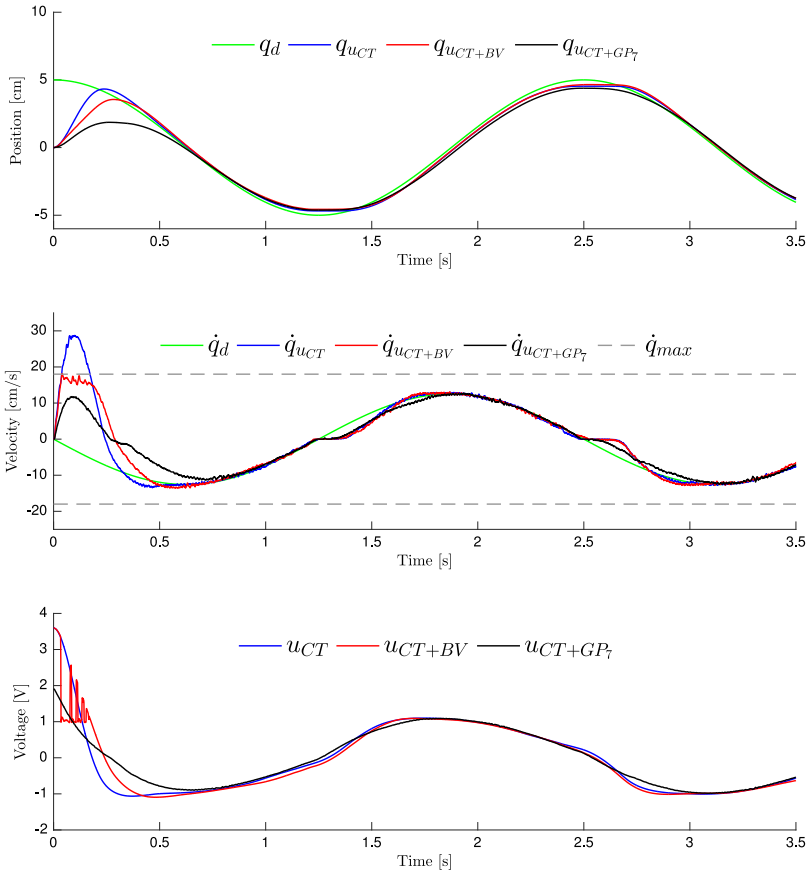


Fig. 14. Real-time results of the IP02 plant under the action of u_{CT}, u_{CT+BV}, and u_{CT+GP_7}: positions, velocities, and applied voltages.

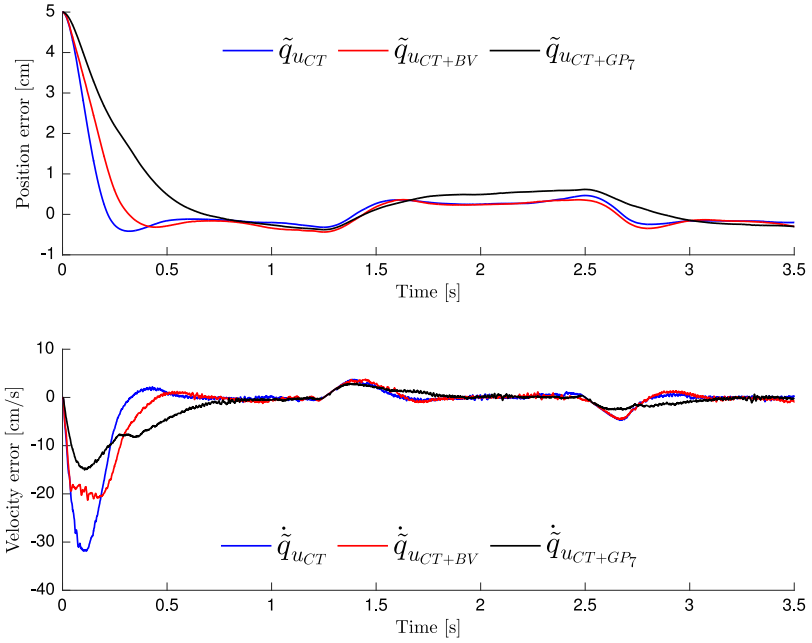


Fig. 15. Real-time results of the IP02 plant under the action of u_{CT}, u_{CT+BV}, and u_{CT+GP_7}: position and velocity errors.

friction; these nonlinear phenomena are present in practical implementations. Despite this, all the controllers exhibits some robustness characteristics to these issues. Also, the controllers allow, both in simulations as in experiments, that the system output tracks the given reference; but only the u_{CT+BV} and the evolved controller u_{CT+GP_7} bound the developed velocity. In this case, as shown, the controller u_{CT+GP_7} exhibits the better performance, which can be modified accordingly to the desired output convergence rate, and with the desired velocity

Table 8
$\mathcal{L}_2$-norm indexes for the IP02 real-time results.

Index	CT	$CT + BV$ (Peñaloza-Mejía et al., 2015)	$CT + GP_7$
$\mathcal{L}_2(\tilde{q})$	0.5487	0.6133	0.7672
$\mathcal{L}_2(\dot{\tilde{q}})$	4.1291	3.5348	2.6223
$\mathcal{L}_2(u)$	0.8476	0.8271	0.7380

bound set by the user. As described in Section 3.5, this corresponds to the flexibility of the evolved controller to be used in the control of SODS subject to velocity constraints.

5. Conclusions

A new methodology devoted to the design of nonlinear analytic controllers, for tracking control in a SODS subject to flow-variable constraints, has been presented. A conceptual model to extend the Behavior-based Control approach through a framework merging Control Theory with Genetic Programming paradigm has been proposed. The conceptual model let us define the *natural* behavior of the system as the summation of its *basis* behaviors given by analytic functions representing its properties, actions and restrictions. These are characterized as the uncontrolled dynamics (the *unforced* behavior), the response imposed by means of controllers (the *forced* and *learned* behaviors), and the unmodeled dynamics. The proposed methodology extends the concept of *basis* behavior as analytic functions, in contrast to the traditional Behavior-based control approach which refers to a minimal block of instructions.

The proposed framework was applied to solve the tracking problem in SODS where its flow variable had to be constrained. The effort variable (represented as the controller for this class of systems) was given by the sum of a CT-based controller, used to solve the tracking problem, and a GP-based controller, dedicated to bound the flow variable response. The CT-based controller was described as a traditional inverse dynamics controller which generates the *forced* behavior of the system. Then, an evolutionary process allowed to build a set of *learned* behaviors. Thus, the *natural* behavior of the system was given by the sum of these two behaviors and its *unforced* behavior. The analysis of the *learned* behaviors let us select the best solutions given its fitness value and its syntactical structure complexity.

In addition, a selected controller from the discovered solutions was applied to a mechatronic prototype modeled as a Second-Order Dynamical System. Numerical simulations and real-time experiments on this mechatronic prototype illustrated the effectiveness and feasibility of implementation of the selected solution. The performance of the mechatronic system applying our proposed controller was better compared to two state-of-the-art controllers. The controller found by our method allowed the system to exhibit a smooth convergence to the desired trajectory while keeping the flow variable bounded without saturation, different from other solutions reported in the literature.

A Multi-Objective approach is proposed as a future work to broaden our methodology, in order to consider multiple constraints, as well as to build robust controllers to deal with uncertainty, unmodeled dynamics, and undesirable phenomena. Thus, a better representation of the *natural* behavior of a system could be reached.

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Estudio Cualitativo sobre el Comportamiento del Consumidor en las Compras en Línea

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Resumen

Se estudia las características principales del comportamiento del consumidor en plataformas de compra en línea en el estado sur de Sonora. Esto se hace mediante un estudio cualitativo basado en la metodología de la Teoría Fundamentada. La idea principal es identificar y categorizar variables sobre la compra en línea basándose en factores relevantes como la motivación de compra, preferencias, hábitos de consumo y patrones de compra. Para llevar a cabo el estudio, se realizaron entrevistas semi-estructuradas a consumidores del estado sur de Sonora, México, con experiencia en compras en línea. De esta manera, al concluir el análisis, se obtuvieron tres categorías principales: motivación de compra, experiencias del consumidor y comportamiento. También se identificaron una serie de variables que tienen mayor influencia en las preferencias, decisión de compra y el patrón de compra en los consumidores. Los resultados obtenidos proporcionan información de utilidad para la creación de estrategias que permitan tomar decisiones efectivas mediante su aplicación en el diseño de plataformas en línea ofreciendo un servicio personalizado a los consumidores.

Palabras clave: análisis cualitativo; teoría fundamentada; compras en línea; comportamiento del consumidor; entrevista semi-estructurada

Qualitative Study of Consumer Behavior in Online Shopping

Abstract

The main characteristics of consumer behavior in online shopping platforms at Sonora, Mexico have been studied. A qualitative study based on the methodology of Fundamental Theory is used to identify and categorize variables about online purchases based on relevant factors such as purchase motivation, preferences, consumption habits and purchasing patterns. Semi-structured interviews to consumers with experience in online purchases were conducted. In this way, three main categories were obtained: purchase motivation, consumer experiences and behavior. Also, some variables with a greater influence on preferences, purchase decision and consumer purchase pattern were identified. The obtained results provide useful information for strategies planning that allow making effective decisions using them in the design of online platforms with a personalized service to consumers.

Keywords: qualitative analysis; grounded theory; online purchases; consumer behavior; semi-structured interview

INTRODUCCIÓN

El imparable desarrollo y expansión de las nuevas tecnologías de la información, en especial en el comercio electrónico ha causado el creciente interés en el comportamiento del consumidor en compras en línea (Zhou et al., 2007). Asimismo, la sociedad actual demanda más comodidad y menos tiempo en la compra de productos o servicios por Internet, por lo cual, están conscientes que es el medio más rápido para la búsqueda de información y muestra la importancia de que las empresas tengan cada vez más capacitación para mantener un efectiva presencia en Internet (Gallaugher, 1997; Grandon y Pearson, 2004; Barrera, 2017). El comercio electrónico consiste en la compra-venta de productos o servicios, en donde los consumidores obtienen información y adquieren productos a través de medios electrónicos (Olson y Olson, 2000). Por esta razón, Zarco y Ruiz (2006), plantean que la estructura comercial, el sistema de distribución y los canales de distribución han tenido considerables transformaciones en los últimos años, de modo que han sido ampliamente promocionados los beneficios potenciales del uso del comercio electrónico (Gefen y Straub, 2000). Sin embargo, para que se obtengan estos beneficios se necesita examinar la interacción del consumidor en el proceso de compra en una plataforma de compra en línea (Pavlou y Fygenson, 2006).

Hoy en día, el estudio del comportamiento del consumidor ha sido ampliamente estudiado desde diferentes perspectivas y áreas (Solomon et al., 2014). La mayoría de los estudios se han centrado principalmente en la acción de compra de productos o servicios y medir la satisfacción del consumidor, enfocándose en las experiencias posteriores a la compra de los consumidores con el fin de encontrar una relación con variables que enriquezcan más el conocimiento acerca del consumidor (Westbrook et al., 1991; Homburg y Annette, 2001). Por otra parte, existen varios estudios, que se centran en el análisis de datos tanto cuantitativos como cualitativos, para demostrar la relación entre la motivación de los consumidores y su comportamiento de compra (Joines et al., 2003; Goldsmith y Horowitz, 2006). Por ejemplo, Hausman (2000), probó que la decisión de compra de los consumidores es una consecuencia de los impulsos generados por la motivación a las recompensas que se obtendrán por realizar una compra. Asimismo, Karbasivar (2011), demuestra que existe una relación fundamental entre la publicidad de productos, las actividades promocionales (descuentos, productos o servicios gratuitos) y el comportamiento de compra del consumidor. Por lo cual, se afirma que el comportamiento del consumidor no es monolítico, puesto que, antes de realizar una compra los consumidores primero participan en la obtención de información de un producto o servicio y en otros factores que proporciona el sitio web. De modo que se plantean retos de investigación relacionados con el análisis y modelización del comportamiento del consumidor en las compras en línea, por ejemplo, 1) ¿Cuáles son os factores más relevantes para la comprensión del comportamiento del consumidor? Y 2) ¿Cómo se relacionan entres si los factores encontrados?, usando los resultados como la base principal sobre la que se formulan estrategias organizacionales.

En este artículo, se presenta un estudio cualitativo bajo el enfoque de la Teoría Fundamentada para estudiar el comportamiento, actitudes y percepciones de los consumidores que compran productos y servicios en línea. Para esto, el objetivo del estudio es identificar las variables del comportamiento del consumidor de mayor relevancia en el proceso de decisión de compra en línea por medio del análisis de entrevistas de consumidores que realizan compras de productos y servicios en línea. Dentro de esas variables consideramos la interpretación y medición de la relación de los diferentes factores relevantes para las compras en línea, tales como la percepción de los productos, motivación de compra, preferencias, hábitos de consumo, influencias y comportamientos de compra. Asimismo, con la finalidad de identificar si el proceso de decisión de compras se ha visto alterado y cuáles han sido las variables del comportamiento del consumidor que han sido influenciadas. Los resultados obtenidos de esta investigación demuestran la importancia de 3 categorías para definir el comportamiento del consumidor en las compras en línea las cuales son: 1) la motivación de compra, 2) las experiencias, y 3) el comportamiento del consumidor. Además, se presenta cómo la motivación y la experiencia influyen en el comportamiento del consumidor.

METODOLOGIA

La Teoría Fundamenta nos permite construir teorías, hipótesis y conceptos acerca de un fenómeno en particular, partiendo directamente de los datos mediante la utilización de un método comparativo constante (Glaser y Strauss, 1967). En este trabajo se realizó un estudio cualitativo para analizar e identificar las variables del comportamiento del consumidor de mayor relevancia en el proceso de decisión de compra.

Preguntas de investigación

Este proyecto de investigación se basó en tres preguntas enfocadas a consumidores de productos y servicios en línea: P1. ¿Cuáles son las prácticas de compras por Internet que ejercen los consumidores?; P2. ¿Cuáles son los motivos por lo que los consumidores compran a través de Internet?; y P3. ¿Qué caracteriza la experiencia y el comportamiento de consumidores en sus compras por Internet?

Informantes

El estudio se llevó a cabo en el sur del estado de Sonora, en México, donde participaron personas adultas con experiencia en compras en línea. Para el proceso de selección, los participantes debían cumplir los siguientes criterios de elegibilidad: residir en el sur del estado de Sonora, tener entre 18 y 45 años de edad, contar con experiencia en compras en línea, tener suficiente capacidad de destreza cognitiva, visual y manual para el uso de la computadora o dispositivo móvil, tener acceso diario a una computadora personal con conexión a Internet y contar con cualquier nivel ingreso, educación y ocupación. Para el proceso de selección de participantes, se realizó una breve entrevista telefónica a catorce personas para determinar la elegibilidad de los participantes. Al finalizar las entrevistas telefónicas, se seleccionaron once personas que cumplieron con los criterios de elegibilidad quienes se comprometieron a participar en el estudio, ver Tabla 1. En esta tabla se presentan los participantes seleccionados y sus características en cuanto a la edad, ocupación y sexo donde se seleccionaron 4 de las entrevistas realizadas, dos de estudiantes (P5 y P10) y dos profesionistas (P2 y P3).

Tabla 1: Descripción de participantes.

No. Participante	*Ocupación*	*Edad*	*Sexo*
P1	Estudiante de Posgrado	24	F
P2	Técnico en Electrónica	35	M
P3	Ejecutivo de Ventas	42	F
P4	Técnico de Sistemas	25	M
P5	Estudiante de Posgrado	23	F
P6	Estudiante de Posgrado	36	M
P7	Estudiante de Carrera	20	F
P8	Desarrollador Web	24	M
P9	Profesor de Español	33	M
P10	Estudiante de posgrado	27	M
P11	Contador Público	32	M

Con el objetivo de determinar un adecuado tamaño muestral para este trabajo de investigación, se empleó el método del muestreo selectivo basado en la Teoría Fundamentada donde la estructuración de la muestra de los participantes se realiza gradualmente a lo largo del proceso, por lo que el número y los rasgos de la población no se conocen *a priori*. Por ello, Glaser y Strauss (1967) definen que en este tipo de muestro la elección de individuos a estudiar se produce durante el proceso de interpretación de datos. Asimismo, Flick (2012) considera que el muestreo teórico puede partir de personas específicas donde la extensión de la población no se conoce, el tamaño de la muestra no está definido y el muestro acaba cuando se alcanza la saturación teórica, a diferencia del muestreo estadístico donde todo esto se conoce *a priori*. Glaser y Strauss (1967), definen como saturación teórica el criterio para determinar cuándo dejar de muestrear los distintos individuos, grupos o casos. Por lo tanto, se considera que se ha llegado a la saturación cuando no se hallan datos, o bien, cuando ya no emerge nada nuevo (Valles, 2009). De esta manera, la muestra no se obtiene a través de un muestreo aleatorio, sino que los individuos son seleccionados mediante las expectativas que generan en el aporte a ideas nuevas en relación con la teoría que se desea desarrollar. Adicionalmente, es importante considerar el tiempo disponible para llevar a cabo la investigación cualitativa debido a que el análisis de los datos cualitativos recolectados es muy rigoroso y toma demasiado tiempo para llevarlo a cabo de forma manual. Para este estudio, se recolectaron once entrevistas de las cuales se analizaron cuatro, debido a que se encontró saturación teórica, tomando un tiempo de tres meses para la codificación y análisis de las cuatro entrevistas. Así mismo, con la codificación de los datos y el análisis de los mismos se consideró que la información recogida resultó suficiente en relación con el objetivo del estudio.

Protocolo de entrevista

Los datos se obtuvieron de las entrevistas realizadas a los participantes. Cada una de las entrevistas semiestructuradas con preguntas abiertas fueron conducidas por el investigador con cada participante para documentar sus experiencias sobre las compras realizadas por Internet. Para esto, la entrevista se dividió en bloques de preguntas para facilitar el análisis, se obtuvieron diez bloques con diferentes temas a tratar: compras por Internet en general, acerca de su última compra realizada, compras en tiendas extranjeras, servicio de paquetería seleccionado, formas de pago utilizadas, tipo de dispositivos en los que realizan compras en línea, la confianza, la utilidad y control percibido a la hora de realizar compras en línea, la utilidad de la información proporcionada en los sitios de compras en línea, ver Tabla 2.

Tabla 2: Estructura de la guía de entrevista.

Bloques de preguntas	*Número de preguntas*
Acerca de compras en línea	9
Acerca de su última compra	9
Compras en tiendas extranjeras	8
Utilidad de los sitios de compra por internet	5
Control percibido	10
Envío de productos	6
Formas de pago	9
Tipo de dispositivos en las compras por internet	9
Confianza percibida	5
Utilidad de la información de un sitio de compra en línea	10

La entrevista consistió en llevar a cabo preguntas generales de inicio y posteriormente profundizar con preguntas cada vez más específicas como por ejemplo: "¿Con qué regularidad compras en línea?", "¿Qué es lo que más valoras a la hora de comprar en línea?" y "¿Cuáles han sido tus experiencias en la compra en línea?". Cada entrevista duró aproximadamente de 30 a 45 minutos, las cuales fueron transcritas para su posterior análisis. Una vez transcritas fueron codificadas de forma abierta acorde a la Teoría Fundamentada.

Análisis de datos

Se utilizó la técnica de Teoría Fundamentada, la cual consiste en un procedimiento sistemático para analizar y generar teorías a partir de datos cualitativos (Strauss y Corbin, 1998). Para Strauss et al. (2002), el propósito principal de la Teoría Fundamentada en los datos consiste en generar o encontrar modelos explicativos sobre determinados fenómenos, cuyos principios teóricos se encuentran apoyados en el análisis sistemático y posteriormente a la interpretación de los datos obtenidos de un conjunto de informantes mediante entrevistas. Por lo cual, se debe basar en el análisis comparativo constante entre las opiniones de los informantes en relación con la situación de cada pregunta con respecto a sus compras realizadas, con el fin de identificar patrones de recurrencia y sus relaciones. Como resultado del uso de esta metodología es la generación de teoría a partir de la inducción, de esta manera, ayuda a la explicación exacta del fenómeno estudiado aportando al investigador la habilidad de explicar un suceso. De esta manera, la aplicación de esta metodología permite crear teoría basada en la realidad, usando lo expresado por los informantes buscando mantener la esencia de las palabras que nos otorgaron.

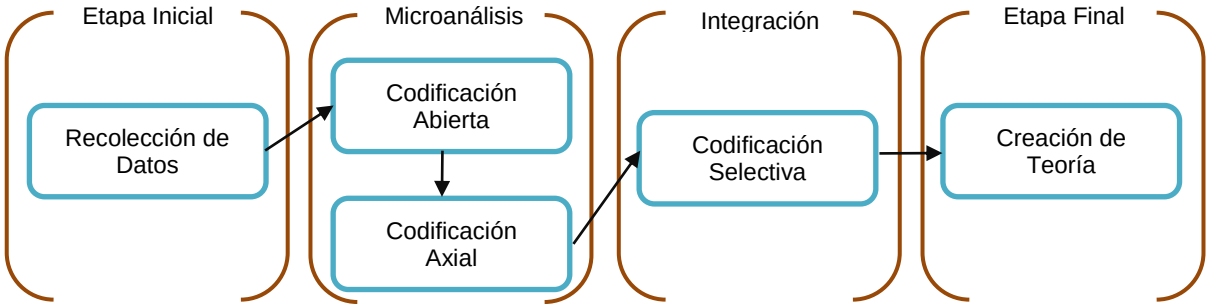

Fig. 1: Pasos de la Teoría Fundamentada

La metodología utilizada se basa en un modelo de cuatro etapas presentadas en la Figura 1. En este modelo se identifican las 4 etapas y 5 procesos a seguir para la creación de teoría. Primeramente en la etapa inicial se comienza con la identificación de área de interés a explorar y la selección de las fuentes de información, subsiguiente con la recolección de los datos. En la etapa de Microanálisis se comienza con el análisis de los datos y se van identificando que información relevante para el estudio, en esta etapa se realiza la codificación abierta y axial. La codificación abierta de los datos, se entiende como el análisis minucioso para identificar y conceptualizar los significados que el texto contiene. El resultado es una lista de códigos y al compararlos respecto de sus propiedades y dimensiones, se obtiene una clasificación, denominada categoría. Posteriormente, se lleva a cabo un análisis de codificación axial, en la cual, de acuerdo con Spiggle (1994), se identifican las relaciones entre las categorías obtenidas en la codificación abierta y sus subcategorías, esta relación está determinada por

las propiedades y dimensiones de las subcategorías y categorías que se quieren relacionar; por ejemplo, el código A causa el código B, el código A confirma el código B.

Una vez llevada a cabo la etapa de microanálisis, se procede a la etapa de integración donde se realiza la codificación selectiva, la cual, es una extensión de la codificación axial, pero con un mayor nivel de abstracción. Su propósito es obtener una categoría central que exprese el fenómeno de investigación para desarrollar una única línea narrativa con la cual todas las demás categorías relacionadas con la central estén cubiertas (Locke, 2001). Finalmente, en la última etapa se lleva a cabo el proceso de la creación de teoría, en la cual se empieza a delimitar las teorías emergentes y se formula una teoría con un grupo pequeño de conceptos de alta abstracción que permitirán construir conocimiento basado en las experiencias aportadas por los informantes. Esta metodología exige un laborioso trabajo de selección de contenidos relevantes, en función de lo expresado por los participantes, lo cual implica un alto nivel de abstracción donde el investigador no debe perder el sentido subjetivo que el informante transmitió.

Codificación abierta

Para llevar a cabo la codificación abierta de los datos obtenidos mediante las entrevistas, se analizaron detalladamente las transcripciones de éstas, línea por línea para identificar códigos y definir las categorías mediante la agrupación de conceptos. En la Figura 2, se muestra la codificación abierta de la transcripción de la entrevista del participante dos (P2). De esta manera, se detectan códigos abiertos sobre los datos recogidos, por ejemplo, en la respuesta del participante dos se identificó un patrón de navegación, al indicar la utilización de un buscador en los sitios de compra en línea, a su vez, manifiesta la necesidad de un catálogo en los sitios de compras en línea y se detecta un problema durante la navegación. Estos códigos seleccionados sirvieron posteriormente para la identificación de patrones e información importante para la siguiente fase.

154 E2 Yo utilizo el buscador y ya con eso me es suficiente pero no todos tienen
155 buscador ehl [Patrón de navegación] yo digo que deben tener un catálogo
156 que estén divido por categorías que sea simple y sencillo y que también
157 tengan un buscador [necesidades en compras]. Porque es muy difícil
158 navegar cuando no tienen y solo los dividen por marca [Problemas: difícil
159 navegación]. Por ejemplo si yo entro a Privalia no le voy poner una "blusa
160 roja" no, o sea es lo que este actual las ofertas actuales y ver todo el
161 catalogo que tienen.

Fig. 2: Codificación abierta: rotulación a entrevista

Codificación Axial

En esta fase del proceso de análisis se identificaron las relaciones entre las categorías obtenidas en la codificación abierta, en la cual se determinaron la variedad de condiciones, acciones/interacciones y consecuencias asociadas al comportamiento del consumidor en compras en línea. Por lo cual se llevó a cabo la jerarquización en subcategorías que son relacionadas con las categorías obtenidas previamente, ver Tabla 3.
Esta Tabla presenta el análisis y el desarrollo de las categorías relevantes para el estudio del comportamiento del consumidor, la cual está conformada por cuatro columnas: categorías, subcategorías, propiedades y dimensiones.

Tabla 3: Descripción de categorías, subcategorías, propiedades y dimensiones

Categorías	*Subcategorías*	*Propiedades*	*Dimensiones*
Comportamiento	Patrón de compra	Frecuencia de compras	Regularmente
			Ocasionalmente
		Horario	Mañana
			Tarde
			Noche

Tabla 3 *(continuación)*

		Tipo de compras	Planteadas
			Por impulso
			No previstas
		Tipo de productos	Tecnológicos
			Entretenimiento
			Vestimenta
		Medio de interacción	Computadora
			Dispositivos móviles
		Gastos	Limitados
			Ilimitados
		Ubicación	Casa
			Oficina
	Preferencias	Tipos de sitios	Nacional
			Extranjero
		Medios de envío	Servicio regular o exprés
			Envío a sucursal o domicilio
Motivación de compra	Necesidades existentes por satisfacer	Métodos de pago	Transferencia electrónica bancaria (debito/crédito)
			Transferencia electrónica PayPal
			Depósito OXXO
			Depósito bancario
		Promociones	Precio accesible
			Ofertas
			Descuentos
		Servicios	Rápidos
			Eficientes
			Existencia
		Información	Clara
			Real
			Detallada
		Aceptación	Personal
			Social
	Necesidades latentes de los sitios	Recomendaciones	Personalizado
		Avisos	Personalizado
		contexto	Personalizado
Experiencia del consumidor	Problemas	Proceso de compra	Método de pago
			Autorización de compra
			Error de cobro
		Búsqueda de productos	Descripción escaza
			Visualización falsa
	Proceso de búsqueda de sitios	Fuentes	Publicidad
			Búsqueda propia
			Recomendaciones
	Personal	Conocimiento	Experiencia en computación
			Experiencia en los métodos de pago
			Experiencia en la navegación de sitios
			Experiencia en comparación
		Experiencias	Positivas
			Negativas
		Confianza	Alta, media, baja
		Influencias	Amigos, conocidos
			Blogs

En la Tabla 3 se muestra una de las categorías que se definieron para la interpretación del estudio del comportamiento del consumidor, la cual nos define el comportamiento del consumidor y da a conocer las relaciones causales donde el comportamiento del consumidor genera un patrón de compra y otras subcategorías

como lo son las preferencias del consumidor. Una vez que la categoría se identificó, se describieron sus propiedades y las características de dimensión.

Codificación selectiva

En esta fase del proceso se selecciona una categoría para ser el núcleo, y se relacionan todas las demás categorías con la central. La categoría central en este estudio es la del *comportamiento* presentada como una categoría en la Tabla 3. Así mismo, se describen otras dos categorías, la motivación y la experiencia del consumidor, las cuales están directamente relacionadas con la categoría central y explican las condiciones y consecuencias de la misma. En conjunto, las tres categorías ayudaron de manera significativa para la creación de teoría que explica el comportamiento del consumidor en compras en línea. La recolección y análisis de datos en el proceso de investigación ocurrió simultáneamente y la teoría que surgió al concluir el proceso de análisis de los datos. En el cual, los códigos obtenidos de la recolección y análisis de los datos fueron comparados e interpretados dentro del contexto de transcripciones generales presentados en la siguiente sección.

RESULTADOS

Los datos se presentaron utilizando el marco propuesto por Strauss y Corbin (1998) para el desarrollo de categorías y subcategorías. La codificación selectiva se concentró en la formulación de una categoría central para obtener la idea conceptual bajo la cual se agruparán todos los elementos de las categorías alrededor de la central. Las categorías seleccionadas y desarrolladas fueron: comportamiento, motivación de compra y experiencias del consumidor. Finalmente, se generaron ideas a partir de las relaciones de las categorías, las cuales dieron origen a la teoría que describe los factores que influyen en mayor medida el comportamiento del consumidor en compras en línea, presentada en la Figura 3. En la Figura 3 se muestra como la motivación y la experiencia influyen en el comportamiento del consumidor. Asimismo, se identifican las variables que conforman a cada uno de estas categorías. A continuación se describe cada uno de las categorías del modelo teórico – explicativo.

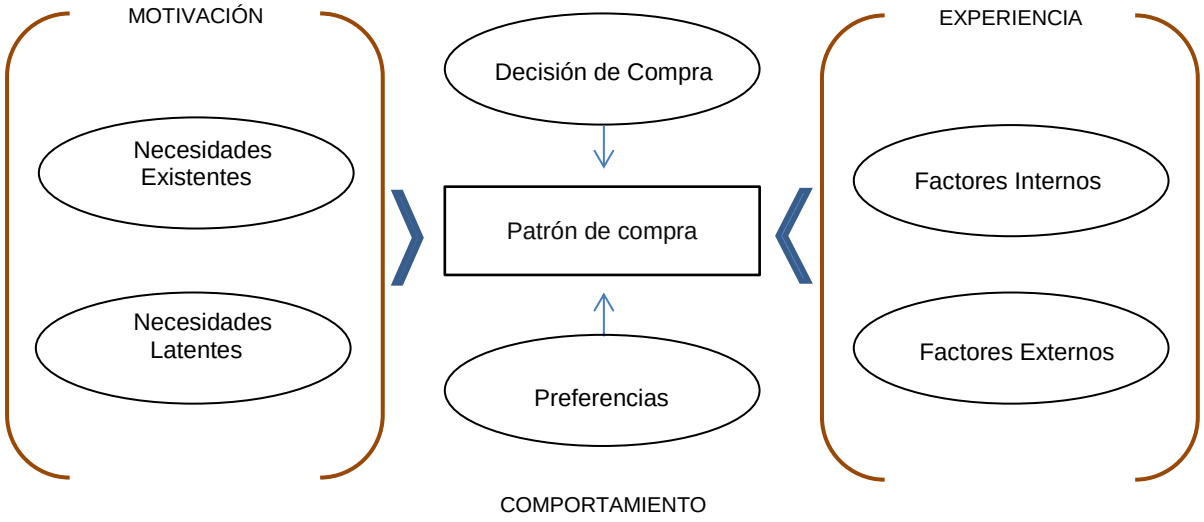

Fig. 3: Modelo teórico-explicativo del comportamiento del consumidor

Categoría 1: Comportamiento

Esta categoría es la principal del estudio, en ella se define el comportamiento del consumidor. Por lo cual, el comportamiento es definido por las actividades del consumidor orientadas a la compra de productos y servicios, incluyendo los procesos de decisión y sus preferencias, influenciadas por las dos subcategorías (motivación y experiencia) que preceden y determinan el patrón de compras del consumidor.

Variable 1: Patrón de compras

Con base en los comentarios de los participantes se identificó que durante los últimos años los consumidores adquieren productos y servicios mediante una mayor búsqueda de información y procesos de selección que tiene mucho que ver con sus preferencias de consumo sobre qué, dónde y cuánto comprar. Por lo tanto, los participantes manifestaron un alto empoderamiento de sus decisiones de compra como se observa en el comentario del participante 3, en donde expone que son capaces de exigir mayores y mejores condiciones en sus compras en línea, realizando búsquedas previas en diferentes sitios de comercio electrónico para seleccionar

el más adecuado a sus preferencias. Comentario del participante 3 (P3): *"Pues depende que es lo que estoy comprando y en donde, por ejemplo, yo siempre por regla comparo los precios, nunca, nunca, nunca jaja, la verdad no compro la primera vez que entro al sitio, por ejemplo, la última compra que quería hacer la última semana… compare ese producto en las tiendas físicas, entonces ya sabía los precios de las tiendas que si tenía en mi ciudad y luego comparé en línea porque a veces ponen ofertas exclusivas en línea".*

Asimismo, el comentario del P10 nos demuestra que no solo se limitan a obtener información de productos y servicios en general, sino que también analizan los comentarios de revisiones de otros consumidores que han adquirido un producto o servicio, esto indica que es una actividad que influye en gran medida en su decisión de compra. El comentario de este participante es el siguiente: *"Al tener el sitio donde es más barato reviso los comentarios de los clientes que han comprado el mismo producto para ver si me decido comprar".* Por otra parte, en el comentario del participante 10 se identifica una fase de exploración obligatoria, en donde sienten una responsabilidad de indagar, explorar y encontrar información para sentirse seguros al realizar su compra, tal como sigue: *"Pues, yo creo depende de la personalidad de como sea la persona, por ejemplo yo soy muy paciente al buscar porque puedo durar 2 horas metida buscando artículos y porque quiero encontrar cosas que me gusten y estén baratas pero a mí se me hace muy fácil sobre todo si tiene los filtros para cambio rangos de precios, o por marcas y si esos filtros no los tuviera la verdad sería una flojera y así es más fácil encontrar algo que busco, mientras más detallado un filtro mejor y es lo que me ha gustado en los sitios que uso para comprar".*

Variable 2: Preferencias

Con base en las experiencias de los participantes, se encontró que los consumidores tienen una lista priorizada de sus preferencias, como se muestra en los siguientes comentarios de los participantes 2, 3 y 5: "Las compras por las páginas chinas usan correos de México, si he comprado en páginas así y he pagado extra el envío y ha sido DHL para que me llegue rápido, pero sólo en páginas en donde ofrecen eso porque no todos los vendedores te lo ofrecen." (P3) "Uso más mercado libre por la rapidez de envío… lo que más valoró es la rapidez de entrega…" (P2) "También se me hace más seguro comprar en Amazon que en otro sitio, además que este sitio tiene el servicio de envío gratuito."(P5)

Por ejemplo, en cuanto a preferencias de los tipos de sitios, los medios de envío y los métodos de pago, están influenciadas directamente con las necesidades existentes por satisfacer y por la motivación de compra. Sin embargo, a la hora de la toma de decisión de compra se ven más inclinados a los medios de envío por encima de los precios y sitios de compra, como lo demuestra el comentario del participante 10: "Por ejemplo, un día compré en una página donde si tu pedido era mayor a los 70 dólares tu envío era gratis pero como yo quería que me llegará pronto me valió pagar extra por el pedido." (P10)

Categoría 2: Motivación de compra

Esta categoría influye directamente sobre el comportamiento de compra, siendo identificada como el estímulo de comprar en línea.

Variable 3: Necesidades existentes por satisfacer

En este estudio, se describió esos estímulos como necesidades existentes por satisfacer incluyendo las promociones, servicios, información y aceptación que proporcionan estos sitios en línea.
Refiriéndose a esto, los participantes declararon: "La variedad de los productos, que actualicen su catálogo de productos." (P5); "Quiero encontrar cosas que me gusten y estén baratas." (P10); y "Por los costos muy bajos y porque encuentras cosas que en otros sitios no encuentra."(P2)

Variable 4: Necesidades latentes de los sitios

También se detectaron necesidades relacionadas al medir, sentir o palpar el producto donde los participantes mostraron interés que deben ser atendidas de alguna manera para tener mejores experiencias de compra. A continuación comentarios del participante 10: "…la experiencia de medirse, sentirlo y ver cómo te queda no lo tienes y poner fotos reales puede acércanos un poco a esta experiencia de las tiendas físicas. También estaría padre tener a alguien ahí por la plataforma para poder preguntarle cosas sobre los productos." (P10)

Categoría 3: Experiencias del consumidor

En cuanto a la categoría de experiencias del consumidor, los participantes comentaron que es un factor importante para la definición del comportamiento de compra, debido a que los consumidores poseen conocimientos previos a la hora de navegar por sitios de compras en línea, esto indica que al momento de sentir el estímulo que anteriormente se define como motivación, la experiencia proporciona la información suficiente

que influirá en su comportamiento de compra. Esta experiencia se dividió en problemas (variable 5), proceso de búsqueda (variable 6) y personal (variable 7) donde cada una de estas variables se explican a continuación.

Variable 5. Problemas

De acuerdo a los comentarios de los participantes, las compras en línea implican un acto de fe en el que el consumidor pone su confianza en los sitios de compras en línea, para que sus pedidos sean enviados en tiempo y forma. Sin embargo, todos han pasado por desafortunadas situaciones que hicieron no obtener su producto o servicio y perder su dinero. Por lo cual, proporcionan sus experiencias y lecciones aprendidas de los eventos problemáticos a la hora de comprar, como lo expresa el siguiente comentario: "Lo debes hacer con moderación, checar muy bien el sitio que vas a utilizar, que sea un sitio web conocido, que tenga muchos usuarios y leer de perdida unos puntos de contrato de privacidad que te proporcionan algunos sitios." (P2)

Variable 6. Proceso de búsqueda

Con base a las experiencias de los participantes, se encontró que la distribución y existencia de los elementos básicos de navegación en un sitio de compras en línea es de vital importancia para la decisión de compra, como se muestra en el comentario del participante 3: "Que este CLARO todo, que este todo completo, lo que te presentan y ¡claro!. Que sea fácil y que el buscador ¡híjole!, el buscador es algo que se busca, bueno por lo menos yo es lo primero que uso cuando quiero algo en específico, pero a veces entro a páginas nomas para ver qué hay de nuevo..."(P3)

Variable 7. Personal

Del mismo modo, las experiencias buenas y malas son un factor clave para el comportamiento de consumidor, porque son las responsables de influir en mayor medida en las preferencias y decisión de compra de los consumidores. El comentario del participante 3 expresa tener una vasta experiencia en compras en línea y que la mayoría han sido buenas: *"Mis experiencias son bastante buenas, son que encuentras siempre lo que buscas, es económico, no batallé en el proceso de compra, al momento de buscar y hacer el pedido." (P3).* Por lo cual, a partir del establecimiento de las conexiones de las categorías relacionadas (motivación y experiencia) con la categoría central (comportamiento) se pueden enriquecer el conocimiento actual sobre el comportamiento del consumidor ante plataformas de compra en línea, mediante la implementación de estrategias de mejora con respecto a los resultados obtenidos, como se muestra en la Tabla 4.

Tabla 4: Estrategia de mejora en plataformas de compra en línea de acuerdo a las categorías definidas en el estudio

Categorías	*Estrategia de mejora en plataformas de compra en línea*
Motivación	1) Actualización constante del catálogo de productos y servicios. 2) Mantener siempre descuentos y promociones. 3) Contar una descripción de productos detallada, al igual que fotos de productos reales que se pueden observar todas las características del producto. 4) Proporcionar un chat online para resolver las inquietudes o miedos que le vayan surgiendo a los consumidores de la plataforma de compra en línea en tiempo real.
Comportamiento	5) Contar con una sección de comentarios para que los consumidores expresen sus opiniones acerca de los productos y servicios consumidos y ayuden en la decisión de compra de futuros consumidores. 6) Proporcionar filtros de búsqueda de productos y servicios de diferentes tipos: marca, precio, departamento, entre otros. 7) Ofrecer diferentes medios de pago y paquetería.
Experiencia	8) Proporcionar información acerca de garantías, políticas y contrato de privacidad. 9) Contar con un buscador interno de productos. 10) Ofrecer información acerca de devoluciones y reembolso. 11) Contar con una sección de contacto para solución de problemas.

La implementación de estas estrategias de mejora en las plataformas de compra en línea pueden garantizar un mayor conocimiento del comportamiento y patrón de compra del consumidor. Puesto que las plataformas que conformen todos los elementos que se proporcionan en la Tabla 4, podrán ir adaptándose de acuerdo al análisis del consumidor periódicamente consiguiendo una toma de decisiones efectiva asegurando una mejor aceptación y satisfacción del consumidor.

DISCUSIÓN

En el comportamiento del consumidor existe una serie de influencias en el proceso de compra como se describe anteriormente: la motivación y las experiencias. Para esto, una de las influencias más importante está relacionada con la necesidad de existencia de productos, ya que, por ejemplo, cuando no existen los productos en tiendas locales, aumenta la tendencia de consumo en línea. Como ejemplo de ello, el participante 2 opinó *"Porque no hay localmente."* (P2), el participante 10 comentó *"No hay existencia en las tiendas física."* (P10) y el participante 5 *"a veces en las tiendas no hay lo que buscas y aparte que sale mucho más caro…*" (P5); Esta información demuestra que la tendencia de compra en línea podría aumentar al existir escasez de un producto y el alto costo en las tiendas locales. Puesto que en un estudio de la Asociación de Internet MX (2018), demuestra que las compras en línea han aumentado un 17% más que en el año 2017, manteniendo un 54% de usuarios que compran en línea. Sin embargo, este estudio afirma que hay una presencia de las páginas de comercio electrónico en la vida del usuario con un 39%, al contrario, nuestro estudio demuestra que el 75% de participantes están de acuerdo que el uso de plataformas de compra en línea cambiaron sus hábitos de compra ya que estas exhiben un mayor catálogo de productos y mejores ofertas.

En definitiva, los consumidores toman en primer lugar esta necesidad como su motivación principal para comprar en sitios de compra en línea, y esto es debido a la influencia de blogs y redes sociales actuales, los cuales han influido de manera notable en el proceso de decisión de compra. En ese sentido, algunos estudios se demuestra la importancia que han tomado las redes sociales por medio de la comunicación y la interacción de información de productos, lo cual afecta el comportamiento de compra favoreciendo la compra en línea (Guardia y Gómez, 2009; Vargas, 2015). Esto es debido a que la publicidad proporcionada en las redes sociales tiene una influencia directa en los aspectos intelectuales, sensitivos y emotivos del consumidor como se ha demostrado en estudios previos (Hsu, Chuan-Chuan y Chiang, 2013). Como ejemplo de ello, el participante 10 opinó: "Las de ropa y todo eso, si fue por publicidad en Facebook, YouTube e Instagram, como yo me la llevo buscando y viendo en esas redes sociales noto esa publicidad…" (P10). Por lo tanto, la influencia de las redes sociales y los blogs pueden influir en las distintas fases del proceso de decisión de compra. Más aún, en este estudio se encontró que los comentarios de los usuarios de los medios sociales tienen un mayor poder de influencia en la decisión de compra que los mensajes de comunicación comercial de cualquier otro medio, en el segmento de población estudiado nacidos entre 1975 y 1995, tomando en cuenta la generación X a la generación Z.

Agregando a lo anterior, los productos y servicios de entretenimiento y de moda son los más consumidos en sitios de compra en línea, puesto que el tiempo entre estímulo de compra (motivación) y la compra (decisión de compra) se ha disminuido en gran medida por causa de la influencia de las redes sociales mencionadas anteriormente, por lo cual los consumidores adquieren más productos en menos tiempo. Sin embargo, un estudio de la Asociación Mexicana de Venta Online (AMVO) demuestra las ventas generadas por el comercio electrónico, donde el sólo el 2% se genera en México. A pesar de ello, nuestro estudio señala que la población del estado de Sonora, cada vez adquieren mayor confianza para realizar compras en línea de acuerdo a su experiencia en compras previas, las cuales indicaron la existencia de mejores ofertas que en tiendas físicas, variedad de productos y marcas exclusivamente en línea; y de motivación, puesto a las influencias de redes sociales y blogs que promueven una reputación positiva a productos ofrecidos en línea y que las tiendas físicas empiezan a contar con su propio portal de compra en línea. Por otra parte, tanto los sitios web y aplicaciones de compras en línea, han mejorado su proceso de compra, para ofrecer una mayor facilidad y rapidez en la compra de los productos y servicios, lo cual estimulan con mayor intensidad la decisión de compra.

El tipo de perfiles de los participantes seleccionados para el análisis demostraron que las preferencias y patrón de compras son distintos, porque se manifiesta otro tipo de motivaciones y experiencias. El perfil del consumidor en línea generalmente conoce sus posibilidades en el nuevo medio de realizar compras, estas posibilidades de compra se expanden, desde el lugar de conexión, las valoraciones de productos y las recomendaciones personalizadas para la toma de decisiones de compra. Asimismo, las dos clasificaciones de los perfiles de los consumidores son 1) los que desean un ahorro de tiempo y 2) los que desean un ahorro de dinero. Sin embargo, nuestros resultados demuestran el origen del por qué un consumidor se clasifica en uno de los dos grupos y también, el cómo poder anticipar el perfil del consumidor para poder ofrecer un servicio personalizado de acuerdo a las características del usuario en la plataforma de compra en línea. Por otro lado, además de las características abordadas en este trabajo, otros estudios mencionan que una de las características que consideran más importantes para la compra en línea son la confianza y la fiabilidad que percibe el consumidor al momento de realizar la compra en el sitio en línea (Al-Debei, Akroush y Ashouri, 2015; Sánchez-Alzate y Montoya, 2017). Si bien, estas características no se abordan explícitamente como una categoría en este estudio, se consideraron implícitamente dentro del grupo de elementos fundamentales para la generación de estrategias que conlleve a la satisfacción del consumidor en las compras en línea. Por ejemplo, para los participantes que trabajan y adquieren productos y servicios para sus actividades laborales, el factor de mayor importancia es el precio del producto y servicio, por el contrario, si es de tipo personal el factor más importante es el medio de envío y en segundo lugar el precio. De esta manera, los datos obtenidos sobre el comportamiento del consumidor en compras en línea,

demuestran que los consumidores poseen cada vez más control y es necesario dar a conocer los factores encontrados y sus relaciones que influyen en el patrón y decisión de compra en línea. Asimismo, fue posible generar una teoría con información respecto a aquellos factores de mayor importancia en la decisión y patrón de compra por Internet en los consumidores del estado de Sonora en la compra de productos y servicios en los sectores de tecnología, vestimenta y entretenimiento.

CONCLUSIONES

Los hallazgos de este estudio demuestran que el enfoque metodológico de la Teoría Fundamentada aplicado en el ámbito de compras por Internet garantizó la identificación de factores clave como la motivación, la experiencia y el comportamiento, los cuales se obtuvieron a partir de una reflexión crítica que permitió relacionar temas de interés para el estudio de comportamiento del consumidor a partir de la realidad observada. Con base en los resultados del estudio, se concluye que el análisis del comportamiento del consumidor puede ayudar a la creación de estrategias para la toma de decisiones efectivas mediante su aplicación en el diseño de plataformas de compra en línea. Estas plataformas podrían proveer al empresario una herramienta tecnológica donde podrá obtener un análisis de sobre el comportamiento de los consumidores para mejorar estrategias de mercadeo y venta.

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Estudio sobre la Percepción de los Factores Involucrados en la Estimación de Precios de Viviendas: El Caso de Cajeme

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Resumen

El objetivo de esta investigación es obtener la información necesaria para identificar la percepción sobre los factores de mayor y menor impacto durante el proceso de valuación de viviendas. Para ello, realizaron diez entrevistas semiestructuradas, las cuales se analizaron mediante Teoría Fundamentada. Los resultados de este trabajo sugieren que tanto los compradores como los vendedores de viviendas perciben a la ubicación, las proporciones y las condiciones de las viviendas como factores determinantes para estimar el valor de éstas. Los resultados de este trabajo pueden ser utilizados para mejorar el diseño de modelos predictivos para la estimación de precios de bienes raíces utilizados en plataformas en línea dedicadas a la compra-venta de bienes raíces. Así mismo, el estudio proporciona las bases necesarias para establecer las variables o parámetros que mejor se adapten al algoritmo predictivo para la estimación de precios de viviendas en la región sur del estado de Sonora, México.

Palabras clave: investigación cualitativa; teoría fundamentada; factores determinantes; valuación de viviendas; mercado inmobiliario; compradores de inmuebles

Study about the Perception of Factors Involved in Housing Price Estimation: The Case of Cajeme

Abstract

This work aims at obtaining the necessary information for identifying the perceived factors of higher or lower impact during the housing valuation process. Ten semi-structured interviews were conducted, and analyzed using Grounded Theory. The results of this work suggest that both buyers and sellers of households perceive the location, proportions and housing conditions as determining factors to estimate the value of these properties. The results of this work can be used to improve the design of predictive models for real estate which are used in online platforms. Furthermore, the study provides the bases to establish the variables or parameters used in the predictive algorithm for estimating housing prices in the southern region of the state of Sonora, Mexico.

Keywords: qualitative research; grounded theory; determining factors; housing valuation; real estate market; real estate buyers

INTRODUCCIÓN

Para muchas personas, comprar o vender una casa es una de las decisiones más importantes en su vida e involucra un amplio umbral de incertidumbre acerca del valor a asignarle a la vivienda, puesto que, además de la asequibilidad del inmueble, otros factores como la ubicación o el panorama de la inversión a largo plazo afectan en mayor o menor medida al proceso de valuación. Debido a esto, la información relacionada con el valor de las viviendas es fundamental para los investigadores, organismos de gobierno, empresas de bienes raíces, vendedores de viviendas y para los propietarios de inmuebles. Esquer (2012) menciona que los métodos de valuación de inmuebles suelen ser bastante lentos y tediosos debido a que requieren de una investigación bien fundada y, en general, los procedimientos actuales deben basarse en información confiable para obtener resultados más precisos.

Asimismo, el impacto de los factores durante el proceso de valuación de viviendas varía dependiendo de la percepción que se tenga sobre estos. Carterette y Friedman (1982) definen la percepción como una parte primordial de la conciencia que consta de hechos abstraídos del mundo externo y, por tanto, se refiere a la realidad tal como es experimentada. Según Arias (2006), "*la percepción depende de la actividad de receptores que son afectados por procesos provenientes del mundo físico y puede entonces definirse como el resultado del procesamiento de información que consta de estimulaciones a receptores en condiciones que en cada caso se deben parcialmente a la propia actividad del sujeto*". Con base en lo anterior, se puede decir que, ya sea que se desee vender o comprar una vivienda o inmueble, tener noción de cómo se determina su costo brinda control sobre el patrimonio en cuestión; además, proporciona seguridad en caso de que se necesite realizar una transacción con dicho inmueble.

Bell et al. (2015) mencionan que en el ámbito inmobiliario hay muchos métodos prescritos para obtener datos de mercado y otra información crítica; dichos métodos pueden ser de carácter cualitativo o cuantitativo. Los métodos más utilizados para este contexto son los cuantitativos debido a que, en muchos casos, los problemas inmobiliarios se prestan de manera predecible a datos cuantificables. Sin embargo, como ya se mencionó, los participantes del mercado inmobiliario tienen percepciones propias que pueden influir en los precios de venta y otros datos cuantificables. Debido a esto, el autor argumenta que el uso de métodos cualitativos puede proporcionar una mejor comprensión de los problemas y las motivaciones dentro del mercado. Durante la revisión de la literatura, se encontró que existe una considerable cantidad de investigadores interesados en el análisis cualitativo como método para obtener la percepción de las personas respecto a diversas cuestiones en áreas como la medicina, psicología, tecnología, gestión empresarial, estudio de mercados, entre otras (Figueira et al 2009; Bedoya et al., 2017; Festen et al. 2014; Riley et al. 2009; Bravo et al., 2018; Oliveira et al. 2016; Padilla et al., 2017; Pérez-Benedito et al., 2017; Kamagahara et al., 2016). Sin embargo, hay escasez de estudios en donde se lleve a cabo el análisis cualitativo para el contexto de bienes raíces.

En el ámbito inmobiliario, Kibet et al. (2016) llevó a cabo un estudio para evaluar el efecto de los factores socioculturales en las inversiones inmobiliarias. Ellos aplicaron una encuesta a una muestra de 300 propietarios de propiedades inmobiliarias comerciales en la ciudad de Kisumu en Kenia. Los datos fueron analizados tanto cualitativa como cuantitativamente y los resultados revelaron que los factores socioculturales influyen en gran medida en la inversión inmobiliaria. De igual forma, Kakulu (2014) describe una serie de estrategias para el análisis cualitativo y diversos métodos para el análisis de datos en el campo de bienes raíces en Nigeria. Asimismo, el autor argumenta que las futuras investigaciones de bienes raíces en dicho país deben tomar en cuenta las percepciones de las personas puesto que es un área que aún está poco investigada en dicha región. El autor recomienda ampliamente el uso de estrategias de investigación de fenomenología y aplicación de casos de estudio, métodos de recolección de datos de grupos focales y, el uso de una herramienta innovadora de análisis de contenido para el análisis de datos y la interpretación de los hallazgos, de tal manera que remarcan la importancia de este tipo de análisis. A pesar de ello, son muy pocos los estudios que se realizan bajo el contexto inmobiliario y sobre todo que utilicen métodos cualitativos de investigación.

Este trabajo tiene como objetivo identificar la percepción sobre los factores de mayor y menor impacto tomados en cuenta durante el proceso de valuación de una vivienda por parte de los compradores y vendedores de viviendas que residen en el municipio de Cajeme, ubicado en la región sur del estado de Sonora. El enfoque de teoría fundamentada, se basa en recopilar y analizar datos obtenidos mediante entrevistas semi-estructuradas. Una vez que se identificaron diversos patrones, categorías y similitudes en los datos analizados, los resultados demostraron que tanto los compradores como los vendedores de viviendas perciben a la ubicación, las proporciones y las condiciones de las viviendas como factores determinantes para estimar el valor de estas. Lo anterior proporciona beneficios para las personas de la región involucradas en la compra-venta de inmuebles, puesto que permitirá hacer aún más robusto el método de valuación a emplear al considerar el impacto que tiene cada uno de los factores. De igual manera, proporcionará las bases necesarias para establecer los parámetros de un algoritmo predictivo para la estimación del valor de las viviendas de la región.

FENÓMENO BAJO ESTUDIO

Según datos del Instituto Nacional de Estadística y Geografía (INEGI, 2010), la población total del municipio de Cajeme fue de 409,310 habitantes en 2010, de los cuales más del 72% se concentraban en Ciudad Obregón, siendo ésta la cabecera municipal donde también se encontraba la mayor actividad económica. Así mismo, se calculó una tasa de crecimiento poblacional del 1.72% para el periodo 2011-2015 con base en históricos de 2005-2010. La agricultura es la principal base para el desarrollo económico del municipio, sin embargo, a través del tiempo se han introducido nuevas tecnologías y presentado nuevos productos al mercado (IMIP, 2017). La estructura urbana de la cabecera municipal se caracteriza por concentrar los edificios y monumentos más antiguos en el centro y por mantener gran parte de las viviendas de los habitantes en la periferia, propiciando el crecimiento urbano en la zona norte y sureste de la ciudad (Ayuntamiento de Cajeme, 2011). En cuanto al tema de seguridad pública, Cajeme fue el segundo municipio con mayor número de delitos registrados en 2012, lo cual representó un aumento gradual en la inseguridad con respecto en años anteriores (INEGI, 2012). Respecto al ámbito inmobiliario, en 2015 había un total de 128,490 viviendas particulares en el municipio, de las cuales más del 98% contaban con servicios básicos de energía eléctrica, agua de la red pública y drenaje. Además, el número de habitantes promedio por vivienda fue de 3.4 personas (INEGI, 2015). En el mismo año, se proyectó un notable crecimiento en el mercado inmobiliario del municipio, puesto que doce nuevos fraccionamientos se encontraban en proceso de desarrollo (CANADEVI, 2015).

En los últimos años, los problemas relacionados con el análisis del mercado inmobiliario han crecido muy rápido ya que este conocimiento es muy relevante para las predicciones inmobiliarias, las inversiones y las cuestiones relacionadas con los impuestos (Del Giudice et al. 2017). Debido a ello, la valuación de viviendas es un tema que ha sido constantemente explorado e investigado. Sin embargo, el impacto de los factores clave para determinar el valor de los inmuebles varía dependiendo de los aspectos socioculturales y de la percepción sobre el tema de valuación de viviendas que se tenga en cada región. Dicho impacto se puede ver afectado por el tipo de personas que viven en alguna comunidad, las condiciones de las viviendas de dicha zona, entre otros. Realizar una investigación de carácter cualitativo permite analizar la percepción que tienen los compradores y vendedores de cierta región sobre los factores clave para estimar el valor de las viviendas; a través de este estudio, se pretende identificar cuáles son los más relevantes en el municipio de Cajeme, Sonora. En la Tabla 1 se muestra una descripción de los factores estándar a tomar en cuenta al momento de realizar la estimación del valor de alguna vivienda. Dichos factores serán contemplados durante la realización de este trabajo de investigación.

Tabla 1: Factores para la valuación de viviendas.

Factor	*Concepto*	*Referencias*
Ubicación	Es uno de los factores con mayor influencia en el valor de las viviendas. El precio de venta o el costo del metro cuadrado de una vivienda varían dependiendo de la región en donde se encuentre. Esto, debido a la demanda que tiene la zona, las condiciones del vecindario, el grado de desarrollo a su alrededor, entre otros.	Basu et al. (1998); Bourassa et al. (2007).
Tipo de propiedad	El valor de la vivienda se puede ver afectado por el tipo de propiedad, es decir, si el inmueble se trata de una casa o un departamento. Aquí también se ven involucradas la cantidad de habitaciones y tipos de habitaciones con las que cuenta la propiedad.	Daniels et al. (1999); Zietz et al. (2008).
Condiciones de vivienda	En este punto se tocan aspectos como: el año de construcción, condiciones del techo, condiciones del piso, condiciones de las paredes, material exterior, tipo de tejado, reparaciones, vistas e iluminación.	Haurin et al. (1996); Zietz et al. (2008); Bourassa et al. (2007).
Proporciones de la vivienda	Involucra diversos aspectos de la vivienda, tales como: área, perímetro, número de pisos, cochera, estacionamiento y patio.	Daniels et al. (1999); Haurin et al. (1996); Zietz et al. (2008).
Instalaciones	La antigüedad de la vivienda se relaciona directamente con las condiciones de sus instalaciones debido al deterioro que pueden presentar. Los tipos de instalaciones van desde instalaciones eléctricas, de agua potable, red de saneamiento, de ventilación o servicios.	Zietz et al. (2008); Schram (2006).
Sitios cercanos	Los sitios cercanos al inmueble pueden tener influencias positivas o negativas en los precios de las viviendas. Entre los ejemplos de sitios cercanos se incluyen: escuelas, supermercados, hospitales o transporte público.	Basu et al. (1998); Zietz et al. (2008); Bourassa et al. (2007).

METODOLOGÍA

El propósito de esta sección es describir el método de la teoría fundamentada que se utilizó para llevar a cabo el trabajo de investigación. A continuación, se presenta un listado de los pasos realizados durante la investigación con la finalidad de lograr los objetivos planteados. Posteriormente, se describen las preguntas de investigación, el proceso de recopilación de datos y el análisis de los mismos. Como se mencionó anteriormente, para llevar a cabo esta investigación se utilizó un enfoque de teoría fundamentada. Strauss y Corbin (1994) definen a la teoría fundamentada como una metodología generalizada para desarrollar teoría sobre un fenómeno de estudio en particular, basándose en datos recolectados y analizados sistemáticamente. La teoría evoluciona durante el proceso de investigación, y lo hace a través de la interacción continua entre el análisis y la recopilación de datos. Glaser y Strauss (2017) argumentan que la teoría fundamentada exige identificar categorías teóricas que son derivadas de los datos mediante la utilización de un método comparativo e iterativo. Es decir, se compara el contenido de diversas sesiones de entrevistas o de observación con los conceptos teóricos nacientes del esfuerzo por identificar los temas fundamentales (Wells et al. 1995; Barnes, 1996).

Proceso de investigación

El proceso de investigación que se llevó a cabo, se basó en una serie de pasos definidos por Glaser y Strauss (2017), tal como se muestra en la Figura 1.

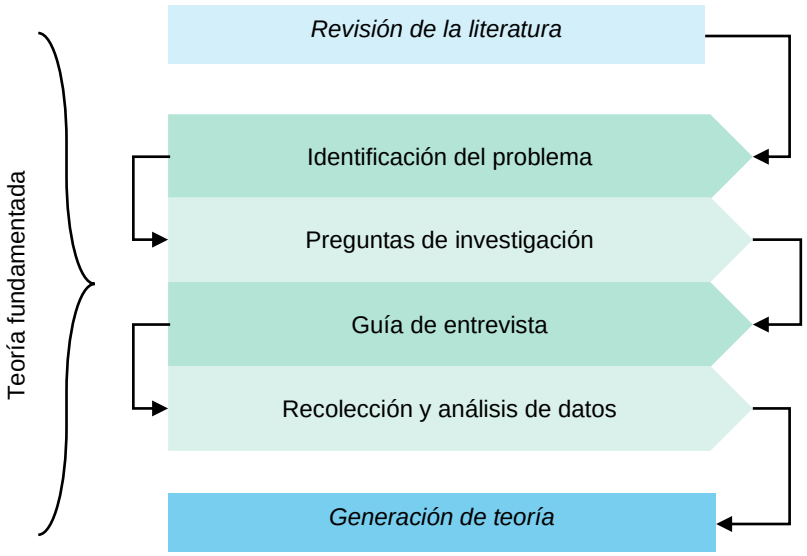

Fig. 1: Metodología de teoría fundamentada como generadora de teoría a partir de los datos.

Preguntas de investigación

Agee (2009) menciona que muchos investigadores con enfoque en los estudios cualitativos ven una simple pregunta como un punto de partida para su investigación. Una vez que la pregunta se encuentra situada satisfactoriamente en su lugar, el estudio puede comenzar. Posterior a la detección del problema o fenómeno de estudio, se identificaron tres preguntas de investigación. En este caso, las preguntas de investigación buscan explorar todos aquellos factores que toman en cuenta los individuos al momento de estimar el valor de una vivienda, así como todos aquellos que ignoran. Se inicia planteando una pregunta general que se complementa con otras dos cuestiones específicas: 1) ¿Cuál es la percepción del individuo sobre los factores que determinan el valor de una vivienda en la región sur del estado de Sonora?; 2) ¿Cuáles son los factores de mayor y menor impacto durante la estimación de costo de una vivienda por parte de los compradores?; 3) ¿Cuáles son los factores de mayor y menor impacto durante la estimación del precio de venta por parte de los vendedores?

Participantes

Con el objetivo de determinar un adecuado tamaño muestral para este trabajo de investigación, se empleó el método del muestreo selectivo propio de la investigación cualitativa. Martínez-Salgado (2012) menciona que, a diferencia del muestreo probabilístico, *"la indagación cualitativa, en cambio, elige las unidades de estudio con un propósito: lograr un conocimiento intensivo, profundo y detallado de y sobre los casos en los que tiene lugar el fenómeno de interés, generalizable para otras situaciones en las que dicho fenómeno ocurre"*. Además

del propósito anterior, es importante tomar en cuenta otros factores al momento de delimitar el tamaño de la muestra; tal es el caso de las semanas disponibles para realizar la investigación, ya que el análisis de los datos cualitativos recolectados es bastante riguroso y toma mucho tiempo al ser llevado a cabo de forma manual (Basit, 2003). En este caso, se contaba solamente con 16 semanas para realizar el estudio. Por ello, se optó por establecer un número limitado de sujetos, los suficientes para representar al sector clave de compradores y vendedores de viviendas en la región estudiada.

Se decidió aplicar un total de 10 entrevistas a habitantes del municipio de Cajeme, ubicado en la región sur del estado de Sonora que compartían rasgos y estilos de vida predominantes en la región. De ellos, 5 correspondían a personas que cuentan con experiencia en cuanto a la compra de inmuebles o personas con planes de adquirir una vivienda. Los otros 5 participantes correspondían a personas con experiencia en la venta de inmuebles; dicha experiencia podía haber sido obtenida con apoyo por parte de profesionales de bienes raíces o por la venta directa de algún inmueble. Las entrevistas tuvieron una duración de 30 a 50 minutos, de las cuales se tuvieron que descartar 2 por falta de claridad y consistencia en la información obtenida (E5 y E6). Se identificó que las 8 entrevistas restantes compartían bastante información en común, lo que hacía posible acotar aún más el número de entrevistas a analizar. Finalmente se eligieron 4 para llevar a cabo el análisis cualitativo. La decisión se basó en la calidad de la información proporcionada, en la similitud de las ideas expuestas y en el rango de edad de los participantes, es decir, personas de 30 años o más. Para esto, los participantes de las entrevistas seleccionadas para el análisis fueron E1, E4, E7 y E9. Dos de las entrevistas son de personas con experiencia en la compra de viviendas y las otras dos entrevistas son de personas con experiencia en la venta de viviendas. Específicamente, el sujeto E1 realizó la compra de una vivienda unifamiliar aislada en un vecindario con nivel socioeconómico medio; el sujeto E4 llevó a cabo la venta de una vivienda unifamiliar aislada en un vecindario con nivel socioeconómico bajo; E7 adquirió una vivienda unifamiliar aislada en un vecindario con nivel socioeconómico alto y el sujeto E9 vendió una vivienda unifamiliar adosada en un vecindario con nivel socioeconómico medio. En la Tabla 2 se puede apreciar el perfil general de los participantes que fueron entrevistados.

Tabla 2: Perfil de los participantes.

Participante	*Edad*	*Plan de compra*	*Experiencia de compra*	*Presencia durante el proceso de venta*	*Experiencia de venta*	*Calidad en la información*
E1	44		X			X
E2	36	X				X
E3	25	X				X
E4	60				X	X
E5	38		X			
E6	37				X	
E7	34		X			X
E8	46			X		X
E9	30				X	X
E10	45			X		X

Recolección de datos

Para llevar a cabo la recolección de los datos se diseñó una guía de entrevista de tipo semiestructurada, tomando como base las preguntas de investigación mencionadas anteriormente. Cohen et al. (2006) menciona que las guías de entrevistas semiestructuradas proporcionan un conjunto claro de instrucciones para los entrevistadores y, puede generar datos cualitativos fiables y comparables. También brindan la oportunidad de identificar nuevas formas de ver y comprender el tema bajo estudio. Por otro lado, Clifford et al. (2016) menciona que las entrevistas semiestructuradas se desarrollan de una manera conversacional, ofreciendo a los participantes la oportunidad de explorar cuestiones que ellos crean relevantes. Este tipo de entrevista semiestructurada tiene como objetivo alentar al sujeto entrevistado para que narre algún evento importante de su vida y del contexto social (Muylaert et al. 2014). La guía o protocolo de entrevista llevada a cabo en este estudio, cubre los siguientes temas: i) Situación del individuo: Preguntas generales sobre antecedentes del participante, incluyendo su situación actual personal y de la vivienda, así como los conocimientos base que posee sobre la valuación de viviendas; ii) Experiencias con la compra o venta de viviendas: El propósito de estas preguntas es conocer cómo fue el proceso de compra o venta de la vivienda en cuestión; iii) Percepción de factores clave: Se realizan preguntas para conocer la percepción que tiene el participante sobre los diversos factores involucrados en la estimación del valor de las viviendas.

Análisis de los datos

Una vez concluidas las entrevistas, se realizó su transcripción para proceder con el análisis de línea por línea. El objetivo de llevar a cabo el análisis de las trascripciones es profundizar aún más en las historias compartidas por los participantes, en busca de información relevante que responda a las preguntas de investigación planteadas. Por lo tanto, es necesario analizar e interpretar los datos para construir un sentido e ir generando la teoría a partir de estos. El proceso de análisis se puede ver reflejado en la Figura 2, en donde la codificación abierta se refiere a descomponer la información línea por línea, la codificación axial sugiere la creación de categorías, en la codificación selectiva se elige una categoría base y, por último, se procede con la generación de una teoría.

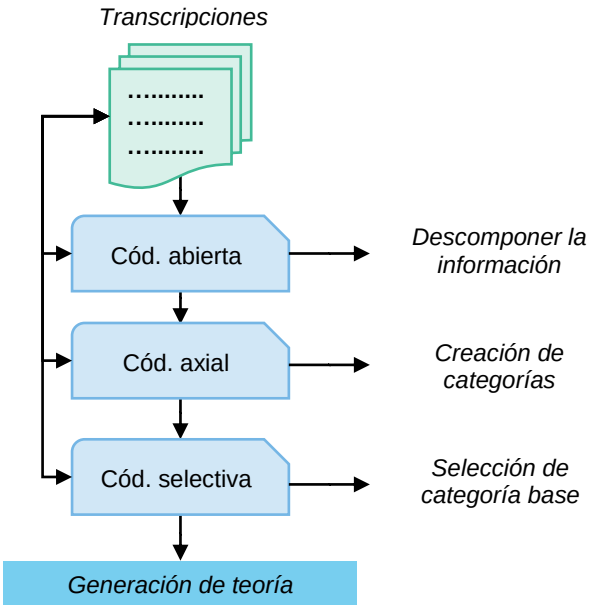

Fig. 2: Tipos de codificación para el análisis de datos.

Codificación abierta

Codificar los datos significa identificar todas y cada una de las ideas representadas en cada línea de texto de las transcripciones. Para esto, se debe dar un nombre clave a cada nueva idea, preferentemente que sean palabras claras y concisas (Grams, 2001). La codificación abierta incluye conceptos de etiquetado, definiendo y desarrollando categorías basadas en sus propiedades y dimensiones. Durante este proceso, los conceptos surgen de los datos brutos y luego se agrupan en categorías conceptuales. El objetivo es construir un marco preliminar descriptivo y multidimensional para su análisis posterior. El proceso por sí solo asegura la validez del trabajo debido a que se construye directamente a partir de los datos brutos (Khandkar, 2009). Durante esta fase, se fraccionaron los datos de las trascripciones para obtener diversos códigos que después se agruparían por categorías. En la Figura 3 se puede observar un fragmento de la transcripción de una entrevista y su respectiva codificación abierta, las palabras en rojo corresponden a las etiquetas resultantes según se analizaba el texto línea por línea.

Codificación axial

Strauss y Corbin (2002) definen la codificación axial como “el proceso de relacionar las categorías a sus subcategorías, denominado ‘axial’ porque la codificación ocurre alrededor del eje de una categoría, y enlaza las categorías en cuanto a sus propiedades y dimensiones”. Es por ello que el propósito de la codificación axial consiste en iniciar con la reagrupación de los datos que se fracturaron durante la codificación abierta. En la codificación axial, las categorías se relacionan con sus subcategorías para formar unas explicaciones más precisas y completas sobre los fenómenos (Strauss et al. 1998). En esta fase, se analizaron los códigos resultantes de la codificación abierta y se agruparon por categorías, subcategorías, propiedades y dimensiones, lo cual resultó en una mejor comprensión del escenario bajo estudio. En la Tabla 3 se muestran algunos datos resultantes del proceso de codificación axial; se encontraron tres categorías principales, doce subcategorías, sesenta propiedades y ciento veinte dimensiones.

Fig. 3: Fragmento de codificación abierta realizada a transcripción de E4.

6	L	¿Y validó de alguna manera el precio de venta?
7	E4	Sí lo validé, por el tipo de casa que tenía, más o menos le pregunté a alguien que sabía del
8		tema [Necesidad de asesoramiento] y ahí más o menos me orientó [Asesoramiento
9		valuación vivienda], me dijo "pues por lo que es, por la zona, en dónde está y la construcción
10		pues vale más o menos tanto, [Factores determinantes] puedes variar un poco más o poco
11		menos ese precio, pero eso es aproximadamente". [Estimación de precio de venta]
12		Entonces yo tomé como referencia ese precio que me dio esa persona que sabe sobre
13		valuación de viviendas y modifiqué un poco el precio [Ajuste de precio de venta] ya viendo
14		y analizando bien la casa [Verificar condiciones de vivienda] y las ofertas de los compradores
15		que tenía en ese momento. [Analizar ofertas]

Las categorías principales se definen a continuación: i) Contexto actual del individuo: Concentra toda aquella información en torno a la situación actual del individuo bajo estudio. Es decir, involucra aspectos de su vida personal, características esenciales de su vivienda (ej. si es propia o rentada), así como su nivel de conocimientos sobre el tema de valuación de viviendas; ii) Experiencias del individuo: Se refiere a todos los aspectos relacionados con la experiencia, ya sea en la compra de viviendas o con la venta de estas. Así mismo, involucra propiedades como el tipo de experiencia, las ventajas, los problemas ocurridos, así como las habilidades y conocimientos puestos en marcha durante el proceso de compra o de venta; iii) Percepción de factores estimación: Aquí se concentra información importante sobre la percepción del individuo en cuanto a los diversos factores involucrados durante la estimación del valor de una vivienda, ya sea para su compra o venta, tales factores son: ubicación, sitios cercanos, vecinos, proporciones de la vivienda, condiciones de la vivienda, instalaciones, seguridad, terreno excedente de la vivienda. Así mismo, se determina el grado de importancia (alto o bajo) que percibe el individuo bajo estudio para cada uno de dichos factores, las ventajas y desventajas percibidas y demás información relevante que permite profundizar en la percepción que tienen de los mismos.

Tabla 3: Fragmento de codificación axial realizada durante análisis de datos.

Categorías	*Subcategorías*	*Propiedades*	*Dimensiones*
I. Contexto actual del individuo		Vida personal Características de la vivienda Habilidades y conocimientos sobre valuación	Edad, Estado civil, … Rentada, Compartida, propia, remodelada, … Alto, medio, bajo
II. Experiencias del individuo	Compra de viviendas	Tipo de experiencias Ventajas Problemas Habilidades y conocimientos Tipo plan de compra	Satisfactoria, insatisfactoria Asesoría, claridad en procesos de compra, facilidades de pago, … Estimación de costos, … Largo o corto plazo
	Venta de viviendas	Tipo de experiencia Ventajas Problemas Habilidades y conocimientos	Positiva o Negativa Asesoría, Uso de Tecnología, … Periodos de espera, … Intereses de compradores, …
III. Percepción de factores estimación	Factores determinantes para compra	Nivel de impacto	Alto, Medio, Bajo
	Factores determinantes para venta	Nivel de impacto	Alto, Medio, Bajo

Tabla 3 *(continuación)*

	Ubicación	Grado de importancia Ventajas Desventajas Relación con plusvalía Relación con otros factores Relación con valor de vivienda	Alto, Bajo Buen mantenimiento, … Precios elevados por ubicación,… Aumento/Decremento Vecinos, calidad de vida, … Alto, Medio, Bajo
	Sitios cercanos	Grado de importancia Grado de satisfacción Ventajas Percepción sobre sitios cercanos problemáticos Problemas Tipos de sitios cercanos Relación con valor de vivienda	Alto, Bajo Alto, Bajo Ahorro de gasolina, comodidad,… Centros comerciales, deportivos y carreteras Tráfico, ruido, … Comerciales, escolares, … Alto, Medio, Bajo
	Vecinos	Grado de importancia Tipos de vecinos Conocimiento de comunidad Percepción de vecindario Confianza Tipo de relación con vecinos Relación con valor de vivienda Relación con otros factores	Alto, Bajo Agradable, tranquilos, … Alto, nulo Tranquilo, ruidoso Alta, Nula Buena, mala Alto, Medio, Bajo Ubicación
	Proporciones de la vivienda	Grado de importancia Tipo de proporciones Problemas Percepción de utilidad Relación con valor de la vivienda	Alto, Bajo Tamaño, metros cuadrados, … Necesidad de adaptación, … Alto, Medio, Bajo Alto, Medio, Bajo
	Condiciones de la vivienda	Grado de importancia Nivel de deterioro Grado de satisfacción Descripción de construcción Condiciones de construcción Ventajas Desventajas Relación con valor de vivienda	Alto, Bajo Alto, Medio, Bajo Alto, Bajo Tipo de construcción, … Buenas, en remodelación, … Buena regulación de temperatura Reparación de techos, … Alto, Medio, Bajo
	Instalaciones	Grado de importancia Tipos de instalaciones Ventajas Problemas Relación con valor de vivienda	Alto, Bajo Eléctricas, agua potable, … Facilidad de reemplazo, … Requiere conocimientos expertos Alto, Medio, Bajo
	Seguridad	Grado de importancia Nivel de seguridad Frecuencia de vandalismo Relación con valor de vivienda	Alto, Bajo Alto, Medio, Bajo Abundante, Nulo Alto, Medio, Bajo
	Terreno excedente	Grado de importancia Ventajas Desventajas	Alto, Bajo Proyecciones a futuro, … Costos adicionales …

RESULTADOS

Una vez concluido el análisis mediante la codificación abierta y la codificación axial, se comenzó el proceso de integrar y refinar la teoría, también llamado codificación selectiva. Strauss y Corbin (1998) argumentan que, al igual que en todas las fases del análisis, la integración de la teoría requiere de la interacción constante entre el analista y los datos. Esta fase inicia con la selección de una categoría medular que representa el tema principal de la investigación. En este caso las preguntas de investigación no cambiaron conforme avanzaba el análisis, esto debido a que los datos continuaron relacionados con las mismas preguntas. Se eligió la tercera categoría como núcleo central para darle respuesta a las preguntas de investigación planteadas. Es decir, la categoría sobre la "percepción de los factores de estimación".

En la Figura 4 se puede observar la evolución del proceso de análisis de datos mediante las fases de codificación abierta, axial y selectiva. Se puede apreciar que los códigos resultantes se clasificaron en tres categorías principales (Contexto actual del individuo, Experiencias del individuo, Percepción de los factores) que interactuaban con algunas subcategorías (Factores determinantes en la compra/venta de viviendas, Experiencias con la compra/venta de viviendas), propiedades y dimensiones (Grado de importancia, Tipo de experiencia, Habilidades/Conocimientos, Contexto de vivienda actual, Contexto personal). Con la elección de

la categoría central, se reordenaron las relaciones entre categorías, subcategorías, propiedades y dimensiones, quedando la categoría sobre la percepción de los factores de estimación al centro y manteniendo una relación con las experiencias de los individuos, el contexto actual del individuo y el listado de los factores determinantes para la compra/venta de viviendas.

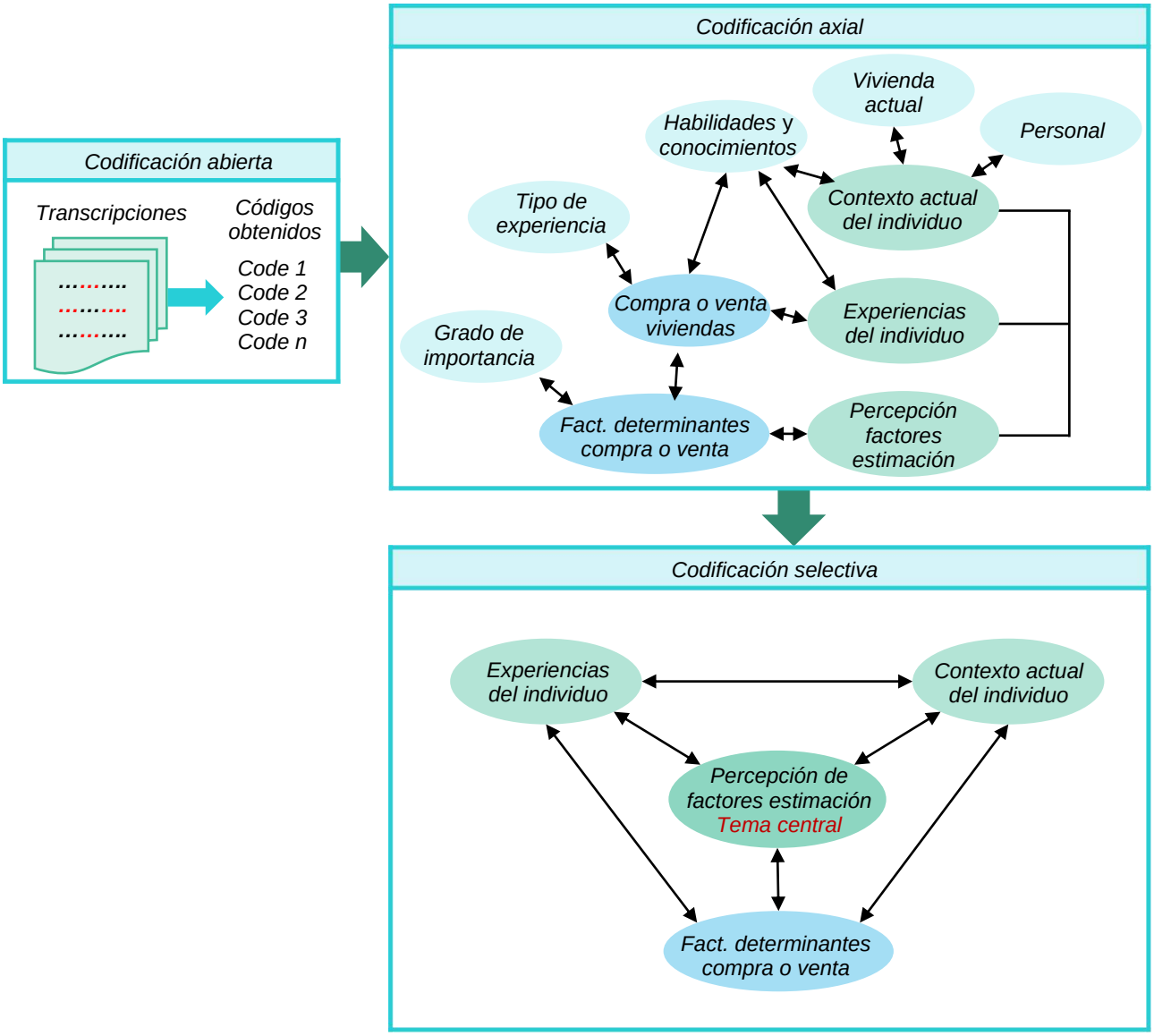

Fig. 4: Proceso de análisis de los datos: Codificación abierta, axial y selectiva.

Percepción general sobre los factores que determinan el valor de una vivienda

Tal como se menciona anteriormente, el análisis de las entrevistas arrojó a la categoría sobre la "percepción de los factores de estimación" como la central. Dicha categoría, en relación con las otras dos categorías identificadas, permite responder a las preguntas de investigación planteadas. En la Figura 5 se puede observar que los compradores y vendedores de viviendas de la región perciben tres factores como determinantes clave del valor de las viviendas, es decir: la ubicación, las proporciones y las condiciones de la vivienda. Todos los individuos entrevistados coincidieron en que dichos factores son los más importantes al momento de determinar, ya sea el costo o el precio de venta del inmueble. Por ejemplo, E7 (comprador) hizo énfasis en la relación directa que existe entre la ubicación de una vivienda y su costo: *"si es en una zona de las afueras de la ciudad pues está más barata, si es céntrica ahí aumenta más el costo y si es en un residencial pues aún más cara todavía"* (E7). Por otro lado, E9 (vendedor) menciona que, para los vendedores, la ubicación *"es importante por la plusvalía que le puedes dar al inmueble"* (E9). En cuanto a las proporciones de la vivienda, E4 (vendedor) comenta: *"Considero muy importante las proporciones. Sí tienen mucho que ver para sacar el precio de la vivienda, por los metros cuadrados. Tienes que ver el factor ese, es muy importante, el tamaño del terreno. Es primordial"* (E4). Así mismo, E1 (comprador) afirma que las condiciones de la vivienda *"Sí, tienen mucho que ver para la valuación de una vivienda, el tipo de material y construcción que*

tenga es uno de los factores más importantes en los que todas las personas y valuadores se fijan o toman en cuenta" (E1). Sin embargo, las opiniones de los participantes difieren en un par de factores, los compradores consideran determinantes para el costo de la vivienda a la seguridad y el terreno excedente. E1 (comprador) asegura que *"por el riesgo que hay en el vecindario debería valer menos la casa"* (E1). Es decir, si el nivel de seguridad en la zona es bajo, el costo de la vivienda debería disminuir por dicho factor. Por otro lado, E7 (comprador) comenta porqué piensa que el terreno excedente determina el costo: *"La casa que elegí no se me hizo cara, tuve que dar un extra de dinero pero fue porque yo compré terreno excedente"* (E7).

Fig. 5: Diagrama de Venn sobre la percepción de compradores y vendedores respecto a los factores que determinan el valor de una vivienda.

Por otro lado, los vendedores ni siquiera mencionaron esos factores, ellos hicieron énfasis en los sitios cercanos con los que cuentan las viviendas para determinar el precio de venta. En ese sentido, E4 (vendedor) justifica el precio de venta elevado de la siguiente manera: *"Allá en dónde está la casa que vendí, el camión pasa por la casa, el seguro está cerca, la laguna, la escuela, el ITSON, las escuelas primarias o secundarias están ahí cerquitas (sic), tiene muchas cosas buenas que pueden influir en la vida de los compradores que vivan ahí, por el fácil acceso al transporte público y sitios cercanos que ya mencioné"* (E4). Las opiniones entre compradores y vendedores difieren debido al tipo de experiencias y percepciones con los que cuentan. En ese sentido, la categoría sobre la percepción de los factores se ve relacionada con el contexto actual del individuo y sus experiencias. Los compradores consideran importante a la seguridad y al terreno excedente por sus intereses, es decir, buscan vivir en un sitio libre de delincuencia y en el que exista la posibilidad de expandir la construcción en un futuro, el siguiente fragmento de la entrevista a E1 (comprador) muestra su percepción sobre la importancia de la seguridad y el terreno excedente según sus intereses y experiencias: *"Hubo un factor muy importante que no contemplé que fue la seguridad que había en la zona y al final terminé arrepintiéndome de dicha compra de la vivienda, por eso la regresé, por la poca seguridad que había ahí. …El terreno excedente es uno de los factores más importantes al momento de determinar el valor o el costo de la vivienda… antes de comprarla se debe ver que sea lo suficientemente amplio como para expandirse o ampliarse de alguna manera la casa, es muy importante ver más allá, a largo plazo, por si crece la familia en algún momento tener terreno suficiente para poner uno o más cuartos"* (E1). La percepción sobre las instalaciones (eléctricas, agua potable, saneamiento, servicios de telecomunicaciones) y los vecinos con los que cuenta la vivienda fueron bastante dispersas y dependen de otros subfactores más específicos dentro de cada tipo de participante, es por ello que no se incluyen en la Figura 5. Sin embargo, se explica la perspectiva de cada uno de esos factores como respuesta a las dos últimas preguntas de investigación.

Factores de mayor y menor impacto por parte de los compradores

Los compradores de la región sur del estado de Sonora que fueron entrevistados consideran como factores de mayor impacto a la ubicación, las proporciones, las condiciones, la seguridad y el terreno excedente. En la sección anterior se expusieron los motivos por los cuales dichos factores son catalogados como factores de mayor impacto o determinantes del valor de viviendas. Ahora bien, los factores considerados como factores de menor impacto son: Los sitios cercanos comerciales y de esparcimiento y las instalaciones de la vivienda (Ver Figura 6). E7 (comprador) comenta que no percibe relación entre los sitios cercanos y el costo de las viviendas: *"Pues yo digo que con el costo no influyen, aunque ahora hace mucho auge eso de los sitios cercanos al fraccionamiento, ahora que hicieron la plaza comercial ahí cerca… No creo que influya en el costo pero en las personas sí, por ejemplo, dicen: 'está cerca de la Plaza Sendero ahí voy y compro'…"* (E7).

Las instalaciones de la vivienda son consideradas como un factor flexible que no influye realmente en el costo de la vivienda por parte de los compradores: "…No creo realmente que haya una relación entre las condiciones de las instalaciones y el costo de la misma. Es opcional al estimar el costo porque esas son cosas que se pueden reparar después… es algo que se puede reemplazar fácilmente. Claro que implica un costo pero es algo que se mira después de realizada la compra y se va arreglando poco a poco, conforme se tenga la posibilidad" (E1).

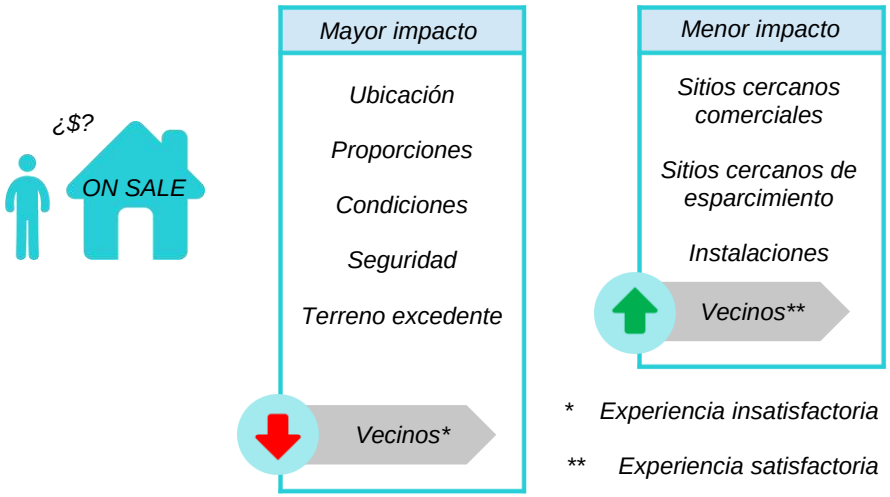

Fig. 6: Factores de mayor y menor impacto percibidos por compradores de viviendas.

La percepción y el nivel de impacto de los vecinos o el tipo de vecinos con los que cuenta una vivienda varía. Esto depende del tipo de experiencia previa con la que cuente el comprador en cuestión. Es decir, si el comprador ha tenido una experiencia insatisfactoria con los vecinos, entonces va a catalogar al "factor vecinos" como de mayor impacto para estimar el valor de alguna vivienda. E1 comenta que su experiencia con los vecinos ha sido insatisfactoria: "Mi experiencia no fue buena puesto que… me dejé llevar por la calle y no me fijé en los vecinos que tenía dicha vivienda o en el vecindario… tiempo después de que compré dicha casa…ya estaba pensando en mudarme ahí pero me di cuenta de que el barrio era realmente peligroso y los vecinos se veían peligrosos, me dio mucho miedo porque yo tengo dos hijas y preferí regresar esa casa y perdí la inversión que le había hecho con el piso y todo eso" (E1).

También menciona cómo eso ha influido en su percepción sobre la relación de los vecinos y el costo de las viviendas: "Hay un tipo de vecinos que son problemáticos… Por el riesgo que hay en el vecindario debería valer menos la casa, por eso te menciono que percibo esa relación entre esos dos puntos que son el tipo de vecinos y el costo de la casa" (E1). Por el contrario, si el comprador ha tenido una experiencia satisfactoria o neutral con los vecinos, entonces va a catalogar al "factor vecinos" como de menor impacto o como factor flexible para estimar el valor de alguna vivienda. E7 comenta que su experiencia con los vecinos ha sido satisfactoria: "Mi experiencia ha sido buena. Pues ahorita se ve que son vecinos tranquilos y que están al pendiente de las demás casas…" (E7). Debido a ello, no toma en cuenta o no cree que exista una relación entre los vecinos con los que cuenta una vivienda y el costo de la misma: "Pues no creo que los vecinos tengan algo que ver como tal con el costo de una vivienda… más bien segmentan por zonas de distintos niveles económicos en el fraccionamiento, haz de cuenta que por eso hay varias casas, hay unas más baratas y otras más caras, obviamente el tipo de persona no es la misma" (E7).

Factores de mayor y menor impacto por parte de los vendedores

Los vendedores de viviendas de la región sur del estado de Sonora que fueron entrevistados no mencionan la seguridad ni terreno excedente como posibles factores de mayor o de menor impacto, más bien se basan en los factores clave o estándar para determinar el valor de las viviendas. Consideran como factores de mayor impacto a la ubicación, las proporciones, las condiciones y los sitios cercanos con los que cuenta la vivienda. En la sección anterior se expusieron los motivos por los cuales dichos factores son catalogados como factores de mayor impacto o determinantes del valor de viviendas. Ahora bien, el factor considerado como factor de menor impacto fue el de vecinos de la vivienda (Ver Figura 7). E9 comenta que el tipo de vecinos no influye en el precio de venta del inmueble: *"Yo creo que sería más importante sobre la zona como ya mencioné. Sobre los vecinos, no tanto. Porque si te vas a una zona de un nivel estable donde no haya mucho vandalismo ni delincuencia, creo yo que los vecinos importan muy poco… Ya es a criterio de cada quién, pero creo que no influye para estimar el precio de venta del inmueble."* (E9).

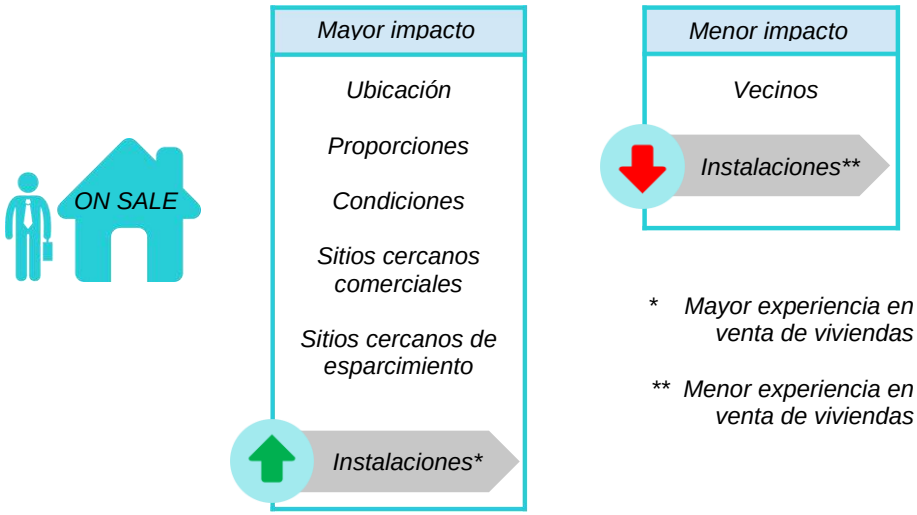

Fig. 7: Factores de mayor y menor impacto percibidos por vendedores de viviendas.

La percepción y el nivel de impacto en cuanto a las instalaciones (eléctricas, agua potable, saneamiento, servicios de telecomunicaciones) de la vivienda varía dependiendo del nivel de experiencia en la venta de viviendas del vendedor. Es decir, si el vendedor posee una mayor experiencia en cuanto a la venta de viviendas, entonces va a catalogar al "factor instalaciones" como de mayor impacto para estimar el valor de alguna vivienda. El participante E9 quién posee una mayor experiencia en cuanto a la compra de viviendas menciona lo siguiente: *"Es muy importante… las instalaciones son algo que se tiene que considerar. También, si tiene algunos servicios, por ejemplo, unos amigos acaban de comprar una casa y, ni Telcel ni Megacable llega para allá…. en los mismos valores catastrales te viene todo eso, si cuenta con todos los servicios e instalaciones o cuenta con algunos servicios, si tienes qué hacer fosa o no…"* (E9).

Por el contrario, si el vendedor posee una menor experiencia en cuanto a la venta de viviendas, entonces va a catalogar al "factor instalaciones" como de menor impacto para estimar el valor de alguna vivienda. E4 posee conocimientos básicos sobre el tema y comenta lo siguiente al respecto: *"…Sería secundario eso de las instalaciones de las tuberías o eléctricas, no lo considero tan importante porque hay otras cosas más importantes para estimar el precio de venta de la casa… porque eso es punto y aparte, se puede arreglar o mejorar poco a poco por parte de los compradores… es de los factores flexibles que mencionaba en la pregunta anterior…"* (E4).

DISCUSIÓN

Durante el proceso de la revisión de literatura, se encontraron numerosas investigaciones cualitativas en donde los autores emplean diversos métodos de análisis de datos cualitativos, tales como la teoría fundamentada o el análisis de contenidos, para conocer la percepción de las personas respecto a temas de interés en diversas áreas como la medicina (Figueira et al., 2009; Bedoya et al., 2017), psicología (Festen et al., 2014), tecnología (Riley et al., 2009; Bravo et al., 2018), gestión empresarial (Oliveira et al., 2016; Padilla et al., 2017; Pérez-Benedito et al., 2017), estudio de mercados (Kamagahara et al., 2016), entre otros. Sin embargo, se identificó cierta escasez respecto a este tipo de estudios cualitativos enfocados al contexto de bienes raíces. Kibet et al. (2016) realizó un estudio híbrido con rasgos cualitativos y cuantitativos para demostrar que los factores socioculturales influyen en la inversión inmobiliaria. Por otro lado, Kakulu (2014) propone una serie de estrategias para llevar a cabo un análisis cualitativo en el contexto inmobiliario. Si bien ambos trabajos involucran el tema de las investigaciones cualitativas y de bienes raíces, ninguno de ellos lleva a cabo un estudio para conocer la percepción de las personas en cuanto a la compra y venta de viviendas. En contraste, haciendo uso del método de la teoría fundamentada, en el presente trabajo se analizaron las percepciones de compradores y vendedores de viviendas para conocer cuáles factores son considerados de mayor y menor impacto durante el proceso de valuación de inmuebles.

El análisis obtenido de este estudio indica que, tanto compradores como vendedores de viviendas en la región sur del estado de Sonora consideran a la ubicación, las proporciones y las condiciones de las viviendas como factores fundamentales al momento de llevar a cabo la estimación del precio de alguna vivienda. Más específicamente, los compradores perciben a la ubicación, las proporciones de la vivienda, las condiciones de la vivienda, la seguridad en la zona y al terreno excedente como factores de mayor impacto; los sitios cercanos a la vivienda y el tipo de instalaciones con las que cuenta la vivienda son considerados factores de

menor impacto. Por otro lado, los vendedores perciben a la ubicación, las proporciones, las condiciones y los sitios cercanos de la vivienda como factores de mayor impacto y consideran irrelevante o de menor impacto el tipo de vecinos. De igual modo, durante la fase de análisis de los datos se encontró que existen más dimensiones del fenómeno de estudio que pueden ser más profundamente analizadas en trabajos futuros.

Los resultados de este estudio beneficiarán a las personas de la región sur del estado de Sonora relacionadas con el contexto de bienes raíces; robusteciendo el método de valuación de viviendas al conocer la influencia percibida para cada uno de los factores involucrados en el proceso de estimación de precios. También proporcionará las bases necesarias para establecer las variables o parámetros a contemplar en un algoritmo predictivo para la estimación del precio de las viviendas en la región. Así mismo, este trabajo puede servir de guía para futuros estudios cualitativos relacionados con bienes raíces que deseen replicar el método utilizado y analizar datos obtenidos de muestras más grandes.

CONCLUSIONES

De acuerdo con los resultados obtenidos, se concluye lo siguiente: 1) Las preguntas de investigación planteadas al inicio de este trabajo de investigación fueron resueltas satisfactoriamente mediante la aplicación del método de la teoría fundamentada; 2) además, se encontró que los factores determinantes del valor de una vivienda desde la perspectiva de compradores y vendedores de viviendas son principalmente: la ubicación, las proporciones y las condiciones de la vivienda; y 3) el impacto del resto de los factores analizados varía dependiendo de distintas situaciones, tal como el perfil del participante (vendedor o comprador), el nivel de experiencia (mayor o menor) en cuanto a la venta y valuación de viviendas por parte de los vendedores e incluso el tipo de experiencia con los vecinos (satisfactorio e insatisfactorio) por parte de los compradores de inmuebles.

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Mobile sensing for behavioral research: A component-based approach for rapid deployment of sensing campaigns

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Abstract

Collecting experimental data from multiple sensing devices has just recently become quite popular in behavioral and social sciences. Among existing devices, mobile phones stand out as they allow researchers to collect data from individuals in an unbiased, precise, unobtrusive, and timely manner. Current mobile sensing applications are typically developed from scratch, provide no reusable components, and frequently do not take advantage of the devices' processing capabilities. In light of such limitations, this work presents a novel tool that leverages mobile phones not only to collect data via their sensors but also to process them on the device as soon as they are gathered. The tool provides researchers with easy-to-use services that allow them to configure the required processing routines on the mobile phones. This work proposes a new approach for rapid deployment of sensing campaigns targeted at scientists with basic technical knowledge and requiring low effort. We performed an evaluation aimed at determining whether there is a significant improvement in terms of user effectiveness and efficiency in the definition of new components. The results suggest that the proposed tool speeds up the time and reduces the effort taken for setting up and deploying a sensing campaign.

Keywords

Mobile phone sensing, sensing tool, data processing

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Introduction

Collecting data from humans has always been both a paramount and challenging task for researchers.[1,2] Although data are virtually needed to conduct any experiment or field investigation, obtaining such data is not always easy or even feasible. This is especially true for social and clinical studies, where relatively large groups of people or cohorts are to be observed in a natural setting, with multiple situations and variables to be measured. In fact, this takes a considerable amount of effort for both researchers and participants. In recent years, new techniques have been proposed to assist the collection of experimental data. Most recently, mobile phone-based sensing, also referred broadly to as mobile sensing, has emerged as a method used to assist the required work to obtain such data.[3] Mobile phones (or smartphones) are particularly suitable for this kind of activities due to their inherent characteristics: portable, unobtrusive, ubiquitous, relatively easy to acquire, and affordable. These types of devices have sensors that allow researchers to obtain unbiased data about users and their environment.[4,5] Also, since mobile phones are small-sized computers, they have storage, processing, and communications capabilities that can be exploited by developing applications that take advantage of those

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capabilities. According to GSMA intelligence 2019, two thirds of the world's population are unique mobile subscribers, which accounts for almost 9 billion mobile connections worldwide, surpassing the current world's population. In this context, mobile phones seem an unparalleled tool for conducting human-centric experiments in the wild, continuously at region, nation if not world-scale.

Despite the aforementioned potential of mobile sensing to conduct human-centric studies, there are still various challenges to overcome. On one hand, researchers, particularly non-STEM (science, technology, engineering and mathematics), may find difficult to set up experiments compared to their traditional tools. On the other hand, mobile sensing applications have to be typically developed from scratch, thus delaying the realization of the study. Also, applications are most often tailored to the needs of a particular study and therefore their reusability for other (similar) studies is low, which could make it less practical and affordable for the long term. In view of these limitations, a new generation of general-purpose mobile sensing frameworks has been proposed.[6–11]

In this work, we propose a new approach for rapid deployment of sensing campaigns targeted at scientists with basic technical knowledge and requiring low effort. We performed an evaluation aimed at determining whether there is a significant improvement in terms of user effectiveness (i.e. new data processing routines work correctly) and user efficiency (i.e. they can be developed in a short time) in the definition of new components using the proposed approach. The results suggest that the proposed tool speeds up the time and reduces the effort taken for setting up and deploying a sensing campaign. This presented proposal is based on the component-based approach[12,13] as the aim is to support the creation of components that implement data processing routines used to define mobile sensing campaigns (from these pre-defined components). In this manner, the construction of mobile sensing campaigns relies on already developed components. This allows researchers to reuse data processing routines (i.e. components) in sensing campaigns, which typically vary in terms of when to trigger data collection (i.e. events) or what data to collect (i.e. raw or processed sensor data). Moreover, the component-based approach in mobile sensing applications allows researchers to download and incorporate pre-existing components (i.e. data processing routines) at runtime into the mobile phone when changes to the collection protocol (or data formats) are required and the detection campaign is already underway. The component-based approach is a widely used technique that has been utilized to approach crucial problems in domains such as face recognition[14] and cloud computing.[15]

The rest of the article is structured as follows. In section "Related work," we provide a brief literature review on specific- and general-purpose mobile sensing applications as well as a discussion about related work. In section "A proposal for rapid deployment of mobile sensing campaigns," we present a new component-based approach for rapid deployment of mobile sensing campaigns, and in section "Technical implementation of the proposed approach," we discuss its implementation details. We present results regarding the evaluation of the proposed component-based model in section "Evaluation." Finally, in section "Conclusion and future work," we provide some concluding remarks and future research directions.

Related work

Collecting data through portable, sensor-enabled devices, such as mobile phones, has become an increasingly used technique to obtain experimental data. As a result, mobile sensing has gained enough relevance to be considered a research area by itself. Some work has been published about this subject that proposes concepts and classifications,[5] where sensing paradigms (e.g. participative and opportunistic) and sensing scales (e.g. individual, group, and community) were identified. In a similar fashion, Khan et al.[16] discussed the domains (e.g. health, social, human-computer interaction, and psychology) that leveraged mobile phone sensing and listed applications that were developed to collect data for specific purposes.

Two types of mobile phone sensing applications are identified from the literature: (1) applications designed for a specific purpose, and (2) applications that seek to provide an adaptable platform that enables researchers to match the requirements of their study or project with basic technical knowledge and low effort.

Specific-purpose mobile sensing applications

Usually, researchers develop custom, domain-specific mobile sensing applications in order to obtain data from participants and their environment, monitor their activities, give feedback to them, and/or allow users to interact with the device in original ways. We describe some of the most representative mobile sensing applications designed for a specific domain and/or purpose.

One of the very first mobile sensing applications is Ubifit Garden.[17] The main idea behind this application is to promote the wellbeing of participants by motivating them to perform physical activity through visual compensation. Ubifit Garden could identify several activities (e.g. walking and sweeping) and keep a record of them. For each activity that Ubifit Garden recognizes, the user gets a flower that is displayed on the

background of the phone's screen. After completing a goal, that is, a series of activities, a butterfly is drawn on the screen along with the flowers, thus developing vivid allegories which are easy for users to relate to their current physical state. In a similar direction, BeWell is developed to monitor, model, and promote the well-being of people.[18] In this case, BeWell monitors, via the mobile phone's accelerometer, GPS, and microphone, three aspects of the user: the amount of sleep, the physical activity carried out, and the social interactions performed. The application quantifies these aspects of wellbeing and offers visual information to the users on how well they are doing. It uses a shoal to determine the level of social interaction, an orange fish to establish the level of physical activity, and the brightness level to show the amount of sleep, all of them being portrayed on the background of the mobile phone's screen.

Despite the high prevalence of mobile sensing applications for health and wellbeing purposes (e.g. assisting older adults[19–23]), there are several other areas that can benefit from the data collected via mobile phones. For example, CarSafe[24] uses both cameras of the mobile phone (for those cells that have both front and rear camera) to monitor the state of the driver and the road. This application uses computer vision and machine learning algorithms to detect whether the driver is tired or distracted and at the same time checks the road conditions. Similarly, Nericell[25] and PotHole[26] use mobile phone sensor data (accelerometer and GPS) to determine the conditions of the road. Noise pollution measurement through phones is developed in community scale applications such as EarPhone[27] and SoundOfTheCity.[28] These applications seek to map large areas and label zones according to their noise pollution level. Users of these applications provide their location and noise samples using the mobile phone GPS and microphone, respectively. Disaster management and crime prevention are other examples of domains that benefit from mobile sensing. Particularly, iSafe promises to evaluate the safety of users based on their spatial and temporal dimensions.[29,30]

General-purpose mobile sensing applications

The development of a mobile sensing application from scratch is a task that normally requires considerable time and human resources as well as high technical knowledge. Researchers have previously proposed tools whose purpose is to reduce the effort required to prototype or just use a mobile sensing application. These tools provide preprogrammed and configurable functionalities that help solve common tasks that could be needed in a sensing campaign. Using a configuration interface provided by these platforms, users can establish an expected behavior from the application without having to modify the application's source code. Some of the most relevant configurable mobile sensing applications are described next:

- MyExperience[6] is one of the very first configurable mobile sensing applications. MyExperience implements a comprehensive architecture that supports a fair number of sensors and allows the user to add more. The application can monitor data coming from the sensors and evaluate such data using user-defined conditions and launch actions using triggers. MyExperience also allows users to define their custom actions and has the ability to send the data to a remote repository. MyExperience provides an XML interface to allow researchers with low technological abilities to configure it.
- AndWellness[7] is another configurable mobile sensing application consisting of three main elements: (1) a server to configure studies and store collected data, (2) an Android application to perform the data collection, and (3) a dashboard used to display participants' statistics and data. The Android application mainly executes surveys so that participants can input their data. These surveys can be launched based on a schedule or on events detected using collected data through the phone sensors supported by AndWellness, that is, location traces (GPS) and activity inference (accelerometer).
- Funf[8] is an open-source framework aimed to help developers to create mobile sensing applications by providing libraries that allow us to easily access the sensors of the phone and send the obtained raw data to remote repositories. It also presents an open-source application named "funf journal" that is based on the funf framework, which allows the user to select the data sources (phone sensors) to obtain information and offers several means to export collected data.
- InCense[9] is a configurable mobile sensing application that implements a handful of practical features: a graphic user interface that is used to design the sensing campaign; remote servers that store sensing campaigns and available mobile phones to execute them; an Android client to run the campaign; and a context database server that is used to store the collected data. Similar to the aforementioned tools, Incense's client supports most of the commonplace sensors available on the phones, can evaluate data and execute actions using triggers, save the collected data in local sinks (i.e. phone's storage), and send it to remote repositories. To the best of our knowledge, this is the only tool that addresses on-device data processing using elements known as filters.

Table 1. Comparative analysis of general-purpose mobile sensing applications.

	Feature	MyExperience[6]	AndWellness[7]	Funf[8]	InCense[9]	mHealthDroid[10]	Aware[11]	This work
F1	Dynamic reconfiguration	•	•		•		•	•
F2	User-defined filters or data processing units				•		•	•
F3	Data gathering	•	•	•	•	•	•	•
F4	Remote data transmission	•	•	•	•	•	•	•
F5	Event-based actions	•	•		•	•	•	•
F6	Explicit user data entry	•	•		•		•	•
F7	Provide a set of extensible libraries as a starting point			•		•	•	•
F8	Data processing routines load at runtime							•
F9	Web interface for contributing new data processing routines							•

- mHealthDroid[10] is an open-source framework that akin to funf is aimed at facilitating the rapid and easy development of mobile health and biomedical applications. The framework implements several functionalities to support resource and communication abstraction, biomedical data acquisition, health knowledge extraction, persistent data storage, adaptive visualization, system management, and value-added services such as intelligent alerts, recommendations, and guidelines.
- Aware[11] is an Android-based open-source mobile context instrumentation framework. It provides a client–server mobile framework that supports the collection of unobtrusive passive sensor data. It follows a modular approach: the AWARE client app abstracts the communication with the sensors and the acquisition of data; then, data are used to generate context through customizable code extensions named plugins.

From the researcher's perspective, having a flexible mobile sensing platform that can be used multiple times for different campaigns is ideal. That is, that the platform allows rapid, straightforward configuration for data collection in a new sensing campaign that may have different requirements or else change the configuration of an ongoing campaign, without too much hassle. Although, this may seem trivial, there are a lot of design features that a mobile sensing platform must consider in order to be as flexible as possible.

As shown in the previous works, some of the revised mobile applications are designed to be reconfigured so that users are able to define new data to be collected or new events without rebuilding the mobile sensing application (F1) as well as to support the triggering of actions based on user-defined events (F5), which is important as mobile context is highly variable. Importantly, a key characteristic of these applications is to provide diverse mechanisms to support automatic data collection from mobile phone sensors (F3) and in the form of surveys to obtain user assessments (F6). Mobile sensing applications are also capable of sending these recollected data over the network at pre-defined events (F4); this is highly desirable since some users may be available to collect data manually. In order to extend the functionality of these applications, platforms are being designed to provide users with mechanisms to (1) allow the inclusion of new filters or data processing components to the platform (F2), enable on-device pre-processing or simple classification; and (2) access and modify existing libraries for developing sensing campaigns (F7). All of this is done using a user-friendly Web interface (F9) for researchers who may not have highly specialized technical knowledge and skills. Finally, mobile sensing applications include a means through which data processing routines can be loaded at runtime without redeploying the mobile sensing application (F8); this feature means that new data processing components can be added into the mobile phone without rebuilding the mobile phone application. In Table 1, we present a comparative analysis of the applications discussed earlier in terms of the mentioned key aspects of general-purpose mobile sensing applications.

Limitations of existing mobile sensing tools

As previously mentioned, there are tools designed to work in particular domains, which can hardly be used for different purposes without changing their underlying design. On the contrary, there are other tools that can be reconfigured to be used with different sensing needs. On the latter category, most of the tools

discussed do not support on-device processing but they rather send all the collected raw data to a server for off-line analysis.

However, in many research studies it may be necessary to perform on-device processing. A crucial reason is privacy, as the ability to process data while in the phone helps to avoid tracking the identity of a user (e.g. personal info and voice). Ensuring privacy can in turn increase the levels of user participation in sensing campaigns, as people often refuse participation due to privacy concerns. Another great benefit derived from on-device processing is storage and network resource optimization. Sensors can generate large amounts of data in short time periods, quickly scaling up as the number of participants grows. By processing sensor data on the device, it is possible to obtain relevant features from it, like the activity performed by the user from accelerometer data or significant chunks from an audio signal, which are most frequently needed in scientific studies rather than raw sensor data.

Despite the clear advantages of on-device processing, some problems inherent to it may arise. One issue has to do with the difficulty in abstracting completely the programming of processing routines in such a way that the non-technical researcher or third party may not require deep knowledge about an entire software application. Another problem could be that as time goes by, many processing routines can be added, which would eventually translate into a large application that might consume a considerable amount of device resources (e.g. processing, memory, and storage), thus potentially deterring participants even more. At the same time, this could make it difficult to maintain in terms of software development and application deployment.

Creating data processing routines to obtain meaningful data from the device is not an easy task. If a place existed where third parties could share their work, researchers could benefit by saving time and effort when reusing that work, that is code. Most of the time, customized applications are not shared or made public by their authors and, therefore, other research groups rarely take advantage of them; thus, potentially slowing down progress of the research community.

A proposal for rapid deployment of mobile sensing campaigns

The literature on configurable tools shows a recurrent, conventional approach that drives the design of such type of tool. This conventional approach has three main elements. The first is usually a Desktop client that enables the user to perform the *Sensing campaign design*. It also typically features a *Data visualization* module, either based on a Graphical User Interface (GUI) or commands/functions. The second is the Mobile client (i.e. mobile phone application) in charge of executing the sensing campaign through a *Sensing application*, which in turn stores collected data locally in a *Data repository*. The third is a series of services such as *Data storage* and *Data processing*. This approach is depicted in Figure 1.

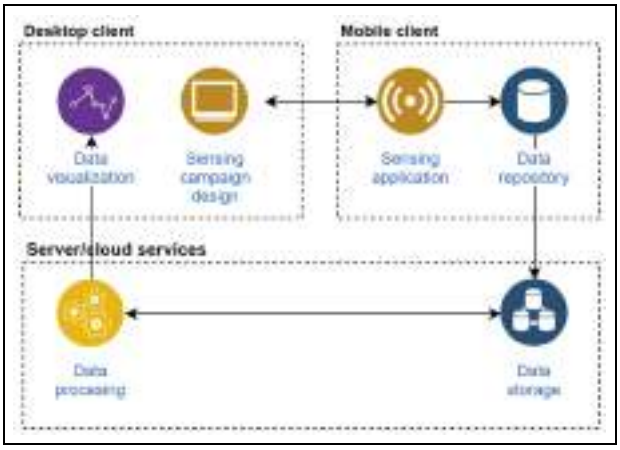

Figure 1. Conventional approach in mobile sensing.

One key disadvantage of this approach is that in order to create an on-device data processing routine, the user needs to deeply understand the mobile client and be able to rebuild it, which typically requires technical knowledge and skills. We propose a modification to this conventional approach that (1) adds an interface for *Component definition*, that is, create new data processing units such as step counter; (2) modifies the *Server/cloud services* so that it supports receiving, storing, searching, and generating components through the *Components API*; and (3) allows modifications in the Mobile client to support downloading and integrating new on-device *Data processing components* at runtime. The proposed component model is shown in Figure 2, which derives from previous works in the area.[9,31]

In particular, the presented proposal abstracts data processing routines and encapsulates them in data processing units called components. Components are written in JSON (JavaScript Object Notation). A component is a fundamental piece that is composed of a series of fields, which describe the component and store the logic to be executed, an expected input, and a defined output. Figure 3 shows the structure of the components, which is depicted as a high-level schema. The component structure is described as follows:

1. *Component Information*. This element was used to group a set of fields that are used to provide information about the component. All these fields will be used as inquiry criteria by a search engine so that other people can be aware of their existence and reuse them:

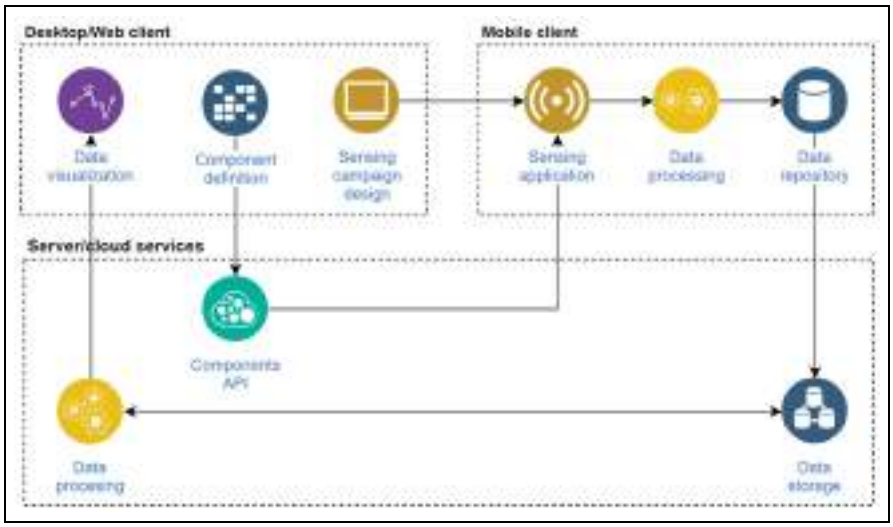

Figure 2. The proposed component-based model.

(a) ID: unique identifier of the component.
(b) Name: tag that suggests what the component is for.
(c) Description: explanation of what and how the component does its tasks. Here, the creator should explain the format of the data that the component requires, the algorithms used for data processing, and the format of the output.
(d) Author: name of the creator.
(e) Author's email: optional field where the email of the author is stored; this field could be used for contact purposes.
(f) Author affiliation: affiliation details of the author.
(g) Energy intake: optional field that describes the approximate battery power consumption of the referred component. It represents the percentage of the battery the component will consume from a fully charged mobile phone until it is completely depleted. It should be noted that this field is rather informative and just an estimation as the value may change among different phones.

2. *Sensor*. This element is used to indicate that the data required by the component come from a logical sensor defined in the platform. The data will be in the format of the output of that sensor. This element can be optional since the data the component will use can be obtained from another component.
(a) ID: identifies the sensor as a unique resource since it can be used by several components.
(b) Name: name of the sensor.
(c) Description: explanation of what the sensor does, what type of data are collected, and their format.
(d) Output data type: complex field where a structured description of the sensor output format is stored. In the InCense platform, users can create custom data types and use them as the output of sensors and input/output of components and other elements of the sensing campaign.

(i) ID: data types are resources that can be reused among campaign elements, thus a unique identifier is assigned to them.
(ii) Name: name providing a general idea of the data type.
(iii) Description: when Data Types are customized such as Socialization Data Type, this includes an explanation of the contents of the data type.
(iv) Fields: represent each of the basic types that will comprise the data type (basic types could be int, char, float, string, etc.). For each field whose type is declared, both name and description should be stated.
(v) Inner types: in case none of the existing basic types complies with what the scientist needs, additional types can be defined within the existing data type and use them as a field. Inner types are declared with a name and a set of inner fields subsequently declared with a type and a name.

(e) Sensor parameters: some of the sensors of the mobile phone can be configured to behave in a certain way. These configuration options vary among sensors (e.g. sampling frequency per second and precision). For each sensor parameter that is defined,

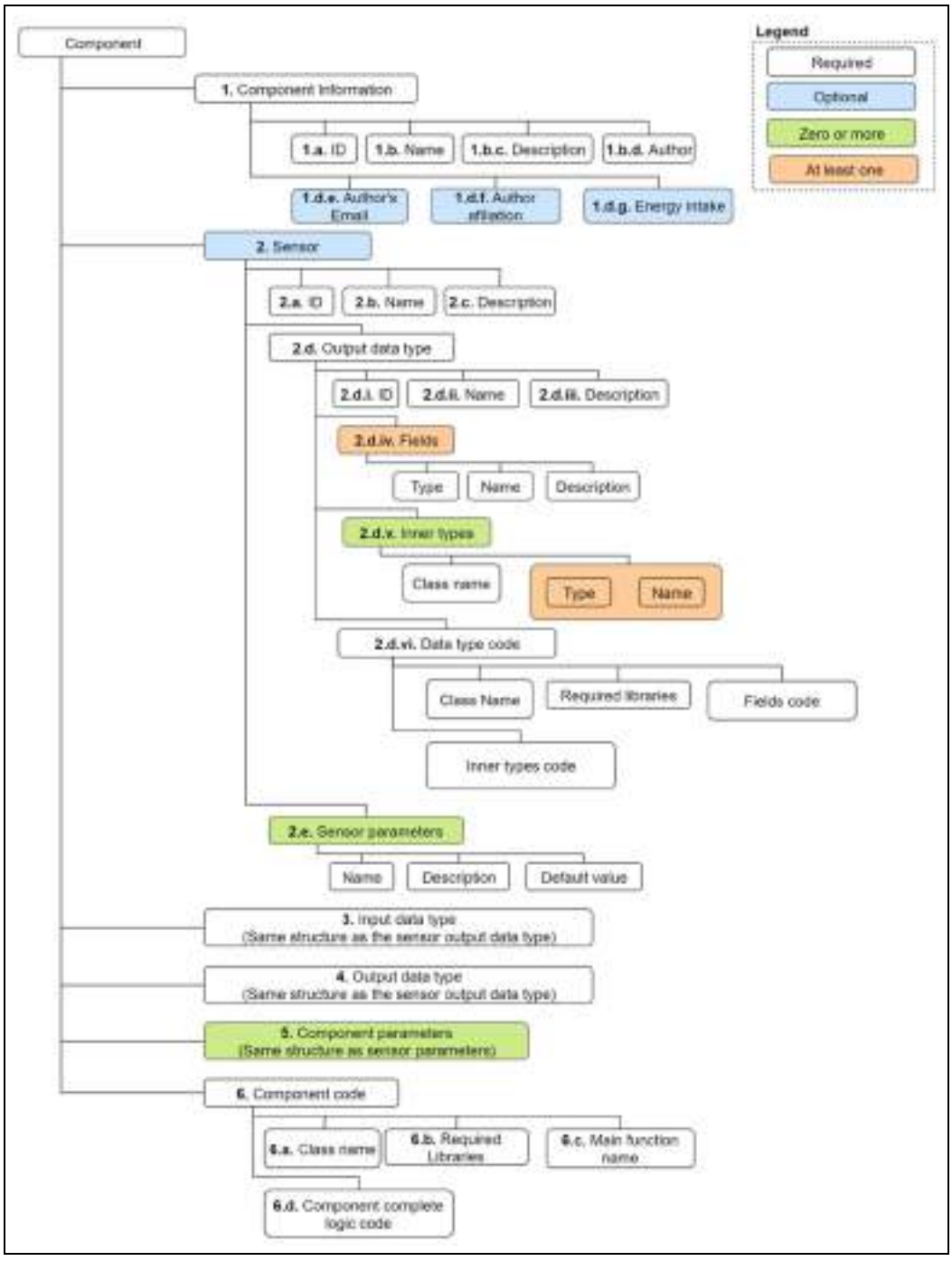

Figure 3. A tree representation of the fields that describe the proposed component schema.

a name needs to be stated that suggests what the parameter is for, a detailed description and possible values within that description, and a default value that would be used in case this parameter is not provided.

3. *Input data type*. This element of the schema uses a defined resource as the one stated in the output data type element of the sensor. It is used to define the data that can be received by the component. For two campaign elements to be compatible, the output data type of the source must be the same data type of the input of the destination.
4. *Output data type*. This element also uses a defined resource as the output data type element

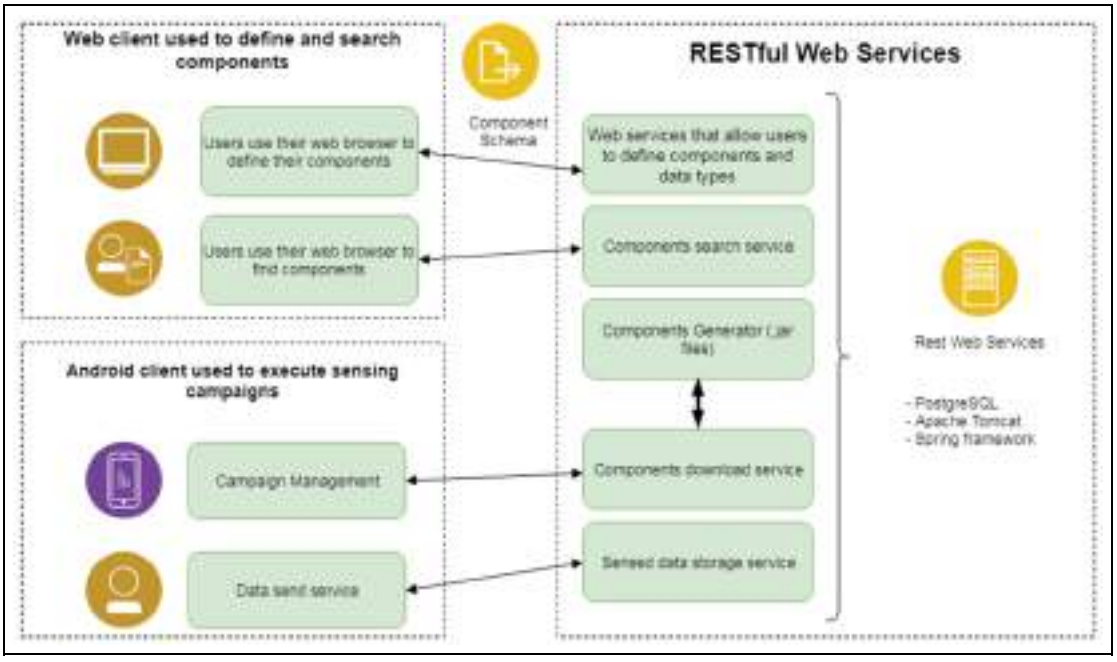

Figure 4. Implementation of the component-based model.

of the sensor, which also defines the output data of the component.

5. *Component parameters*. Components can also be parametrized to customize their behavior just as sensors do (e.g. specify one method to calculate if a person is still or moving, choosing between several options for calculation like fuzzy logic or artificial neural networks). Each parameter must have specified its name, description, and the default value in case nothing is configured.
6. *Component code*. The algorithms that will process the data are defined. All the codes must be created as a java class with all the required functions declared inside the class.
   (a) Class name: stores a suggested name of the class. Since there could be more than one component with the same name, an internally handled name will be used once the component class is integrated with the InCense client.
   (b) Required imports: all the external libraries that are required by the component class must be listed in this field. Available libraries are the ones that exist in the Java and Android SDK.
   (c) Main function name: this is the function that will be called so that the component performs its processing task. This method must receive a parameter of the input data type and return a type of the output data type.
   (d) Component complete logic code: all auxiliary functions, properties, and variables required by this component are declared in this section.
   (e) The creation of components aims to provide a place where researchers can contribute their components by taking advantage of the component schema as a standardized way to define them. Also, by seizing this schema it is possible to develop a service that generates packages that can seamlessly be integrated in the sensing client (i.e. mobile phone sensing application) without the need of updating it each time a new component is defined. All of this without requiring the user to have high technical skills or deep knowledge of the internal functioning of the proposed tool.

Technical implementation of the proposed approach

The proposed component-based model was implemented in the InCense mobile sensing tool using diverse technologies (InCense code repository: https://github.com/incense-platform). We used the PostgreSQL

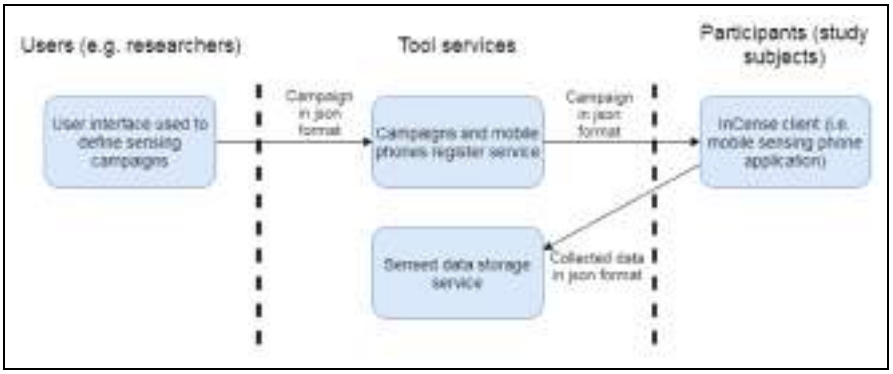

Figure 5. Architectural model of the InCense tool before the implementation of the component-based model.

relational database for storing the information of components since it provides native support for JSON data types. It was also decided to use the REST architectural style[32] implemented with the Spring framework (https://spring.io/) to offer web services (using Apache Tomcat (http://tomcat.apache.org/) as the web server) to define components. Web forms were created and served with Apache Tomcat so that research have an interface that facilitates the definition of components. Figure 4 shows the implementation of the component-based approach. InCense was chosen because it manages on-device data processing by design, we had access to its source code, and we had means to interact with a person who worked directly with its design and development. A representation of the architecture of the InCense tool before the component-based model was implemented is shown in Figure 5.

Web user interface for component development

A web user interface was developed to reduce the need for in-depth knowledge by users about the InCense tool when developing new components (see Figure 6). Still, when adding new components, some Java programming knowledge is needed. This user interface offers web forms to define a component and its elements, namely, sensors and data types (whether input or output). These web forms allow users to fill out the information about the components, the elements that specify the data types that a component utilizes, and the logic/algorithm employed by the component to execute its processing. The logic has to be programmed in Java, since it is the programming language used by the Android operating system (OS), which is the platform on which InCense builds. Developers may consider that libraries from the Android OS and Java Software Development Kit (SDK) will be available for them to use.

The web user interface transforms the data provided by the user with the web form to the component schema (see Figure 3) and sends it to the RESTful web services so that it can be stored in the repository. Figure 7 shows the web form to provide the processing logic of the component. Since components employ user-defined data as their output data, developers must ensure to return the expected data type. As for the input data, components can receive a sensor's output or another component's output. In any case, the function executing the processing must receive the expected input data type.

There is also a web user interface that allows searching components in the repository. This interface prompts for keywords as a search criterion that will be matched against the component description data in order to return relevant components for the user.

Implemented RESTful web services

The web interface utilizes Web services for components to be viewed, defined, and/or searched. Web services are also used by the client (i.e. mobile phone sensing application) in order to request the package that contains the application in bits format, which is compatible with the Android OS and InCense. The operations that the RESTful web services offer are stated below.

1. *Sensor definition*. This is a way to provide the user with information about the sensors that are supported by the InCense client and the data type(s) that these offer. These services offer means to create, update, delete, and list sensors. Since this service is only informative and depends on what is supported by the InCense client, it should be used only by the administrator of InCense. The endpoint for this is in

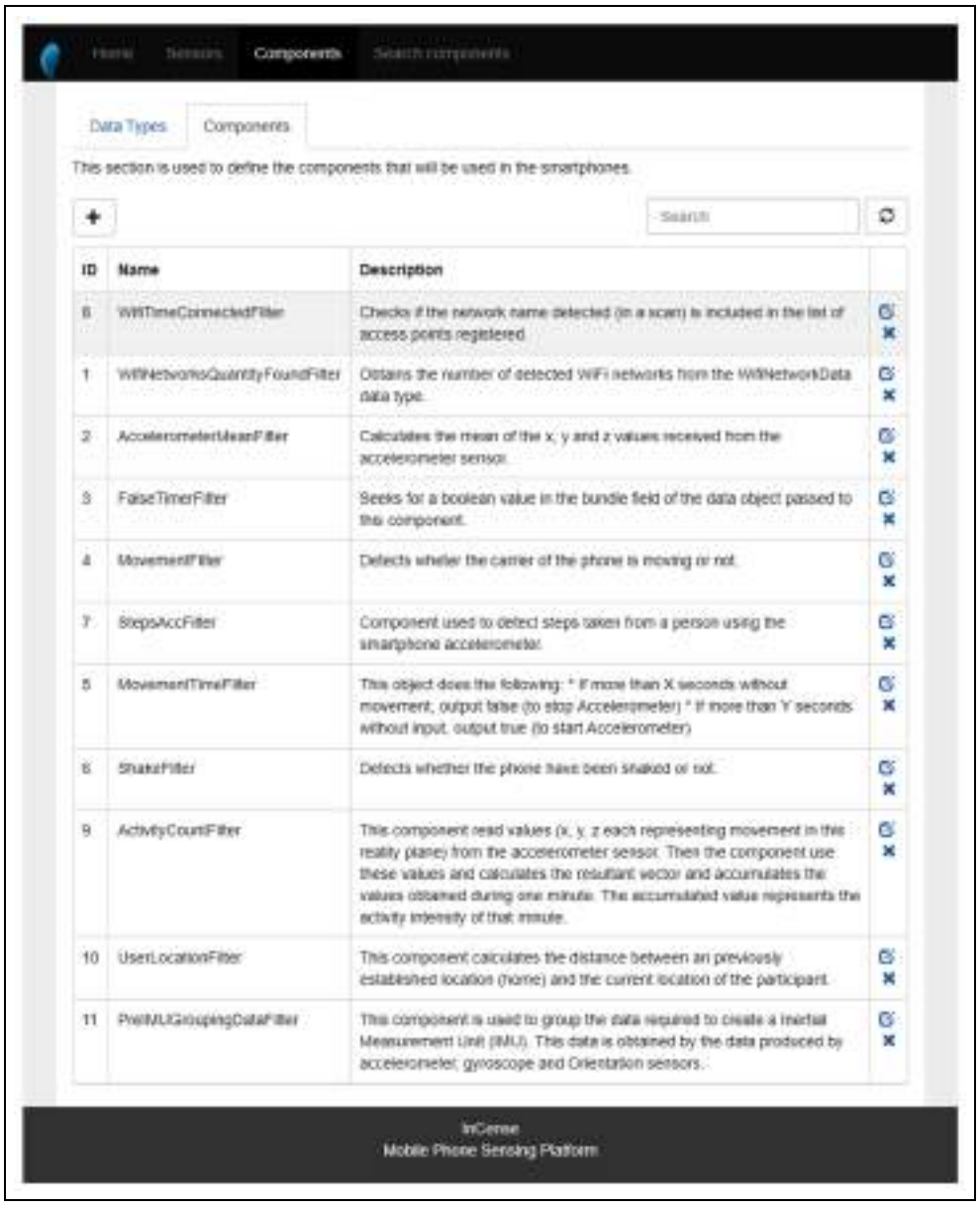

Figure 6. Graphical user interface of the main screen.

`http://InCenseDomain/sensors` with the `POST`, `PUT`, `DELETE`, and `GET` methods implemented for creating, updating, obtaining, removing, and obtaining data regarding the logical sensors implemented. To obtain information related to a particular sensor or remove a particular sensor, the `ID` of the sensor must be included in `http://InCenseDomain/sensors/{id}` via the GET method.

2. *Data types definition*. Data types are necessary for users to establish the structure of the data that go in and out of the component. By knowing the input data type structure, the user knows the data that will be available to the processing. By establishing the output data type, the user can let other users know what is available for them or any other component as a result, that is, after processing. The endpoint for this is in `http://InCenseDomain/datatypes` with the `POST`, `PUT`, `DELETE`, and `GET` methods implemented for creating, updating, obtaining, removing, and obtaining data regarding the logical data types implemented. To obtain information related to a particular data type or remove a particular data type, the `ID` of the data type must be included in `http://InCenseDomain/datatypes/{id}` via the `GET` method.

Figure 7. Web form provided to users for component definition.

3. *Components definition*. These RESTful services allow users to define their components, that is, create, update, delete, or list components. The received web requests will be persisted in the database. In every allowed operation, the component schema is used to reflect what the component is all about and what it does. The endpoint for this is in `http://InCenseDomain/components` with the `POST`, `PUT`, `DELETE`, and `GET` methods implemented for creating, updating, obtaining, removing, and obtaining data regarding the components implemented. To obtain information related to a particular component or remove a particular component, the `ID` of the component must be included in `http://InCenseDomain/components/{id}` via the `GET` method.
4. *Search service*. This service receives one or more keywords that are used as a search criterion that match one or more fields of the component description fields. The service returns a list of all the components that matched the search criteria. This is mainly useful to find one or more components that can be reused or used as a basis for new components.
5. *Components download service*. This service allows downloading a component in *.jar* format containing the component. This is primarily used by the client so that it can seamlessly obtain a component and hot plug it into the app at runtime. The endpoint is in http://InCenseDomain/componentgenerator/{componentID} with the GET method.

Extended InCense mobile client

The client (i.e. the sensing mobile phone application) of InCense was extended so that it could effortlessly integrate the proposed model. As mentioned, the client is capable of interacting with the *component download service* and downloading the required components stated by the sensing campaign. Then, the client can integrate such components into the mobile phone application at runtime, thus only using the components that are needed for the campaign. This can be relevant if there are resource-deprived devices participating in the campaign. This seamless integration is executed automatically by the mobile phone application, thus the user or the participant does not need to intervene in any way. This functionality avoids redeployment of the application (e.g. rebuild and install on the phone) and use only what is needed on demand.

Model implemented in InCense

As a result of the model implementation, now the InCense tool has a new interface for users to manage components and provide services that allow defining, searching, and downloading components. Also, the mobile phone client uses those services in order to provide on-device processing by using only what is needed when is needed. Figure 8 shows the outline of the InCense architecture with the component-based model implemented.

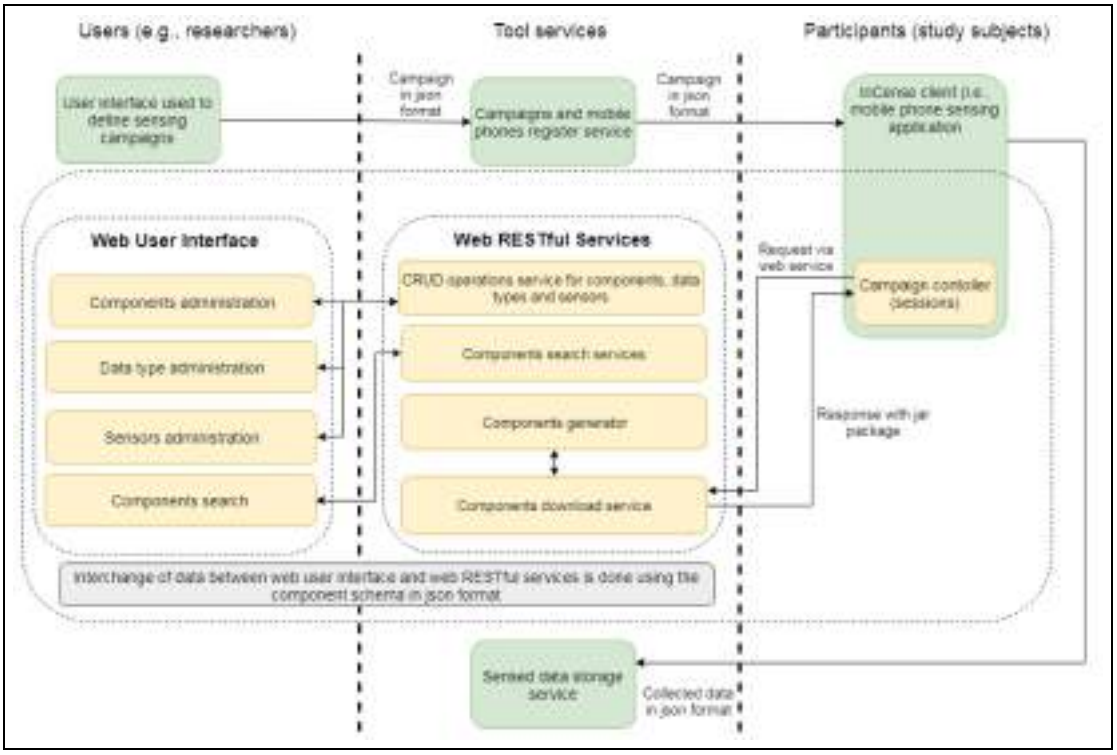

Figure 8. InCense tool with the component-based model implemented.

Evaluation

We performed an evaluation mainly aimed at determining whether there is a significant improvement in terms of user effectiveness (i.e. new data processing components work correctly) and user efficiency (i.e. they can be developed in a short time) in the definition of components. We do so by contrasting the development of components using the proposed component-based model versus the conventional approach (i.e. making modifications directly in the source code).

Participants

We invited 24 software engineering students in their fourth year who were mainly Java developers but were unfamiliar with the InCense source code. Sixteen of them accepted the invitation. The 16 participants were randomly allocated in two groups: a control group (CG) and an experimental group (EG). Four persons of the CG did not attend to all the sessions of the experiment. All participants ranged between 21 and 25 years old, with an average age of 22 years. No incentive was given to any of the participants.

Procedure and description of task

Our participants were invited to participate in five sessions at a university laboratory equipped with Integrated Development Environments (IDEs) and all tools needed for development. During the first session, depending on the group, a presentation was provided about InCense, in which we described the motivation for such a tool, the architecture, the organization of modules, web services implemented, structures of data types, and filter structures. Also, we provided a brief description of the study's purpose and the expected deliverables. Afterward, questions from participants were answered. We also provided each participant with a three-page cheat sheet containing that information. No formal technical documentation was provided.

We asked participants to develop a new component to compute the distance of the user's current location and a fixed point (e.g. home). This component was inspired on the concept of an individual's life space,[33] which basically classifies an individual based on the mobility of the user within an urban area. We provided the formula for computing the distance using math notation and JavaScript source code. We also showed participants an alternate method they could utilize using the Android's `Location` class and the `distanceBetween` method. In any case, the inputs and the type of outputs required were also provided. We also provided the names of the deliverables: component's name for the EG, and class name for the CG. We proposed this particular task (see Pseudocode 1) as it turns to be feasible, technically not challenging, and

Pseudocode 1 User's location component

```
Set value of the homeLongitude variable to -109.44483164
Set the value of the homeLatitude variable to 27.06568788
Function to read the homeLongitude value
Function to set the value of homeLongitude
Function to read the homeLatitude value
Function to set the value of homeLatitude
Functioncalculate Location (GPS location data as input) {
    Compute distance between two locations (homeLatitude,
      homeLongitude, and GPS location data)
    Return the distance results
}
```

GPS: global positioning system.

above all simple enough so that we can derive results from the approach used rather than the task itself.

Hypotheses and variables

Our independent and dependent variables were as follows:

- Independent variable
  - The method used to develop the task: the use of the conventional approach versus the proposed component-based approach.
- Dependent variables
  - User efficiency: the time used to complete the task, that is, completion time.
  - User effectiveness: the developed component behaves as expected, that is, does it work as it should?
  - Ease of use: participants' perception regarding the ease of use of the approach.
  - Usefulness: participants' perception regarding usefulness of the approach.

Our main hypotheses were as follows:

- H1: More participants will be able to complete the task with the component-based approach than with the conventional approach.
- H2: Participants will be able to complete the task in less time with the component-based approach than with the conventional approach.
- H3: Ratings about ease of use will be higher in participants who used the component-based approach than with the conventional approach
- H4: Ratings about usefulness will be higher in participants who used the component-based approach than with the conventional approach

Experimental design

The participants were randomly allocated in two groups (between-groups design) with the purpose of comparing the effectiveness and efficiency. The same task was assigned to both groups. All participants were assigned a PC for the duration of the experiment. We asked participants from the CG to complete this task utilizing the source code of InCense with the Eclipse IDE, a tool they were familiar with. That is, the members of the CG were asked to write the code from the new component and integrate it into the source code of InCense, and thus they had to get familiar with the source code of the platform before adding lines of code. On the contrary, the EG had to complete the task utilizing the web user interface of the implementation of the proposed approach in this work. The EG used no IDE. Both groups received an introductory presentation about InCense and its purpose.

We allocated participants 10 h to complete the task, divided into 5 days (2 h per session). After completing the task or the time was over, they were asked to answer a survey based on the Technology Acceptance Model (TAM).[34] This instrument consists of 12 items grouped into two constructs: one for evaluating the participants' perceived usefulness and another for evaluating the participants' perceived ease of use. The use of the TAM for evaluating user perception on potential future usage is commonplace in interactive systems. Although it may not be enough for certain application domains, it is convenient when evaluating systems that are difficult, expensive, or complex to evaluate in real working applications. In this case, comparing the actual use of both approaches in a real working sensing campaign can be difficult as it would need several research groups using and implementing new components.

The instrument featured assertions about either tool used, for example, "Using InCense could enable to create components rapidly." The answers to such items were 7-point Likert-type scale (1 = extremely likely, 7 = extremely unlikely), thus answers closer to 1 were better for the purpose of this study.

Evaluation results

We excluded from the analysis all data related to the four participants from the control group who did not attend the five allocated sessions. CG in average utilized 8.75 h (standard deviation (SD) = 2.50), whereas the EG completed the task in 4.81 h (SD = 0.96). The difference between the mean values was 3.56 h, which was statistically significant ($t = 3.040$, $df = 3.452$, $p = 0.047$; see Figure 9(a)).

Table 2. Participants' answers to the TAM instrument (1 = best, 7 = worst).

Participant's code	Time (hours)	Complete task?	Working component?	Usefulness items						Ease of use items					
				1	2	3	4	5	6	7	8	9	10	11	12
Control group—CG (*N* = 4)															
sm03	10	No	No	2	3	3	2	2	2	3	3	3	3	2	3
sm06	5	No	No	2	2	2	4	2	4	4	4	5	5	2	2
sm07	10	No	No	3	2	2	3	4	2	4	6	4	4	3	3
sm08	10	No	No	3	2	2	2	3	3	3	3	3	3	2	4
Mean	8.8	No = 4, Yes = 0	No = 4, Yes = 0	2.5	2.3	2.3	2.8	2.8	2.8	3.5	4.0	3.8	3.8	2.3	3.0
Experimental group—EG (*N* = 8)															
cm01	4	Yes	Yes	2	2	2	3	2	2	4	2	2	2	1	3
cm02	5.5	Yes	Yes	1	2	2	1	1	1	1	2	2	2	2	1
cm03	5.5	Yes	No	2	1	3	3	4	1	1	2	1	1	2	1
cm04	5.5	Yes	Yes	2	1	2	2	1	2	2	2	1	2	1	1
cm05	5.5	Yes	No	2	3	2	3	1	1	1	3	1	2	3	1
cm06	3.5	Yes	Yes	2	2	1	4	1	1	3	4	2	2	3	2
cm07	5.5	Yes	No	2	2	1	2	2	1	3	2	2	2	1	2
cm09	3.5	Yes	Yes	1	1	1	1	1	1	3	3	3	2	2	3
Mean	4.8	No = 0, Yes = 8	No = 3, Yes = 5	1.8	1.8	1.8	2.4	1.6	1.3	2.3	2.5	1.8	1.9	1.9	1.8

TAM: Technology Acceptance Model.

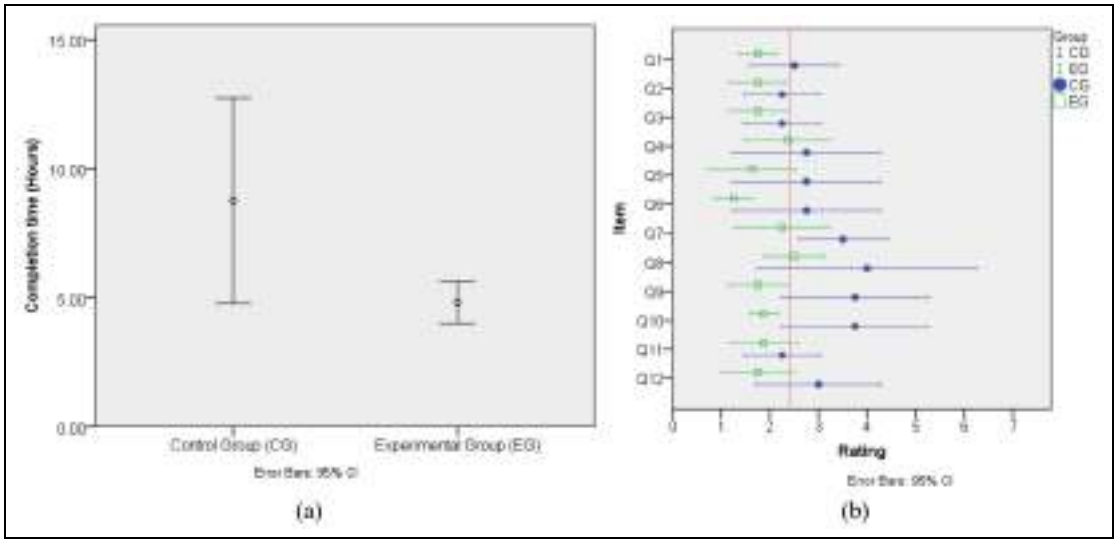

Figure 9. Comparison between the CG and EG in terms of (a) completion time and (b) developers' ratings in terms of Usefulness and Ease of use (vertical line = overall mean rating).

None of the participants from the CG finished the assigned task. A chi-square analysis between the groups and the effectiveness showed that the members of the CG were statistically more effective ($\chi^2(1) = 12.0$, $p = 0.001$), meaning that there is a strong link between the group participants belonged to and their effectiveness.

On the contrary, all EG participants reported having completed the task and invested in average 4.8 h (SD = 0.96) to complete it. From the eight participants of the EG, five (62%) completed a fully functional component whereas three (38%) participants completed a component that did not work correctly. There was a common error from all three participants who did not yield a working component: they provided the parameters in the wrong order to the function that calculates the distance.

As for the TAM survey (see Table 2 and Figure 9(b)), the CG participants had an average perception rating of usefulness of 2.5, which could indicate that utilizing the source code can be useful, whereas for the EG the mean rating was 1.6. Regarding the ease of use perception, CG participants had also an average rating of 3.4, whereas for the EG it was 2.29. These results suggest that the use of the implementation of the component-based model might be easier and more efficient than its conventional counterpart.

Limitations of the evaluation

Some of the limitations of this study design are as follows. First, as the study lasted for five successive days, the activities carried out by participants between sessions were not controlled, that is, some students could have discussed the problems with others or look for information online. Second, we did not provide a documentation of the source code in either approach (conventional and component-based approach). Finally, this type of study designs can benefit from larger sample sizes.

Conclusion and future work

In this work, we proposed a mobile sensing approach through the use of customized processing routines called components. By using the proposed approach, we aim to reduce the learning curve of users, particularly non-STEM, to implement new components, promote code reusability, and improve software maintenance and deployment.

The implementation of the component-based approach is composed of three main elements: (1) a web user interface to define components; (2) RESTful web services that support the web user interface, which allows generating and downloading components into the mobile phones; and (3) an extended mobile phone sensing application that leverages on the RESTful web services to utilize components on demand and on runtime in a transparent fashion to the user.

A usage and acceptance evaluation was performed, where participants were asked to perform a task regarding the creation of a component and asked them for their perception. This latter evaluation showed that the proposed approach could be more effective and

efficient than the conventional approach for deploying sensing campaigns. Future work in this regard includes not only analyzing the participants' perceptions toward the tool but also the quality of the source code generated.

There are several desirable features that may improve this work: (1) thus far, the component schema only considers one data type as input, hence having a component that supports several data types as input could be a feature that helps data processing; and (2) context-aware components could help saving resources (e.g. storage, battery, and processing), in other words, performing the processing of data only in designated places (e.g. home), or taking into account variable device resources such as battery. Finally, future work includes testing this platform in real working sensing campaigns to better understand how this platform can serve the needs of researchers in this area.

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