Advances in Intelligent Systems and Computing 1307

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Advances and Applications in Computer Science, Electronics and Industrial Engineering

Proceedings of CSEI 2020

Springer

Advances in Intelligent Systems and Computing

Volume 1307

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ISSN 2194-5357 ISSN 2194-5365 (electronic)
Advances in Intelligent Systems and Computing
ISBN 978-981-33-4564-5 ISBN 978-981-33-4565-2 (eBook)
https://doi.org/10.1007/978-981-33-4565-2

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

This book contains a selection of papers accepted for presentation and discussion at the 2020 International Conference on Computer Science, Electronics and Industrial Engineering (CSEI 2020). This Conference had the support of AISTI (Iberian Association for Information Systems and Technologies/Associação Ibérica de Sistemas e Tecnologias de Informação), and the Technical University of Ambato. It took place at Ambato, Tungurahua, Ecuador, October 26–30, 2020.

The International Conference on Computer Science, Electronics and Industrial Engineering (CSEI 2020) is a global forum for researchers and practitioners to present and discuss recent results and innovations, current trends, professional experiences, and challenges of modern Information Systems and Technologies research, the technological developments, and industrial applications. One of its main aims is to strengthen the drive toward a holistic symbiosis between academy, society, and industry.

CSEI 2020 is built on the successes of the First CSEI 2019, held in Ambato, Ecuador. The Program Committee of CSEI 2020 was composed of a multidisciplinary group of more than 100 experts in different areas such as Information Systems, Electronics, and Industrial Engineering. They have had the responsibility for evaluating, in a "blind review" process, the papers received for each of the main themes proposed for the Conference: (A) Computer Science, (B) Electronics, and (C) Industrial Engineering.

We are honored to invite 6 experts to give the impressive and excellent keynote speeches: Prof. Ruxandra Stoean from University of Craiova, Romania; Dr. Joshua Emele, from Loon Project, EE.UU; Prof. Bruno Domenech from Universitat Politècnica de Catalunya, Spain; Prof. Guillermo Carpintero del-Barrio from Carlos III University, Spain and Prof. Fernando Gont, from Universidad Tecnológica Nacional/Facultad Regional Haedo, Argentina, Prof. Manuel Ignacio Ayala Chauvin from Universidad Tecnológica Indoamérica, Ecuador.

CSEI 2020 was a successful, fruitful online academic event. Received about 120 contributions from 10 countries around the world. The program included keynote speeches, oral presentations, and discussions covering a wide range of subjects from computers system, electric engineering to industrial engineering. The 18

papers accepted for presentation and discussion at the Conference are published by Springer (this book) in one volume and will be submitted for indexing by ISI, EI Compendex, Scopus, DBLP, and/or Google Scholar, among others.

Thanks to the authors for their valuable contributions and to the attendees for their active participation. We would like to express our gratitude to the reviewers, who provided constructive criticism and stimulating comments and suggestions to the authors. We are grateful to the conference chair, co-chairs, and host, and all members of the technical program committee for their valuable time and advice. We are also grateful to the internationally renowned scientists who acted as keynote speakers at the conference. We would like to thank the organizers who made this conference yet another unforgettable experience.

Bilbao, Spain — Marcelo V. García
Ambato, Ecuador — Félix Fernández-Peña
Ambato, Ecuador — Carlos Gordón-Gallegos
October 2020

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About the Editors

Marcelo V. García, Ph.D. (Scopus ID: 56597269000, Web of Science Researcher ID: J-3195-2019) studied electronics and instrumentation engineering Electronics and Instrumentation Engineering at the University of the Armed Forces-ESPE Forces ESPE. In 2013, he obtained his Master's Degree in Control, Automation, and Robotics Engineering, and in 2018, he obtained his doctorate at the University of the Basque Country (UPV/EHU). His studies were carried out thanks to a grant from the Ecuadorian government. From 2008 to 2013, he worked as an engineer in different companies in the area of oil and gas in Ecuador such as Schlumberger, Petrobras, and Petroamazonas EP. His research interest is focused on the design of next-generation architectures based on Industry 4.0 in various domains such as automation and smart manufacturing.

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Carlos Gordón-Gallegos, Ph.D. (Scopus ID: 56419359600) He, received his Electronics Engineering and the M.Sc. degree in Networks and Telecommunications from the Technical University of Ambato (UTA) Ecuador in 2005 and 2010, respectively. He joined the Department of Optoelectronics and Laser Technology, Universidad Carlos III de Madrid, UC3M, Madrid, Spain, in 2012, and he received Ph.D. degree in Electrical, Electronics and Automation Engineering in 2016, under the supervision of Prof. Guillermo Carpintero del Barrio. He has written more than

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Topical Part: Industrial Engineering

A Prototype Electronic Toy for the Development of Mathematical Logical Reasoning in Children from Five to Seven Years Old Using Python

Francisco Jurado, Diego Donoso, Erika Escobar, Tannia Mayorga, and Alla Bilous

Abstract The technological advance and the great importance that it represents when using Information and Communication Technologies (ICT) as a tool in the educational process allows us to search for strategies to take advantage of the benefits that can be achieved by involving these advances in initial education, in this sense, the development of an electronic device that uses different elements such as readers and labels with Radio Frequency Identification (RF-ID) technology, a sensor to identify colors, a Raspberry Pi minicomputer, LCD screen, among others, are presented, together with the development of strategies and didactics that allow the device made as an electronic toy to an element to help stimulate logical thinking in children between the ages of five and seven, given the already showed importance that early strengthening of abilities such as identifying, relating and operate different types of situations that allow people to function in society in real situations.

Keywords RF-ID · Sensor · Logical · Technology · Children

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M. V. García et al. (eds.), *Advances and Applications in Computer Science, Electronics and Industrial Engineering*, Advances in Intelligent Systems and Computing 1307,
https://doi.org/10.1007/978-981-33-4565-2_1

1 Introduction

The advance that technology and its use as a learning support tool are clear in the development of applications and devices available today. This significant advance has generated important changes in the learning process. This intimate relationship developed between learning and ICT is evidenced, for example, in the way children identify with video games, perhaps for the quality of the graphic environment, the multimedia characteristics, or other factors that make these environments capture their attention; that is why the cognitive area has to be stimulated correctly using all kinds of tools, including technological ones [19].

The main objective of this project is the development of an electronic device that has the characteristics of a toy. This device can be used as a teaching tool that based on some basic concepts of mathematics, presents exercises to the user so that through play reason the solution to the different approaches, for this different objects are used that when combined with some electronic components such as RF-ID readers and tags, color sensors among others allow generating interactivity.

The use of mathematics as part of this project arises from the importance that it has shown for the formation of people because they streamline reasoning and merge the teaching of the other disciplines. In this way, individuals make deductions during the different activities carried out in society when they apply to real situations. The development of logical thinking requires the design of activities where aspects such as the properties of objects, the organization of information, the relationships, diagrams, charts, and diagrams are all considered focused on creating content to perform in activities that for children should be simple, interesting and above all entertaining [2, 4, 14].

The technological means used to develop tools that help in learning must allow the communication of its contents to be effective, and the interaction with the user must be simple to facilitate learning, in terms of the technology used for learning, for children as Poole mentions it should allow the stimulation of sight, hearing, touch, and mind by combining multimedia [5, 16].

Regardless of the technology used, as mentioned by Salguero [20], the most important thing should be to play, due to the importance it has at the educational level in children, it allows them to discover the qualities of objects, make comparisons, build knowledge, and above all, it helps children to relate to others.

In this same sense, Rodríguez mentions that the game, being a way of interacting with reality, is typical of childhood, is universal, and leaves a mark on people because it leaves a psychological framework that gives meaning and evolves with age by reflecting the moments when a relationship is generated between the world and the individual [12].

This project aims to develop a tool that allows children to improve some skills through the use of critical thinking, since as Rivas mentions [18], in this way, it contributes to the formation of the habit of using this kind of thinking in all areas of life without leaving aside creativity and observation.

2 Background Literature

Taking into account that the current generation has developed in a world where technology is present, in almost all human activity, learning when technology seeks to be of great value must allow students to test their skills by making interaction more visual, personalized, and above all, focused on solving a problem [13].

There are several studies focused on highlighting the importance of play in child development as highlighted by Baste [9], who analyzes the experience of several researchers who agree that the selection of a suitable game generate great benefits, especially when it takes the advantages attributed to the game, and those associated with the serious work, in this sense, a game that can become a satisfying, relaxing activity and capable of producing fun, may also require effort, use of memory, among other characteristics that allow the generation of learning that can be conceptual, procedural, and of attitudes.

In this sense, the work carried out by Hofer [11], who highlights the importance of ICT together with logical-mathematical development for children to learn mathematics, for which she developed, an interactive game using PowerPoint, this game, she exposes shapes, colors, and sizes to apply the learning of logical-mathematical, which is very important when it is incorporated from an early age. In this way, the development of the training, the application, and the instrumentation functions make children understand and know their environment.

Also, it is possible to highlight the work of Hidalgo [10], who mentions the importance of logical-mathematical to express the result of reasoning in a clear and organized way. To do this, he presents the introduction to logic, through the approach of a system of strategies, taking into account the importance of mathematical language in the different modes of action that a person can have, hence the importance of linking logical-mathematical intelligence. with the different abilities and strengths that can be detected, and worked with children to enhance the intelligence associated with, for example, problem-solving, pattern detection, understanding the cause and effect of an event, the ability to abstract, and even critical thinking.

Regarding technological applications that serve as a tool for the stimulation of mathematical thinking, the project presented by Vázquez [1] also stands out, who developed a video game that can be used by preschool children to take advantage of the advantages that they can provide physical activity and a video game in between when they support the stimulation of mathematical thinking through mini-games in a classroom.

In this sense, the work of Carrera [6] also stands out, who implemented educational video games that allow the learning of mathematics through a qualitative approach, obtaining as a result that it is possible to capture and sustain the student's attention with this type of digital resources. In this case, applied video games are of great help because children are interested in playing while they are learning due to the characteristics of this type of software that allows them to capture the student's attention.

There is also literature on works focused on a certain group of students, such as that of Tangarife [7], who in his work presents an application designed to facilitate the teaching of basic operations of Mathematics to people with Down's Syndrome, the results obtained with the use of the application mention that there is a positive effect and it contributes with learning. However, he considers the application like a tool to support the teaching process as a contribution to the playful component, which allows the learner to consolidate their knowledge in a fun way without the help of a tutor. Likewise, the results of this study show that as it is frequently practiced in the application, greater skill and knowledge are obtained, which allows increasing the level of abstraction in solving problems.

The different works that are related to the cited documents allow demonstrating the importance of incorporating technological tools to the development of logical thinking in children, even more so if these tools can be incorporated in the first stages of learning. In this way, it is possible to contribute to the development of cognitive skills through logical-mathematical reasoning, for this, the technology must adapt to the needs of children, and that it does not cause adverse effects.

3 Materials and Methods

3.1 Design

A systematic review of the documentation on the characteristics of the activities used to develop the logical reasoning to associate them with the operation of the proposed device was carried out.

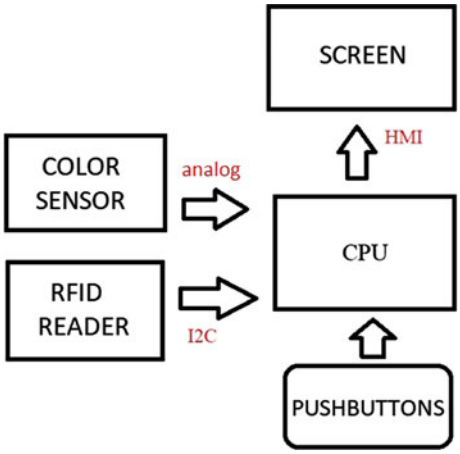
3.2 Search Strategy

To define the characteristics of the activities to be carried out on the electronic device, scientific articles were searched using online databases such as ScienceDirect, Scielo, and Google Scholar.

3.3 Inclusion and Exclusion Criteria

The systematic review of all types of documents published in scientific databases had as inclusion criteria the electronic devices used in the development of logical reasoning for children between five and seven years of age, while the main exclusion criteria were the tools that do not use technology for its operation.

Fig. 1 Connection diagram



4 Development of the Electronic Toy as a Tool for Logical Reasoning

The developed electronic device comprises a minicomputer such as the Raspberry Pi, a graphic interface through a screen of the type Thin Film Transistor—Liquid Crystal TFTDisplay (-LCD) for the development of the exercises, as input elements are It has a color sensor, an RF-ID tag reader and several push buttons (see Fig. 1).

For the interaction with the child, there is a 3.5-inch TFT screen that is equivalent to 480 × 320 pixels, where the menus and the games will be shown, this will present four options to solve the proposed exercise, except for the game with numbers which requires all number symbols from 1 to 10 presenting more options to find the correct answer. The Fig. 2 shows the diagram of the math game menu, this scheme is similar to the menu for the geometric shapes, and color comparison games, this selection scheme that appears on the touch screen is associated with the buttons installed on the device, allowing the selection of options can also be made from these elements.

4.1 Logical Reasoning Games

Games that use a methodological strategy for learning produce great value due to their characteristics, one of them is being suitable for the first levels of child development, this is the reason why various mathematicians, psychologists, and educators have developed and experimented with logic games for children. These games are classified according to two criteria that are applied in the development of the proposed device.

The first criterion is related to the attributes here, there are games of differences and similarities that have been developed, of denial among others, then there is

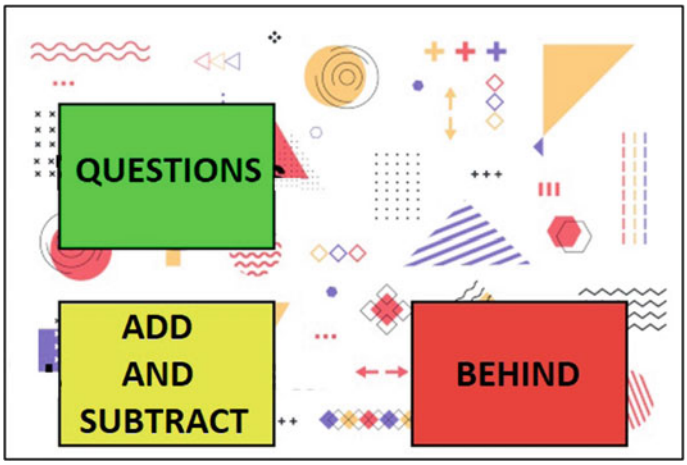


Fig. 2 Math game menu

the criterion related to the material to be used, there are games that use logical blocks, polygonal blocks, cards with objects between others, there are also games with graphic materials that use cards with drawings, sheets with diagrams and others, there are also games that use symbolic material like cards with attributes, cards with mathematical expressions, and verbal propositions that allow establishing values of true and false, finally, there are the logic and number games [21].

For the development of the proposed device, the characteristics of logical reasoning games were taken as a basis, using electronic elements such as peripherals of the Raspberry Pi which contains the program developed in Python to achieve the interaction of the device and children during the development of the different activities proposed.

4.1.1 Games for Learning Two Basic Mathematical Operations (Addition and Subtraction)

For this section called mathematics, different games related to the operation of addition and subtraction will be designed, these games use the Technology of Radio Frequency Identification (RF-ID) with cards that represent numbers. This section has two activities, the first activity called Questions require the child to perform a mental operation of addition or subtraction to answer the question raised, the second activity presents images that must be counted by the child. Showing up next shows an example of the math game that will appear on the screen of the device (see Fig. 3).

These games were developed by taking into account what was mentioned by De Ribosa and Durán [17], many studies show that math games help in cognitive learning, because they support children in the development of their guesses, without the fear of making mistakes, besides providing a basis for mathematical learning.

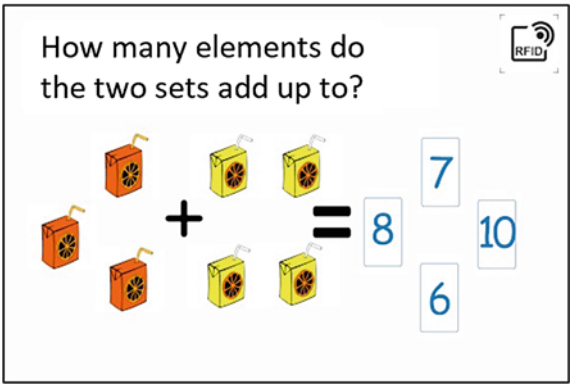


Fig. 3 Game of addition and subtraction

In this same sense, Ferrándiz et al. [8] mention that adequate stimulation at an early age will favor the development of mathematical and logical intelligence, which will allow children to introduce these skills into their daily lives, for this the stimulation must accord to the age and characteristics of the little ones, respecting their rhythm, it must be fun, meaningful, and equipped with reinforcements to make it pleasant.

4.1.2 Geometric Shapes Games

Block-based educational games as presented by Arias [3], positively influence children to recognize different characteristics of the elements such as shapes, sizes, colors, among others, allowing the construction of sets and finding different elements, these games influence mental dexterity by making children able to recognize diverse patterns.

For the design of this class of games, this device uses the recognition of geometric figures, for this, mini RF-ID tags placed on geometric figures were used, so that children must recognize when displayed on the screen (see Fig. 4).

A selection game was also implemented using colored buttons for the child to analyze and choose the correct answer asked (see Fig. 5).

4.1.3 Association Games

These games were developed by the importance that has memorization-based learning, as Caiza et al. mentioned [15], this form of learning is the simplest because it is based on the memorization of information, but, learning is representative when new information like concepts, relationships, among others, as a result of the analysis because they are assimilated and last better.

In this game, the child needs to identify objects according to color and sound, for this purpose, several objects of the same color are displayed on the screen, and

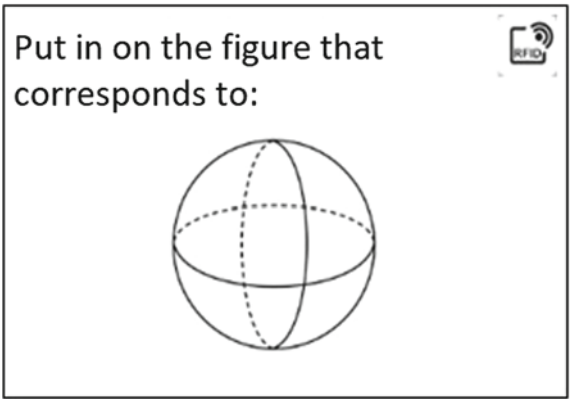


Fig. 4 Set of geometric figures

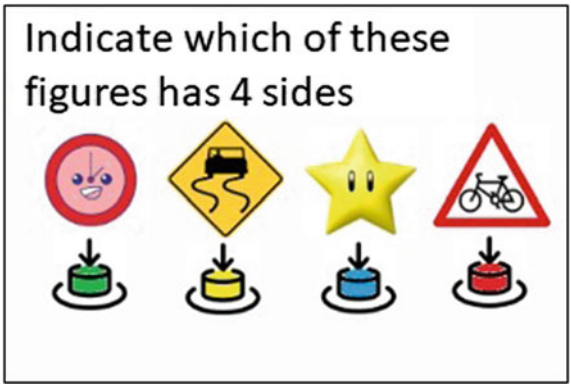


Fig. 5 Selection game

a sound corresponding to the object will be played, an example of this exercise is shown in the Fig. 6, in which it is required to identify a bird, in this way, the child must relate the color of the object and the sound to solve the exercise.

4.2 Electronic Toy Design

Using the Fritzing software, the diagram of the connections is made, in this is showing how the different elements used to the construction of the electronic toy are connected, as it can be seen almost all Raspberry GP-IO (general-purpose input/output) ports are busy, most of these ports connect the TFT screen with the Raspberry Pi, additional, the connections of the buttons and LED's are directly interconnected to the controller.

The RF-ID reader module uses four connections for the GND, VCC, SCL, and SDA pins. For the operation of the color sensor, it needs five connections for the VCC, GND, Signal, S2, and S3 pins, for this element the S2 and S3 pins are configured so that the output of this sensor works in the frequency of 20 kHz (see Fig. 7).

Fig. 6 Color matching game

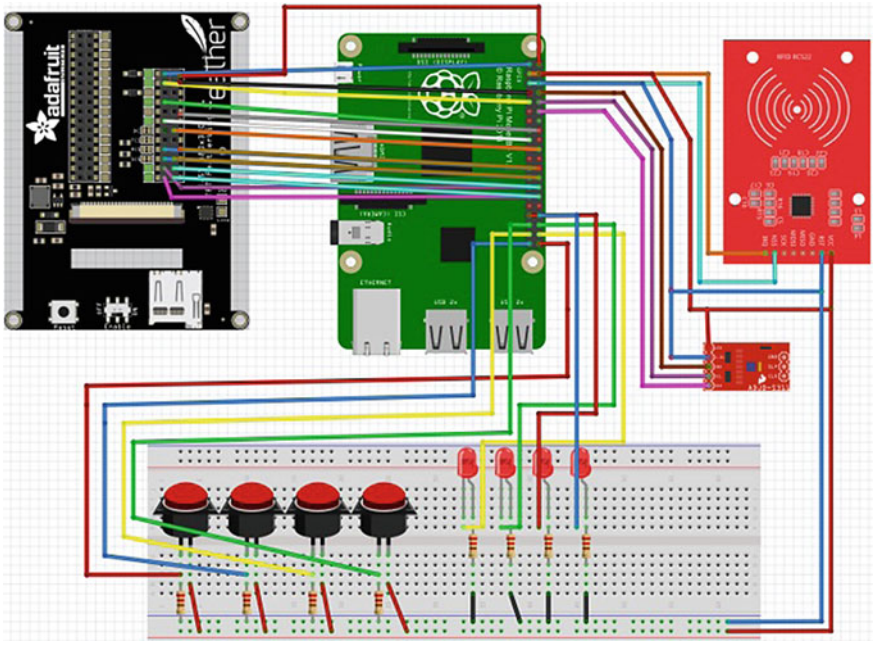


Fig. 7 Color matching game

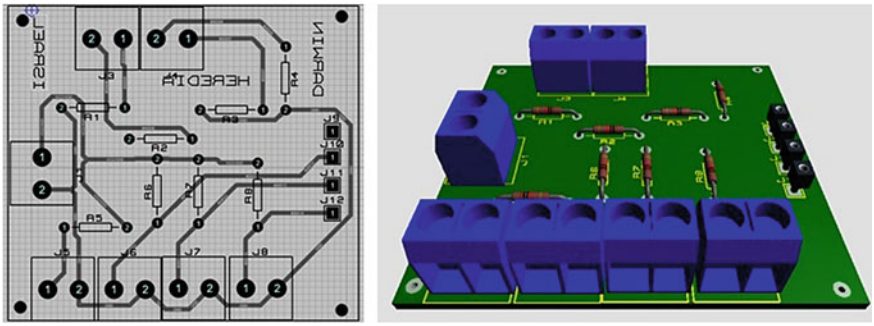


Fig. 8 PCB board

4.2.1 PCB Design for Buttons and LED's

The PCB board has two VCC, and GND power outputs from the Raspberry Pi, for the connection of buttons the resistors were configured in Pull Up to maintain a logical state of one always to the controller's GP-IO input. Lastly, they are made the connections of the protection resistors of the LED's that through terminals will be connected to the Raspberry controller. The Raspberry pi has 3.3 V and 5-volt output pins, due to precautions in the use of GP-IO ports, it was decided to use the 3.3 V outputs to supply the circuit with the buttons and the color sensor that can support between 3 and 5 V.

To the final design of the PCB board, the Proteus Ares software was used, which allows showing the final location of the resistors and the terminals that will allow the connection of the buttons and LED's. In total, there are eight terminals, eight resistors, and four connection pins for the signal input when a button is activated (see Fig. 8).

4.2.2 Device Programming

As mentioned earlier, the programming was carried out in the Python program, for which the corresponding flow diagram (see Fig. 9), it presents the operation logic of the device, generally, when it starts automatically, it shows the game presentation screen. Then the main menu will appear, here it is possible to choose from among the three exercises created, of mathematics where the main objective is the use of numerical reasoning, that of shapes to identify different types of geometric figures and that of colors to identify an object according to certain characteristics.

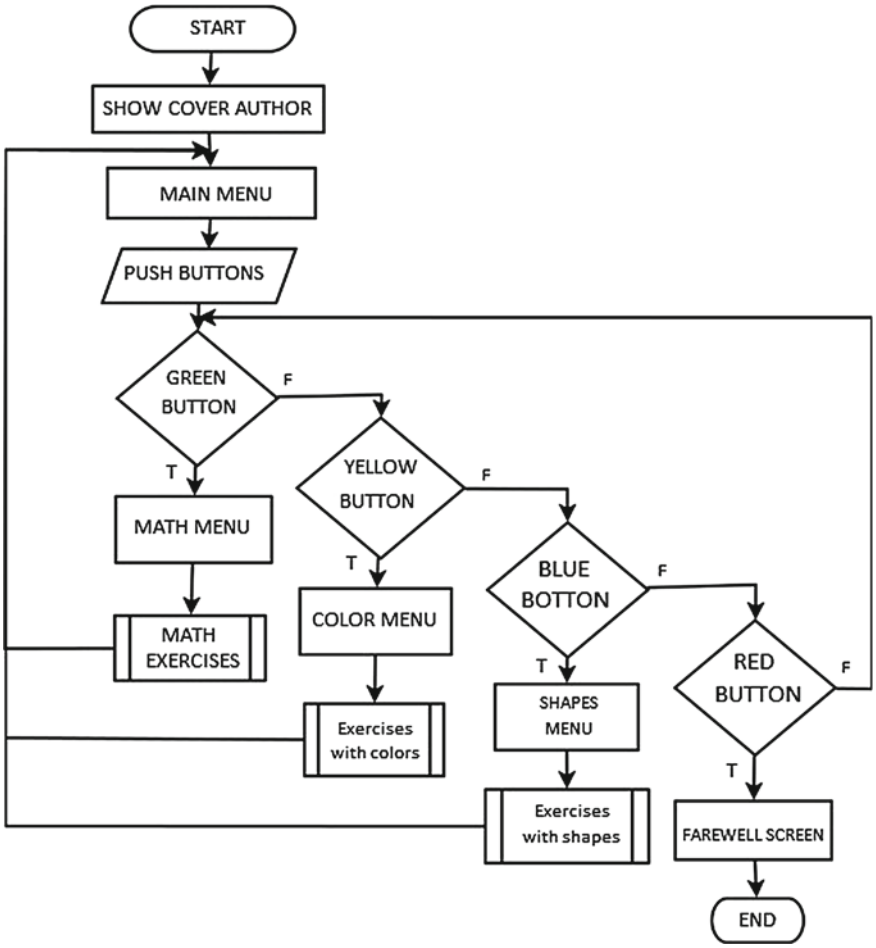


Fig. 9 General flow diagram

To the proposed exercises, there are three forms to solve it, the first using buttons, the second with RF-ID tags, and the last using the color sensor, the figure shows the example of the math game's operating logic (see Fig. 10), this has two kinds of exercises, the first one for questions and the second one for numbers. The first option has different problems to solve by pressing the button with the correct answer, while the exercise with numbers will use the RF-ID cards corresponding to each number, according to the problem, the card corresponding to the response to the RF-ID reader should be approached. This logic also applies to figure exercises.

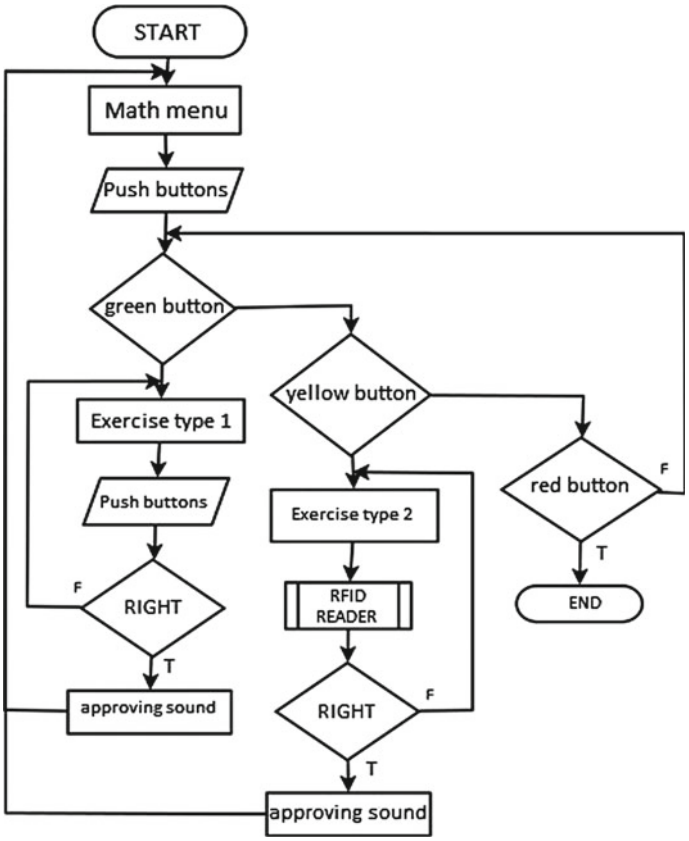


Fig. 10 Math exercises flow chart

4.2.3 End Device

For the elaboration of the structure of the prototype, MDF wood is used as a material whose shape similar to that of a video juices machine to be built in this material is presented in the see Fig. 11, the structure has the screen perpendicular to the child, It has buttons with the same color as the options that appear on the touch screen. The color sensor and the RF-ID reader will be placed under the buttons, when they are required to be used to prevent objects from approaching the screen as a precaution, they will also be placed separately to avoid interference during operation, thus facilitating the interaction between the toy and the child.

Fig. 11 Structure design

5 Performance Tests and Results Analysis

Once the assembly of all the components of the prototype was completed, including the details, so that they could capture the attention of a child before using it, the operation of each element that will allow interaction with the children was first verified, these results are shown in Table 1.

The tests carried out on each element determine the correct operation of each one according to the parameters set out in the design, with this validation, it is possible to use the prototype to assess the level of difficulty of the exercises created.

The following general test consists of the use of the device and the solution of the exercises proposed by children, given the limitation presented worldwide by the

Table 1 Operation of device elements

Element	YES	NO
LED lighting according to the color of the menu	X	
Using the program options with the buttons	X	
Using the program options from the touch screen	X	
Detection of Tags and RF-ID cards	X	
RF-ID sensor response with different exercises	X	
Color sensor response with different exercises	X	

Table 2 Usage tests

Functionality	YES	NO
The device is eye-catching for the child	X	
The exercises seem very simples	X	
Exercises are interesting	X	
Using the device is easy	X	
Solving exercises require help	X	

COVID-19, the results obtained correspond only to 10 children, so the result of its usefulness once this health crisis is overcome, these results will be presented in a future article as feedback that allows developing a general idea about the positive characteristics and possible improvements not only of the exercises proposed, but also of the operation of the device. The following Table 2 gives a summary of these results.

With the results obtained, in general, the developed prototype presents positive characteristics such as capturing children's attention, the level of difficulty tests, their reasoning capacity, and generates an activity that involves the adults who are responsible for the child.

6 Conclusions

As a result of the implementation of this research project, the following conclusions are reached.

For the programming of the different games to be developed in the prototype, the Python language was developed because it is simple, flexible, has many tools that help to focus on the development of the programming and not on the details, making modifications such as increasing the games to the device without this requiring new programming.

The use of different electronic elements such as the RF-ID reader, sensors, display screen, and RF-ID cards allowed creating an easy-to-use project, that allows being a tool to help in the development of logical and mathematical thinking, this was evidenced by the children who were part of the functional tests of the device.

The elaborated device met the goal of being used as an electronic toy by being striking and fun as showed by the children who used it by showing interest in solving math problems and object recognition since the different electronic elements were used playful way for children in solving problems of mathematical, logical reasoning.

The elaborated program allows the combination of different mathematical logic exercises, such as multiple-choice questions with addition and subtraction, spatial

reasoning with the objects of geometric figures, the reasoning of fraction problems, comparison of colors that contribute to the development of the child's logical reasoning using the prototype.

For the importance of the interaction betwesen a child and their parents, the device was developed so that the activities are not carried out autonomously by the child, but require the participation of their parents because these types of activities contribute to the emotional development of the child.

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Reconfigurable Manufacturing System Based on the Holonic Paradigm for the Die-Cutting Process in a Sports Shoes Company

Kevin Alvarez and John Reyes

Abstract The present research proposes a holonic architecture for reconfigurable manufacturing system based on ADACOR. The architecture is controlled as an intelligent system, centralized when the process is in a normal state and decentralized through holons in the presence of disturbances. Holarchy is defined with two main holons, supervisor and routing, that are responsible for distributing the jobs based on the operating states of the system. Experimentation starts from a base scenario in which conditions are optimal and the architecture is tested through a simulation model in FlexSim, conventional and holonic control scenarios are defined with partial and total server failures. The results allow to demonstrate the successful application of the model in the footwear industry. Holonic control with partial failure increases throughput by +1.66%, decreases WIP by −3.17%, and increases machine utilization by +1.38% compared to conventional control. In total failure, similar results are achieved with +0.68%, −0.68%, and +0.62%, respectively.

Keywords Reconfigurability · Self-organization · Holonic · Intelligent systems · Flexibility

1 Introduction

Manufacturing, as the wealth creation sector of an economy, plays a key role in the overall growth of countries [15, 20]. The Ecuadorian footwear industry is constantly growing; however, in order to reach out to the world's major producers and compete in international markets it is necessary to develop production strategies and efficient production systems [1].

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M. V. García et al. (eds.), *Advances and Applications in Computer Science, Electronics and Industrial Engineering*, Advances in Intelligent Systems and Computing 1307,
https://doi.org/10.1007/978-981-33-4565-2_2

Nowadays, the global economy is complicated and unpredictable. The manufacturing industry is under tremendous pressure from the buyers' market, ranging from fluctuations in product demand to product diversity. Customized production has become the trend [9, 19]. In the twentieth century, manufacturing companies faced two problems, i.e., unexpected market changes and introduction of new products. So to stay in the global competition, manufacturing companies started making reconfigurations in existing manufacturing system at different levels, i.e., machine level, material handling level, layout level, process planning level, and so on [4, 28].

The introduction of new product families and variants requires the production system to adjust its capacity by addition of production and material handling resources, and new product introduction may require rapid rearrangement of production and material handling resources and the increase in demand for a product requires the capacity to be increased incrementally [5, 24].

Traditional manufacturing approaches are not fulfilling the requirements of unpredictable market changes in terms of big fluctuations in the demand of product as well as the change in desired functionality [15]. In Dedicated Manufacturing System (DMS) product variety is less and product volume is very high [28], whereas Flexible Manufacturing System (FMS) may be defined as a highly automated group technology machine cell consisting of a group of processing work stations interconnected by an automated material handling and storage system and controlled by a distributed computer system [18]. Nevertheless, FMS are expensive, and thus are usually not a practical option for large manufacturing systems [8].

In recent times, Reconfigurable Manufacturing System (RMS) has been acknowledged as the most promising solution to these challenges [10, 13, 15]. According to a National Research Council study [7], the RMS has been identified as a top priority for future manufacturing model research and is considered one of the six major challenges faced by manufacturing enterprises in the year 2020. RMS enables building a "live" factory that can quickly and cost effectively respond to the changing customer needs [8].

In the competitive industrial environment, it is imperative that production systems be controlled optimally [30] and it is hard to handle using only centralized optimization methods, since they have a high response time and do not provide autonomous and dynamic behavior [2]. So Holonic Control Architectures (HCA) have proven well suited to implement highly reconfigurable and robust control in RMS [14]. For the last 20 years, HCA have been widely studied and developed. This constant flow of information spread by and available for all the actors opens many opportunities to enhance the behavior of the whole process, as in the case of a production system with the perspective to adjust the behavior of the shop floor in real time due to abnormal conditions or changes [6].

While automation can achieve higher throughput, improved quality, and reduced labor costs, it often also results in decreased versatility, large initial costs, and unemployment. Otherwise a Holonic Manufacturing System (HMS) implies a highly distributed organization of the manufacturing system, where control is distributed over the individual entities increased versatility [17]. These systems are built using some autonomous structures called "holons"; these are able to work under the control of

others, as well as independent of others. Which means that if a manufacturing unit (holon) fails or cannot respond to some problems, other holons create a reconfiguration of operations in order to avoid large disorders [27].

HMS and RMS are complementary to achieve a good performance in the production system, especially since today's market is customer centric (e.g., original decorative art, footwear, or car accessory produced by additive manufacturing) where customer desires customized product with low cost, high quality and that too with short lead times. The challenge is to produce individualized products at a reasonable cost, so the middle class can afford them, and consequently individualized products will be manufactured in large quantities for the benefit of society [8].

The goal of this research is to design an RMS based on the holonic paradigm named H-RMS. The current performance of the manufacturing system is determined and proposes the characteristics of the Adaptive Holonic Control Architecture (ADACOR) [16] so that the self-organization of the process during unexpected disturbances is carried out through pheromone-like mechanisms such as ant hive. The intelligent distribution of order jobs allows the improvement of the whole performance system.

The rest of the paper is organized as follows: Sect. 2 begins with a brief synopsis of the principles applied in this study followed by a description of the methodology used. Section 3 describes the system architecture, modeling process, and presents the simulation tool applied to a case study. Section 4 shows the discussion of the results. Finally, Sect. 5 rounds up the paper with the conclusions.

2 Materials and Methods

2.1 Intelligent Manufacturing System

Artificial intelligence, robotics, Internet of Things (IoT), autonomous vehicles, 3D Printing, big data, Machine to Machine (M2M), Cyber Physical System (CPS), sensors, mobile computing, and so on are giving the manufacturing industries a new look to develop smart factories [11, 23]. Recent trends like Industry 4.0 is assuring in a new era of decentralized industrial production system and process. It is completely restructuring the production processes. These smart technologies could make work flow, machine, and product smarter to interact with each other independently. These changes are fundamental to the success of future RMS [28].

RMS being coined as a system "designed for rapid adjustment of production capacity and functionality, in response to new circumstances, by rearrangement or change of its components" [25]. RMS is a manufacturing system, which has "exactly the production resources needed, exactly when needed" [8].

A modern tendency in control theory has been seeking toward "miniaturization", "decentralization", and "intellectualization" in systems of very many interacting autonomous agents having social, technical, or informational nature [22]. Intelligent manufacturing system can utilize decision-making capabilities of computers and

Table 1 Holon classes

Characteristic	Description
Product	Representing the products available in the factory plant catalog and the process flow
Task	Responsible for managing the real-time execution of production orders on the shop floor
Operational	Representing the system resources. The operational holons manage the agenda of the resources, i.e., the planned list of work orders that the manufacturing resources have to execute over the time
Supervisor	Responsible for introducing optimization into the system

there have been numerous examples: Multi-agent system [29], Genetic Algorithm [26], and HMS [6].

2.2 ADACOR

The ADACOR adaptive holonic architecture intends to combine the best practices of hierarchical and heterarchical control approaches, being as decentralized as possible and as centralized as necessary, i.e., using a centralized approach when the objective is optimization, and a more heterarchical approach in the presence of unexpected events and modifications [3].

A holon, as devised by Koestler [12], is an identifiable part of a (manufacturing) system that has a unique identity, yet is made up of sub-ordinate parts and in turn is part of a larger whole [16]. Complementary an HMS is a paradigm that translates the concepts of living organisms and social organizations to the manufacturing world [3]. ADACOR holons are of the plug and produce type, being possible to add a new element without the need to re-initialize and re-program the system, thus allowing high flexibility in system adaptation and re-configuration [16]. It can represent a physical or logical activity, such as a robot, a machine, an order, or even a human operator [17]. ADACOR architecture defines four manufacturing holon classes as shown in Table 1.

2.3 Research Background

The investigation of the project is carried out in an important company of the Ecuadorian footwear industry due to the complexity of its production systems. The die-cutting process is responsible for cutting the pieces that make up sports shoes. Production begins once the day's schedule is sent, with which work orders are prepared for each process and distributed to workers in two work shifts.

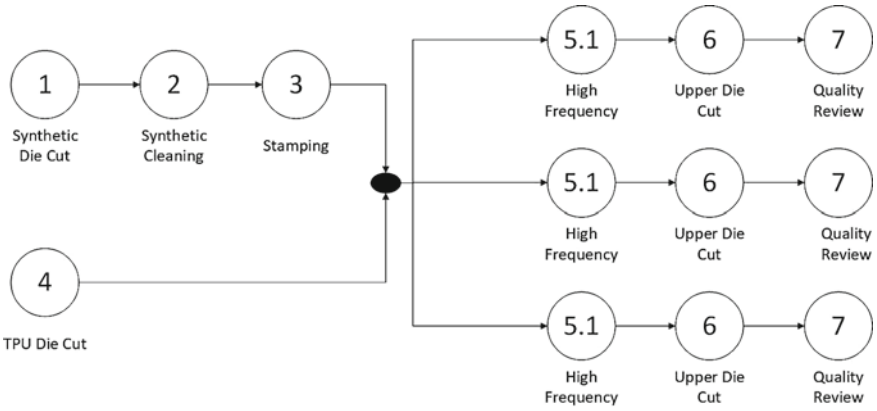

Fig. 1 Assembly diagram

Sports shoes as the main feature must be striking, which requires a more complex process flow, techniques such as stamping or high frequency that is needed to be implemented. In this context, Fig. 1 shows the assembly diagram investigated in this project.

The process starts in parallel with the die-cut of synthetic and TPU (polyur-ethane) and continues with the stamping. There are three resources for the high-frequency process for this research which are called servers. Finally, the upper die-cutting and quality review are carried out.

2.4 Probability Distributions for Process Times

For data collection, 30 samples of each of the 7 processes are taken at different times of the day. The variability that exists in the process time data is identified in this research, so a statistical analysis of the probability distributions that best represent these data is carried out.

We use the distribution-fitting software named ExpertFit 2019 that will automatically and accurately determine which probability distribution best represents the data set.

The steps are the same for all processes, so the analysis of the first process is shown. The data is entered into ExpertFit and 32 eligible distributions are obtained through automated fitting. The software calculates the relative score of each one and orders them from highest to lowest, in this case the distribution with the best fit of 98.39 is Johnson Bounded.

To complement the analysis, a graphical comparison of the real data (blue bar on Fig. 2) and the data of the probability distribution (red line on Fig. 2) is made. The

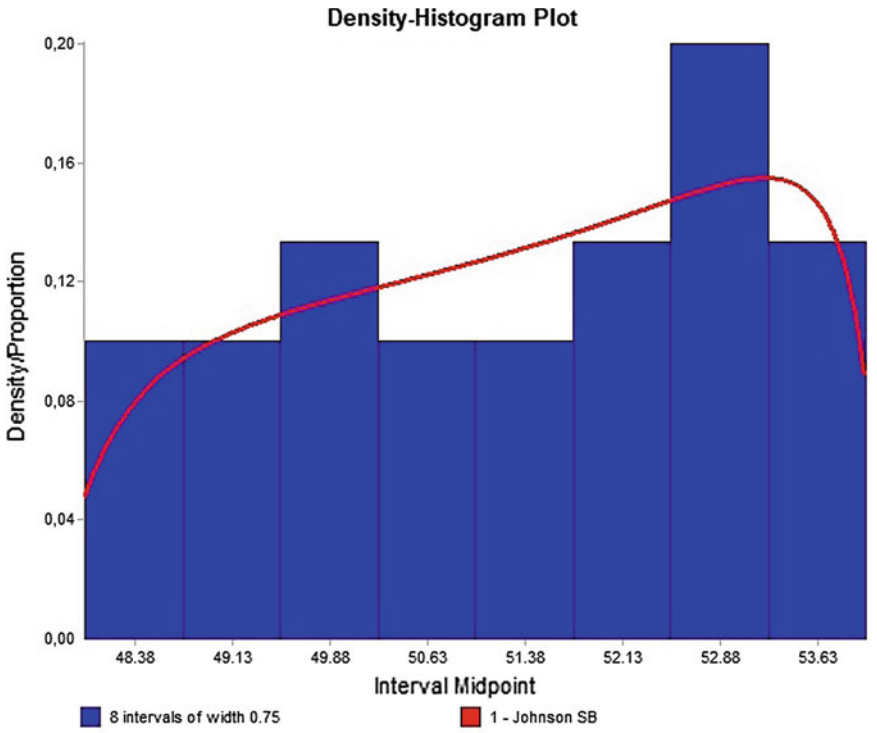

Fig. 2 Probability distribution adjustment from ExpertFit

closeness of the density function to the histogram visually confirms the quality of the Johnson Bounded representation.

The software automatically calculates the representative values of the probability distribution and even locates them in the form of a code for entering FlexSim as indicated in Table 2. For processes 1, 2, 3, 5, and 7, the Johnson Bounded distribution contains a threshold parameter and a scale parameter. The two shape parameters for the Johnson Bounded distribution are called gamma and delta.

For process 4, the Beta distribution contains lower endpoint 23,9; upper endpoint 28,5; shape 1 of 1,2; and shape 2 of 6,6. For process 6, the Weibull distribution contains location 53,1, scale or alfa of 1,6 and shape or beta of 8,4 that means the data has a left-skewed curve.

Table 2 Probability distributions and parameters from ExpertFit

Process	Distribution
1	Johnsonbounded (47.710345, 54.165108, −0.217169, 0.695390)
2	Johnsonbounded (5.694251, 5.819827, 0.334539, 0.795730)
3	Johnsonbounded (21.011593, 21.406689, 0.695854, 1.002483)
4	Beta (23.997244, 28.519174, 1.218161, 6.626747)
5	Johnsonbounded (96.502048, 97.940534, 0.303219, 0.920731)
6	Weibull (53.156971, 1.656830, 8.488930)
7	Johnsonbounded (61.504329, 71.863338, 0.036299, 0.473419)

Table 3 Experimentation scenarios

Scenario	Control type	Failure type	Order job distribution
0	Conventional	No fault	Equiprobable
1	Conventional	Partial	Equiprobable
2	H-RMS	Partial	Work in process (WIP)
3	Conventional	Total	Equiprobable
4	H-RMS	Total	Work in process (WIP)

2.5 Experimentation Procedure

The research aims to demonstrate that heterarchical or decentralized control of processes in the presence of disturbances achieves better results than hierarchical or centralized control.

FlexSim software version 2019 is used as a support tool for the validation of process behavior under different scenarios. The experimentation methodology begins with the definition of the process to simulate, definition of the holarchy and in order to evaluate performance metrics of the conventional control with respect to the proposed control H-RMS, the comparison in the scenarios detailed in Table 3 is defined as experimentation. In all scenarios, server 1 is considered for the simulation of failures, the rest of the servers are not considered as the results are the same. Physically, in each scenario there is only one operator in each process and when a failure occurs the idle worker is not involved in the system.

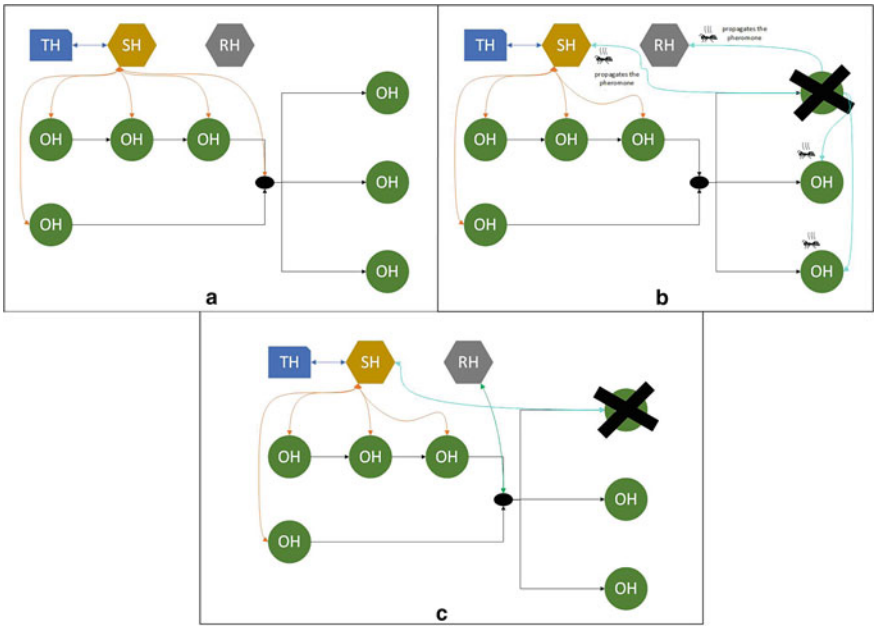

Fig. 3 **a** Process in normal state, **b** Failure propagation, **c** Process in failure state

3 Case Study

3.1 Proposed Architecture

An RMS with a holonic approach called H-RMS is proposed. The architecture of the control system is dynamic, that is, it is re-organized according to the operational state of the system as in ADACOR. When the process is in a normal state Fig. 3a, the architecture is hierarchical and there is only one decisional entity (SH) that controls the process, production rates are maintained and there is no failure.

In this research, two types of failure are analyzed; the first case is considered to a total machine stop where the production rate is zero and the second case is considered a partial failure where the production rate decreases by half. Once a failure occurs on the server (see Fig. 3b), it begins the process of propagating the failure through pheromone-like mechanisms; that is, the server (OH) issues an alert with an intensity level according to the type of failure to the other servers in the same group and to the SH and RH control holons that act in the process and becomes a heterarchical architecture. When the process is in a fault state the RH holon takes control of routing and intelligently distributes orders job (see Fig. 3c). The routing dynamic is explained more detailed later in this paper.

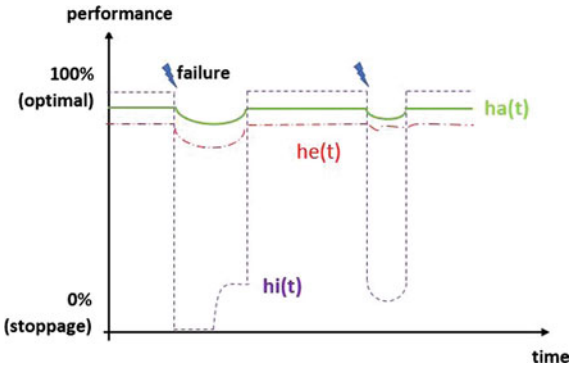

Fig. 4 Hierarchical and heterarchical performance levels [3]

By combining the characteristics of holonic manufacturing he(t) with the optimization of the performance of traditional manufacturing systems hi(t) using H-RMS, the performances of Fig. 4 are obtained.

Under normal conditions, the conventional hierarchical control hi(t) obtains better results: hi(t) > he(t).

In the presence of system failures, the hierarchical control he(t) obtains better results: he(t) > hi(t).

The combination of the types of control achieves an architecture ha(t) with the best of both approaches: ha(t) > he(t) > hi(t).

3.2 Definition of Holarchy

The holarchy in this research is derived from ADACOR with its four types of holons: product, order, resource, and supervisor who are in charge of planning, orders job, machines, and production control, respectively. In the particular case of H-RMS, the resource holon is called the server holon [21] and the supervisory holon is disaggregated into two independent entities called the controller holon and the routing holon. The main characteristics of these holons are described as well:

- Controller Holon (SH): take control of production rates of server holons.
- Server Holon (OH): represents the physical and logical part of a high-frequency machine, this holon issues a pheromone-type alert (more intense when the fault is greater) and informs its operational status to the routing holon.
- Routing Holon (RH): represents the routing dynamics within the system, goes from conventional control to intelligent control depending on the operating state of the server holon.

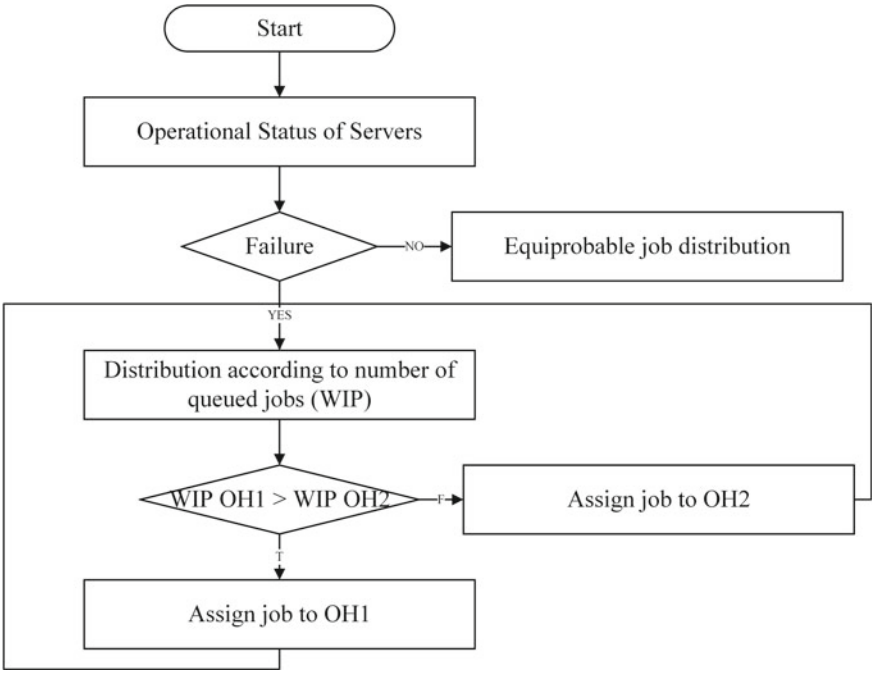

Fig. 5 Order job routing

3.3 Routing Dynamics

Routing dynamics represents the way orders job are distributed within the process from hierarchical architecture to transformation into heterarchical architecture. Configuration in H-RMS is done by system availability, a measure that allows the system to reconfigure itself when a failure occurs; that is, when the process operates without disturbances, there is full availability of all servers, so the distribution of orders job is equiprobable. When a failure appears on any server, the distribution of jobs is assigned based on the WIP of each one, the queued jobs are compared and assigned to the lowest value (see Fig. 5).

3.4 Modeling

The input variables of the simulation model are the times of each activity that are defined according to Table 2, and the arrival of raw material is assumed to be constant. The work shift is considered 8 h or 28800 s. The output variables of interest are the throughput—output rate of products from each server, WIP—average number of jobs in process, and utilization—percentage of time that the server is processing.

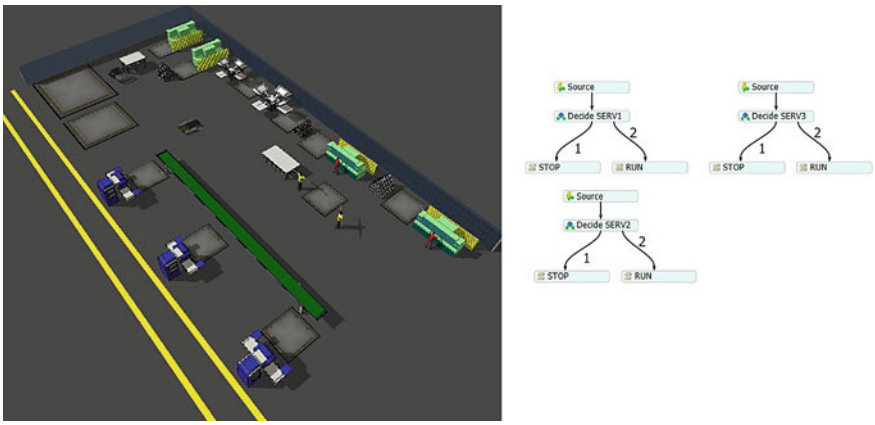

Fig. 6 Screenshot of H-RMS process and process flow from FlexSim

Fig. 7 Screenshot of H-RMS dashboard and user interface from FlexSim

The control system developed in FlexSim is divided into four sections. Figure 6 shows section process that is modeled through the software object libraries and section process flow uses to control the failures of servers. Figure 7 shows section dashboard that links the results of each server to the output variables that are defined and section user interface that allows you to manipulate the operational state of the server: active or in failure.

The holarchy is modeled according to Fig. 8. The servers report their operational status to the routing holon and controller holon who validate the failure mode and, if so, execute the control commands; thus, the controller holon yields the distribution decisions to the routing holon which changes the programming logic and assigns jobs to the servers according to "shortest queue if available" of FlexSim. In this case, it is required that the servers additionally report the WIP for the respective comparisons and that the intelligent distribution by number of jobs in process works properly.

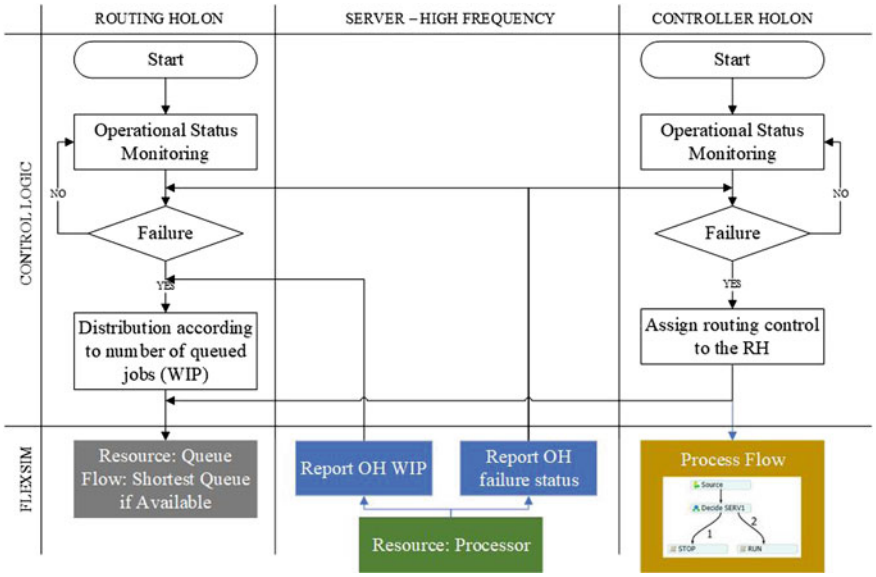

Fig. 8 Screenshot of H-RMS control system from FlexSim

4 Results

The research represents a significant contribution to the footwear industry since there have been no cases in Ecuador with similar applications.

4.1 Scenario 0: Conventional Control Without Failure

The base scenario or 0 represents the best possible situation during production; that is, without the presence of faults. Table 4 shows the results. In these equilibrium conditions, the throughput is the maximum achievable with 866 pairs and the production cost only in the servers is 0.24 $/pair.

Table 4 Results scenario 0

Server	Throughput—0	Wip—0	Utilization—0	Cost—0
S1	295	9.85	99.69	0.235
S2	290	9.63	98.04	0.239
S3	281	9.12	95.08	0.247
Total	866	28.6	292.81	0.240

Table 5 Results scenario 1

Server	Throughput—1	Wip—1	Utilization—1	Cost—1
S1	147	9.88	99.69	0.472
S2	291	9.74	98.21	0.238
S3	284	9.43	96.07	0.244
Total	722	29.05	293.97	0.290

Table 6 Comparison 1 versus 0

Server (%)	Throughput (%)	Wip (%)	Utilization (%)	Cost (%)
S1	−50.17	0.30	0.00	100.72
S2	0.34	1.14	0.17	−0.33
S3	1.07	3.40	1.04	−1.09
Total	−16.63	1.57	0.40	20.83

4.2 Scenario 1: Conventional Control with Partial Failure

Because server 1 is at fault, total throughput inevitably drops to 722 pairs from the base scenario percentage by 16.63% and the production cost is 0.29 $/pair in Table 5. Conventional control tries to reduce the impact of the disturbance, so in servers 2 and 3 the throughput increases by 0.34% and 1.07%, respectively. The total WIP increases by 1.57% and reaches a maximum of 3.40% in the case of server 3, that is, the control of materials becomes more complex (Table 6). Servers 2 and 3 increase production since conventional control sends work orders that are not executed on server 1 with the same equiprobable distribution logic. This situation is possible, since the utilization percentage is not yet 100.

4.3 Scenario 2: H-RMS with Partial Failure

The throughput with H-RMS control is 734 pairs in Table 7, with respect to the base scenario it decreases 15.24%. The intelligent control with H-RMS makes the impact of the disturbance less (Table 8), the throughput on servers 2 and 3 increases by 1.38% and 4.27%, respectively.

WIP decreases by 4.37% and 2.70% on servers 1 and 2, and in the case of server 3 it increases by 2.41%; however, the total WIP decreases by 1.64%; that is, routing is more effective.

Server utilization also benefits from H-RMS in which a maximum increase of 4.19% is achieved on server 3 and a global increase of 1.78%.

Comparing the two types of control in the presence of failure, it is shown in Table 9 that H-RMS with heterarchical architecture achieves better results than con-

Table 7 Results scenario 2

Server	Throughput—2	Wip—2	Utilization—2	Cost—2
S1	147	9.42	99.69	0.472
S2	294	9.37	99.27	0.236
S3	293	9.34	99.06	0.237
Total	734	28.13	298.02	0.280

Table 8 Comparison 2 versus 0

Server (%)	Throughput (%)	Wip (%)	Utilization (%)	Cost (%)
S1	−50.17	−4.37	0.00	100.72
S2	1.38	−2.70	1.25	−1.38
S3	4.27	2.41	4.19	−4.13
Total	−15.24	−1.64	1.78	16.67

Table 9 Comparison 2 versus 1

Server (%)	Throughput (%)	Wip (%)	Utilization (%)	Cost (%)
S1	0.00	−4.66	0.00	0.00
S2	1.03	−3.80	1.08	−1.05
S3	3.17	−0.95	3.11	−3.07
Total	1.66	−3.17	1.38	−3.45

ventional control with hierarchical architecture. Throughput increases by 1.66%, WIP decreases by 3.17%, server utilization increases by 1.38%, and the production cost decreases by 3.45%.

4.4 Scenario 3: Conventional Control with Total Failure

In this scenario the failure is total, the production rate is zero during the simulation time. A total throughput of 584 pairs is obtained. As a consequence of the total failure, the WIP and the use of servers decreases (Table 10).

4.5 Scenario 4: H-RMS with Total Failure

In the presence of a greater disturbance, the H-RMS control is still better than the conventional control (Table 11). It is observed in Table 12 that the throughput does

Table 10 Results scenario 3

Server	Throughput—3	Wip—3	Utilization—3	Cost—3
S1	0	1	0	69.360
S2	294	9.86	99.48	0.236
S3	290	9.66	97.96	0.239
Total	734	20.52	197.44	0.360

Table 11 Results scenario 4

Server	Throughput—4	Wip—4	Utilization—4	Cost—4
S1	0	1	0	69.360
S2	294	9.70	99.48	0.236
S3	294	9.68	99.18	0.239
Total	588	20.38	198.66	0.350

Table 12 Comparison 4 versus 3

Server (%)	Throughput (%)	Wip (%)	Utilization (%)	Cost (%)
S1	0.00	0.00	0.00	0.00
S2	0.00	−1.62	0.00	0.00
S3	1.38	0.21	1.25	−1.38
Total	0.68	−0.68	0.62	−2.78

not increase in server 2 and it does increase in server 3 with 1.38%, which positively impacts the total throughput by 0.68%.

WIP decreases on server 2 with 1.62% and increases on server 3 with 0.21%. Server utilization is directly related to throughput where server 3 is observed to have better utilization and consequently better throughput. The production cost decreases by −2.78%.

5 Conclusions

An experimental case study was proposed based on RMS and holonic approach. Thus, through the results present (see Table 13), it was possible to obtain an intelligent distribution of order jobs by the FlexSim platform. In this sense, traditional manufacturing systems with a hierarchical control approach with a single decisional entity have limitations to react to unexpected disturbances, while maintaining productivity and quality.

When a partial failure of a server occurs in the system, the equiprobable job distribution in the conventional control reaches 147 pairs in the failed server and the

Table 13 Results throughput

	Partial Failure		Total Failure	
Server	T1	T2	T3	T4
S1	147	147	0	0
S2	291	294	294	294
S3	284	293	290	294
Total	722	734	584	588

other servers achieve 291 and 284 pairs, respectively. In this scenario, it is not possible to distribute co-operatively. When the control is done with H-RMS, the failed server reaches 147 pairs. However, the distribution according to the number of jobs in the queue allows a co-operative reaction between the servers and 294 and 293 pairs are produced, which represents an increase of 1.03% and 3.17% in throughput. Overall, between scenarios 2 and 1 of partial failure, the H-RMS increases the throughput by 1.06%.

When a total failure occurs in the system, the production of this server is 0 pairs. In the conventional control, a total throughput of 584 pairs is achieved and with H-RMS a total throughput of 588 pairs, that is, an increase of 0.68% occurs.

New control trends, such as the architecture proposed in this research, are based on the stratification of the system into autonomous and co-operative decision-making entities that allow adaptive routing dynamics to be implemented; that is, in the presence of disturbances, the control logic changes, the server holons support others from the same group, and the distribution of jobs is entrusted to a routing holon that records the number of work in process, compares them and executes the intelligent distribution.

Acknowledgements The authors would like to thank to Universidad Técnica de Ambato and the Master in Industrial Production and Operations for the support, encouragement, and facilities provided to undertake this research.

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A Model DevOps Framework for SaaS in the Cloud

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Abstract The corporate organizational structure and culture should evolve in the development of software technology as the company grow; otherwise, it will present weaknesses that hinder the implementation of any software methodology. In this paper, the beneficial characteristics acquired by software products that have been developed under a DevOps conception have been identified, which has given DevOps a greater degree of relevance, promoting its study in greater detail, and assessing the growing interest of companies in having software as a quality that does not require additional costs for updating and maintenance. Additionally, the paper presents a systematic literature review, obtaining a conceptual schema of the relationship of DevOps with service-oriented software development, mitigating the lack of formalization of the concepts involved in each stage through an ontology. The result approximates a Model DevOps-based framework for SaaS development which can contribute as a guide for enterprises interested in the adoption of DevOps in their software production process for the first time.

Keywords DevOps · Software engineering · SaaS · Development · Framework

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M. V. García et al. (eds.), *Advances and Applications in Computer Science, Electronics and Industrial Engineering*, Advances in Intelligent Systems and Computing 1307,
https://doi.org/10.1007/978-981-33-4565-2_3

1 Introduction

Currently there is a growing interest in software development in an agile way to meet high standards that guarantee customer or user satisfaction with the product. This has encouraged organizations to move into practices and methodologies that optimize delivery times without negatively impacting software quality. Therefore, it is important to note that the software concept has evolved, highlighting the trend of offering software as a service using a cloud-based infrastructure, reducing high operating costs [4, 7, 28]. A cloud-based infrastructure is responsible for providing adequate technological resources for service proper functioning, offering greater scalability, and allowing multiple instances existence according to received demand by the service. Considering the qualities of DevOps, a study by Bayser et al. [3] determines that it has more relevant role in cloud applications development. Studies by other authors have made approximations of DevOps relationship with traditional software cycle; however, the steps required to apply DevOps in the development process have not been specified; furthermore, service-oriented software nature is not exactly the same as traditional software. In the present investigation, a systematic review is carried out to explain the reasons why DevOps is appropriate for services-oriented applications or software as a service (SaaS) development with the aim of providing a DevOps-based framework for SaaS development that will work as a guide for business organizations that wish to implement this trend in their development processes. This article is organized as follows: in Sect. 2 a systematic review is carried out to answer the key research questions, in Sect. 3 a discussion of the information collected is presented, in Sect. 4 the proposed framework is described, and finally in Sect. 5 the conclusions of the work are presented.

2 Background

Software development has gained popularity over the years in both scientific and industrial sector [27, 40] due to the need of delivering high-quality tools to users, developers, and stakeholders in the shortest possible time [12, 39]. This is the reason that allowed the agile methodologies emergence such as Extreme Programming, Scrum, and Kanban, which in a short time managed to position themselves within software industry. However, the increase in services demand and today's market competition has led to the need of introducing new development practices, such as DevOps.

The DevOps concept was promoted in 2008 by Patrick Debois [12], describing an organizations new trend of reducing the complexity between development and operations, mitigating the inefficiency produced by the organizational division between processes. Other researchers define DevOps as the inter-functional coordination between development and operations teams [13], so they have argued that DevOps should be restricted to communication context. Bayser et al. [3], meanwhile,

define DevOps as a modern method for software development which responds to the interdependencies between development and operations by using tools that offer convergence between developers and operators; consequently, they claim that DevOps focuses on reducing the duration of continuous software development cycle. These authors explicitly mention that DevOps was created for the cloud applications fast delivery. On the other hand, Jabbari et al. [27] conducted a systematic literary review which defines DevOps as "a development methodology, which seeks to create a bridge between development and operations, emphasizing communication and collaboration, continuous integration, quality control and delivery in an automatic way by using a set of best practices for development".

However, there is controversy about evidence lack of scientific value for agile development practices, such as DevOps, in the last nine years, caused by the difficulty in identifying DevOps implementation in software engineering. This has led to a series of literary reviews and empirical studies whose main objective is the DevOps associated concepts formalization as a methodology, principles, or best practices [3, 8, 12, 27].

Empirical studies have been carried out mostly in industrial sector, where it is common for companies to have a dedicated department or contracting external services for software development and continuous improvement, implementing protocols, methodologies, or practices that reduce production times, identifying the desirability of including DevOps in software development in general, but omitting to provide a guide to achieve a DevOps environment.

Based on the general concept and the particular observation of Bayser et al. [3] about DevOps applicability for cloud applications development, the key questions of this research are raised:

Q1: What makes DevOps appropriate for cloud application development?

Q2: What improvements are obtained by applying DevOps in software development?

Q3: Which are the DevOps activities present in the development of SaaS?

To answer these questions, the methodology for the systematic literary reviews of Barbara Kitchenham was used [29].

2.1 Relationship of DevOps with the Cloud Environment (Q1)

Although they can be found in the literature with different names [60]; DevOps, according to [25, 48, 60] is based on five principles: Culture, Automation, Lean, Measurement, and Sharing, better known as the CALMS principles. The quality communication ideal between developers and operators, and the knowledge exchange are within the Culture and Sharing principles. These directly impact in the software production teams traditional organization structure. Regarding the Automation, Lean, and Measurement principles, the lack of a DevOps standardized definition causes interpretation-based implementations that best suits the working environment of

those who choose to adopt this trend [15, 34], maintaining collaboration between developers and operators always.

This scenario leads to the existence of two perspectives associated with DevOps, as [44, 48] support them. One focuses on the interpersonal relationships aspect while the other is oriented to techniques and tools application that streamline production processes. Considering previous investigations like [15, 27, 34] that are oriented toward conceptually defining the scope of DevOps from a cultural perspective, the interest of this research is linked to the technological aspects within DevOps, for which it is important to analyze the conditions that facilitate its adoption. Commonly, adopting process of a new form of work must be preceded by a preparation stage in which basic requirements are met. This fact is applied to DevOps implementation in an existing development flow, as stated in [14, 50]. These documents refer to the capabilities and enablers to consider at the time of begin to use DevOps, doing focus on the conditions that allow accelerating the products development and delivery. DevOps agility gives rise to continuous deployment and continuous delivery practices, which involve not only development process automation through the use of dedicated tools [53] but also the ability of reducing tasks extension and grouping them into modules that are easier to develop [1].

The Service-Oriented Architecture (SOA) presents this modularity, specifically microservices, which are characterized by offering greater agility, scalability, reliability, and ease of maintenance [47, 59] because each service has only one functionality, which is independent from rest of the system [18, 46]. Initially, microservices were only implemented using virtual machines (VMs); however, unnecessary resources expenditure caused performance inefficiency [1]. The quality of services optimization need gave impetus to cloud computing paradigm emergence, which is essentially a service model that allows for ubiquitous, convenient, and on-demand access to a shared set of configurable computing resources that can be quickly provisioned and released with minimal management effort and interaction with service provider [37]. Thus, three service models arise infrastructure as a service (IaaS), platform as a service (PaaS), and software as a service (SaaS), being the latter the interest focus of this work.

The SaaS concept is derived from the application service provider (ASP), which is a traditional model where software owner manages his or her own infrastructure [33]; however, this model operating costs were high [4, 28] promoting infrastructure providers hiring to improve existing operations quality in order to quickly innovate at low cost [33], guaranteeing investments in necessary resources only. According to [37], a SaaS has the following characteristics:

- Multi-instance: Different users access their data and configurations in isolation, using the same instance of the software.
- Internet access: The service must be accessible from different devices with an Internet connection and available in many geographic locations.
- Service orientation: There must be a service contract for software use where limits and responsibilities are established.

– Self-organization: The user must be able to manage, allocate, or deallocate the resources and services of infrastructure, on demand, without requiring the assistant of people from the service provider.
– Payment for use: The price scheme where the user pays for service on demand.

In addition to the above, [37] adds that in the SaaS model the client does not manage or control the infrastructure underlying the platform, which includes networks, servers, storage, or individual application capabilities, except for some specific configurations and application settings. SaaS is a software that provides its service from cloud and it is mostly composed of modules with specific functions, characteristics that perfectly match with DevOps practices, such reducing tasks complexity. SaaS needs to be constantly updated without affecting the quality of service to handle new requirements, aspect that DevOps practices can satisfy by its continuous delivery and deployments while keeping high communication between operations and developers teams.

2.2 DevOps in Software Development Improvement (Q2)

DevOps implementation in services model as PaaS, during software development provide the project with features that can be brought to SaaS, such as those mentioned by [32]:

– Tasks Planning: Consist in carrying out an analysis of the application purpose, in order to get a thorough view of activities, distributing them in less complex tasks, which will subsequently be implemented as system modules or components.
– Concurrences Coordination: This feature is desirable for a SaaS environment too, where high concurrence rates for a service are common, so this should be anticipated in development early stages.
– Resource management: Best distribution of both human and technical resources that guarantees the right conditions for product development is evaluated.
– Constant monitoring: An analysis of production and service system records allows to detect any type of unusual behavior and to take action quickly.

These characteristics allow us to reach profit conditions that are supported in the literature [2, 19, 25, 32, 34, 46, 47, 49]:

– Components Reusability.
– Descriptions and individual installation guides of the components
– Greater scalability
– Development automation
– Improvements in code quality
– Reduction of time lapses between deliveries
– Early detection and correction of errors
– Reduction of test costs.
– Ease of undoing changes thanks to version control.

Once the favorable qualities that software products acquire through DevOps implementation have been identified, the next thing to be analyzed is DevOps activities relation with SaaS software cycle.

2.3 Presence of DevOps in the Development of SaaS (Q3)

DevOps has been considered as a key factor in software development [34], so much that in Gupta et al. [23] its main associated practices with general software cycle are identified:

- Continuous Integration. Takes place from planning, defining requirements, design, development, and unit tests (of the programmer) to the code implementation in Quality Assurance (QA) environment in a continuous and automated way. This phase requires a great deal of teams collaboration and it is essential for planning and requirements analysis [17].
- Continuous Testing. The tests are performed after the code integration into QA environment. Importantly, not all systems have the conditions for continuous testing, as mentioned in [14], being the reason why tests are limited to the new characteristics added to the main code [35].
- Continuous Delivery. Practice that seeks for optimization and automation of development, testing, and software updates delivery phases, guaranteeing its quality [10, 31]. All changes made to the main code are automatically saved and associated with a version number, enabling the recovering possibility of a previous version.
- Continuous Deployment. Process that ensures changes delivery to end users in different environments; according to Fitzgerald et al. [17] continuous delivery is a prerequisite for continuous deployment, but not the opposite, because continuous delivery focuses on release delivery while continuous deployment on the changes integration.
- Continuous Monitoring. Once software is integrated into production and operation environment, it is constantly monitored to give rapid feedback to development and operation teams, enabling them to take actions in case of any error.

On the other hand, SaaS development shares phases that are within the traditional software cycle, so it is appropriate to know which ones directly affect SaaS. In [16] the phases within the life cycle for service-oriented software development are highlighted:

- Software Specification. Three important factors must be highlighted, first, SaaS environment requirements must meet not only the business demand but also the platform specifications to operate in a multi-tenant environment and application characteristics must meet the current market needs. Second, all those processes that were done manually should be automated. Third, design must carry with it all necessary documentation, including models, use cases, and software architecture.

Table 1 Conceptual stages of DevOps activities in the SaaS development cycle

DevOps phases activities	SaaS development phases	Components	Attributes	References
Continuous Integration	Software Specification	Requirement Analysis Design	- Application requirements - Application design - Analysis process - Analysis use cases - Application upgrade	[6, 9, 16, 30, 36, 45, 51, 55]
	Software Building	Development	- Develop business services - Develop applications - Develop application integration	[35, 51]
Continuous Testing		Testing	- Testing policies - Testing environment - Testing strategy - Testing metrics - Testing feedback	[3, 30, 35, 38, 42, 49, 58]
Continuous Delivery	Software Deployment	Seamless Release	- Version control - User feedback	[35]
Continuous Deployment		Deployment	- Integration of platform services - Application integration	[24, 51, 52, 57]
Continuous Monitoring	Software Usage	Customization	- Customer requirements - Customer preferences	[22, 35, 56]
	Software Maintenance	Audit and monitoring	- Application upgrade - Improve Performance - Reports Incidents	[5, 35, 51]

– Software Building. This focuses on two essential parts: application development and tests that will ensure the application quality. Application development, beyond coding, must ensure the platform connection, on which the application will be deployed, tenants and application interoperability must be safeguarded. Tests should cover the application development and its platform interaction and employ rigorous metrics to ensure good performance [54].
– Software Usage. With SaaS in operation, continuous monitoring takes place; any incident that occurs during its operation is reported and scaled. Also, application customization is given and vary according to each tenant. The current literature offers strategies and methods to deal with this process [35, 56].
– Software Maintenance. The application maintenance phase is where fixes are carried out and the application evolves as new features are added, starting the cycle again [5].

A sixth phase called Software Commercialization has been excluded from the present study since it is considered that is not involved during SaaS development. The relationship between DevOps activities and the phases of the development of a SaaS is summarized in Table 1 and the attributes or properties that are obtained in each of the phases are identified.

3 Discussion

In [12] it is determined that DevOps was begun as an alternative to eliminate the gap between development and operation teams, thus raising the quality and minimizing software products delivery time. DevOps does not count with many years of maturity and consequently does not have a clear definition, causing to adapt it to the needs and working way, when implementing it in the development cycle. The main factors involved in adapting DevOps are the scale and organizational structure of the entity dedicated to software production.

In this paper, beneficial characteristics acquired by software products developed under a DevOps conception have been identified, given DevOps a greater relevance degree, promoting its detailed study, and assessing the companies growing interest in having software that does not require additional updating and maintenance costs. This interest brings a huge demand for cloud services such as SaaS. As SaaS is a service model in which user pays only for the necessary resources, it offers better control of company budget; moreover, greater flexibility is obtained, expanding or contracting the service scale, which makes it appropriate for different size companies [43].

When identifying DevOps activities or practices, inconsistency was detected when specifying continuous delivery and continuous deployment scope due to constant changes and integrations that can be carried out, which leads us to the questions: When does delivery take place? And when does deployment start? To answer these questions, we must refer to Fitzgerald et al. [17], who offer a clear difference and

scope for each process, supporting that continuous delivery is a prerequisite for continuous deployment but not otherwise. Humble et al. [26] indicates that the delivery process is aimed at delivering releases that are going to production. On the other hand, when analyzing the service-oriented software development phases, finding a concise definition for building software, required an exhaustive literature review, because actual literature has been limited and mostly focused on examining and proposing frameworks for schematization, architecture, and development of databases to be used by multi-tenants in SaaS environment.

DevOps is a complement to Agile methodologies, evidenced by the fact that Lean is precisely one of the principles that govern DevOps [25, 48, 60]. Therefore, from an Agile perspective, DevOps has similar practices, especially those included in continuous testing and continuous delivery, which may be a reason for current difficulty in DevOps identification within the development process. DevOps presence becomes noticeable when performing the first project deployment, because at this point integral product evaluation starts.

In [23] an approach to a DevOps framework applied to general software development was found; however, the practices interaction or relationship with software cycle are not perceived in detail. Part of the main conceptual stages for DevOps activities in the SaaS development cycle (see Table 1) was taken from this work, adding through the review carried out, the attributes or properties that are expected to be obtained during DevOps tasks in each phase of software cycle. Starting from DevOps activities conceptual stages in SaaS development cycle (see Table 1), an ontology is created, as this is an alternative way to model a specific knowledge, avoiding ambiguities, or inconsistencies in the concept definitions that constitute it while ensuring an understandable model by both humans and machines [11, 21].

There are different methodologies for ontologies construction [11, 20] that have in common the requirements analysis, conceptualization, and implementation using languages such as RDF Schema and OWL [57]. On the other hand, dedicated tools such as Protégé [41] have been developed to facilitate the declaring process of classes, properties, and relationships immersed within the ontology. The methodology selected for this study is Methontology. The first step of it is the domain conceptualization, a task done in Sect. 2 of this document that has resulted in the conceptual stages of DevOps activities in the SaaS development cycle (see Table 1).

Since the ontology's objective is to determine DevOps activities that influence each phase of the SaaS-type software cycle, the five DevOps activities and the five SaaS development phases have been taken as main classes. Relationships are given by the elements that each class has in common; however, the identified tasks are subclasses of DevOps activities.

Through the conceptualization of the ontology, the DevOps activities that are involved in the SaaS development cycle are formally defined. In Fig. 1, the diagram generated by the Protégé tool is shown. The graph of the ontology obtained provides a visualization of the elements in common between the DevOps activities and the SaaS development phases; the straight lines denote the subclasses while the dotted ones, the closely related elements.

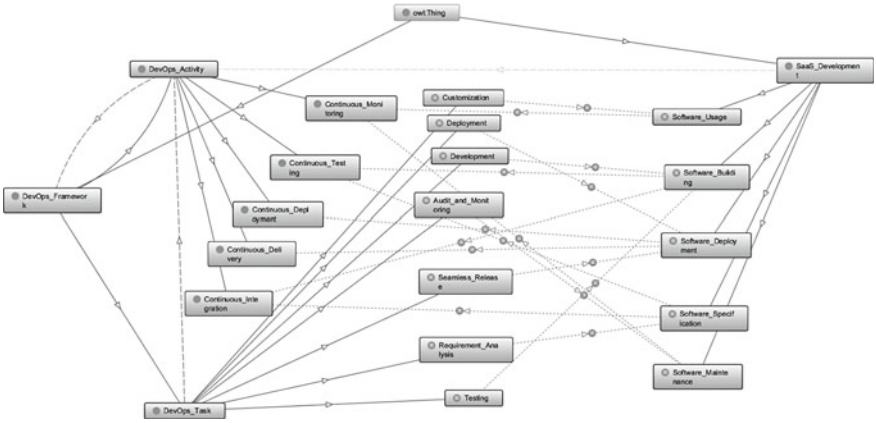

Fig. 1 Ontology graph for DevOps in SaaS development

Having formalized the presence of DevOps within a SaaS development, we proceed to generate a framework approach for projects of this type, which is detailed in the next section.

4 Results: A Model DevOps Framework for SaaS

After examining the related literature to DevOps and SaaS, the need for a guide for those who first ventured into DevOps' practice was identified. The model proposed as a DevOps framework in SaaS is shown in Fig. 2. This approach has been based on

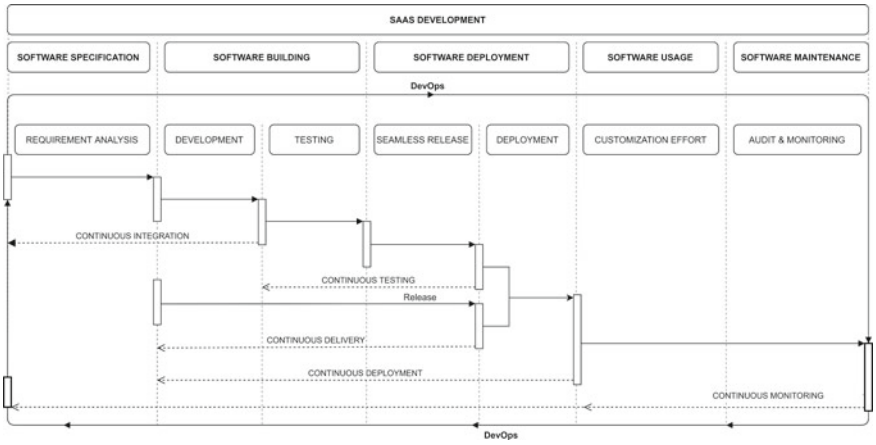

Fig. 2 Continuous and efficient development SaaS framework

the model presented by [23]. It relates SaaS development phases together with the DevOps stages from a methodological perspective, considering common elements between them. The proposed model starts from DevOps stages and their relationship with the SaaS development phases, in the following order:

- Continuous Integration. The first DevOps stage involves integration; software specification and software building phases are executed, being constituted by requirements analysis, application design, and coding. This stage receives feedback when software is tested and after it has been put into operation.
- Continuous Testing. The second stage begins when software building delivers a preliminary product version, starting software deployment process. The programmer executes unit and rigor tests to ensure software quality. The results obtained will determine if official version is released (seamless release) or returned to continuous integration stage for error corrections and improvements inclusion.
- Continuous Delivery. The third stage is responsible for ensuring continuous releases through version control. Software building is involved, programmers must continue working on approved versions improvements, which entails making preliminary deliveries of new versions. In this phase user's opinion is included as development feedback.
- Continuous Deployment. The fourth stage ensures software and platform adequate functioning include software building and software deployment, since deployments are made in the different environments: development, testing, or production. It is a stage that ensures the proper functioning between the software and the platform.
- Continuous Monitoring. The fifth stage is critical, since at this point the SaaS is in operation. This stage consists of the phases of software usage and software maintenance. Its components, customization effort, and audit and monitoring are related to the user experience, which allows identification of possible improvements or repairs to the software, thus returning to the first stage of continuous integration.

This is how this framework integrates the DevOps stages in the SaaS development cycle, improving the collaboration between development and operation teams while ensures, continuous integration, quality control, releases with automated implementations, and continuous software monitoring in operation. DevOps' guidelines regard the use of best practices and tools that automate each of these stages, resulting in a software developed in an agile, precise, and high-quality way that leaves place for improvements and easier and continuous maintenance.

5 Conclusion

In the existing literature, numerous works have been carried out in which the objective of defining DevOps is pursued, being in many cases, interpreted as a set of practices relates to culture and organization within companies; however, in this process only the activities or tasks characteristic of DevOps are identified. Other studies associate

it only with automation tools during development, without explicitly defining which phase of development is associated.

In response to the key questions of this investigation, applicable DevOps activities to SaaS development cycle and acquired qualities by developments that include DevOps, described in previous studies carried out at the industry level were identified. In order to formalize the DevOps presence in SaaS development, an ontology was created, defining relationships and elements shared by both, thus avoiding possible inconsistencies in the definition and scope of each stage of a work scheme founded on DevOps for SaaS.

DevOps does not generate tangibles objects during the SaaS development process; however, at formulation level, evaluation, and projects administration it leads to notable improvements, as a more rigorous and strict projects management under development, supporting the proposed framework. The framework is a tool that will serve as a guide for companies or groups dedicated to software production that wish to implement this flow. The DevOps stream is based on both practices and tools that facilitate the realization of these practices, which makes it an intermediate organizational point, which, like Agile and Lean, arises with the purpose of improving the software development process; however, this in turn implies that the organizational structure plays a fundamental role for the adoption of each of these methodologies.

Acknowledgements We are grateful for the support provided by the Science, Technology and Innovation National Secretariat of Panama (SENACYT), Scientific Master program TIC-UTP-FISC-2019, and to the National Research System (SNI-SENACYT) which one author is a member.

Authors Contribution Conceptualization, K.O, R.P, M.V.; methodology, K.O, R.P, M.V; formal analysis, K.O, R.P; research, K.O, R.P, M.V.; original-writing K.O, R.P, R.D, M.V.; writing–review and edition, K.O, M.V.; Corresponding author, M.V.

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Selection of Optimal Lodging Site in the City of Baños, Ecuador

Kleber Villa Tello

Abstract This study presents a methodology that allows a tourist to select at their discretion the best lodging site in a given jurisdiction. Using pre-established criteria/factors through meetings held with the main tourist entities existing in said jurisdiction. These criteria/factors come from public census information from the 2010 Population and Housing Census, 2010 National Economic Census and a Tourist Census conducted in the jurisdiction. The jurisdiction under study is the city of Baños de Agua Santa in the Tungurahua province of Ecuador. For the development of the investigation, an integration of GIS techniques and multi-criteria decision techniques based on the Analytical Hierarchical Process (AHP) approach is used, with variation in the method validation process. The tourist assumes the role of the decision-maker, having to select the criteria/factors that he wishes to use according to his need, comparing them in pairs. The comparisons allow tourists to make weights between the criteria/factors, and based on them, the accommodation establishments with the highest percentage of compliance with said criteria/factors are determined. Finally, the selected lodging establishments are presented to the tourist and based on final criteria/factors, generally of an economic nature, they make their final decision. An application was developed to automate and validate the methodology, applying it to a certain number of tourists, the results being satisfactory, obtaining from most of them the acceptance of the accommodation selection process carried out in the city of Baños.

Keywords Selection of hosting site · Multi-criteria decision models · AHP

1 Introduction

The tourism market in Ecuador, according to data from the Ministry of Tourism (MINTUR) in its February 2015 Monthly Bulletin, refers to a growth of 105.46%

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M. V. García et al. (eds.), *Advances and Applications in Computer Science, Electronics and Industrial Engineering*, Advances in Intelligent Systems and Computing 1307,
https://doi.org/10.1007/978-981-33-4565-2_4

in the economic income generated by it based on the period 2014 versus 2013. This turns tourism into the third-best income product in Ecuador, surpassed only by Banana and Shrimp [19] tourism being an economic activity marked by a strong dynamic of growth and generating wealth [5].

The city of Baños de Agua Santa, located in the Province of Tungurahua in Ecuador, is known as "El Pedacito de Cielo" [13]. It is the cantonal head of the canton that bears the same name, which has 14,653 inhabitants [15]. Of this population, 12.63% work in accommodation and food service activities [15], but it can be asserted that 90% of economic activities in the city are related to tourism [16], concentrating in the city 3.9% of accommodation establishments in Ecuador [18, 21]. Despite this great economic-tourist movement, the city currently does not have an adequate mechanism for locating and selecting lodging establishments.

Multiple services and tools that make a particular jurisdiction the favorite of tourists must support this growth. A tourist is defined as a person who is outside their usual environment. To carry out activities for leisure, business, and other reason [23], for this reason it is important to select a suitable lodging site, which makes he feels fully satisfied, and returns continuously to the place. Providing a given jurisdiction with economic income and jobs, based on these, the importance of carrying out and providing a methodology that allows selecting a suitable accommodation site to the needs and requirements of the tourist.

The selection of a site is a geographical problem and the different needs that a tourist may require of a certain place of accommodation, determine that it is chosen to integrate GIS and multi-criteria decision techniques to solve the problem of determining a place of accommodation.

The integration between AHP and GIS has been used in similar investigations: Using both vector and raster cartography as a source [2, 20]. With explicitly spatial criteria/factors such as distance or implicitly spatial factors such as population density [4]. Under conditions of uncertainty and certainty [14]. With decision processes by a single decision-maker or a group of decision-makers [6, 17]. In these investigations, it has proven its consistency and validity, making it possible for the decision-maker to use geographic information and its evaluations.

This study presents the AHP-GIS integration, using GIS techniques such as Buffer, Union, Clip, Overlay, and raster transformations, which were combined with the AHP method. This research is carried out to Determine the socio-demographic and economic parameters or variables of greatest interest to tourists, which allow them to select the best lodging establishment. Establish the appropriate evaluation ranges within the selected variables that make it possible to qualify the suitability of a specific accommodation site and check the validity of the methodology by executing it for a specific group of tourists [7, 28].

The methodology proposed here, as well as its data will be for public use, through agreements either with the Indoamérica Technological University or through the Provincial Council of Tungurahua, through their respective web platforms, transforming this methodology into a publicly available technological tool on the website where you are staying. It is therefore evident that the main beneficiary of this research will be the tourist who wishes to visit the city of Baños de Agua Santa, in addition to

the entire population of this city that economically depends on or is related to tourism activity [16], concentrating 3.9% of accommodation establishments in Ecuador in the city [18].

2 Study Area

Baños de Agua Santa is the cantonal head of the canton of the same name, which has an area of 1,065 km^2. It limits to the north with the Province of Napo, to the south with the provinces of Chimborazo and Morona Santiago, to the east with the Province of Pastaza, and to the west with the cantons of Tungurahua, Patate, and Pelileo (Fig. 1). According to the 2010 Population and Housing Census [15], it has 14,653 inhabitants in the cantonal head; 1,658 live in rural areas and 12,995 live in urban areas, consisting of 38 urban census tracts and 13 dispersed census tracts [15].

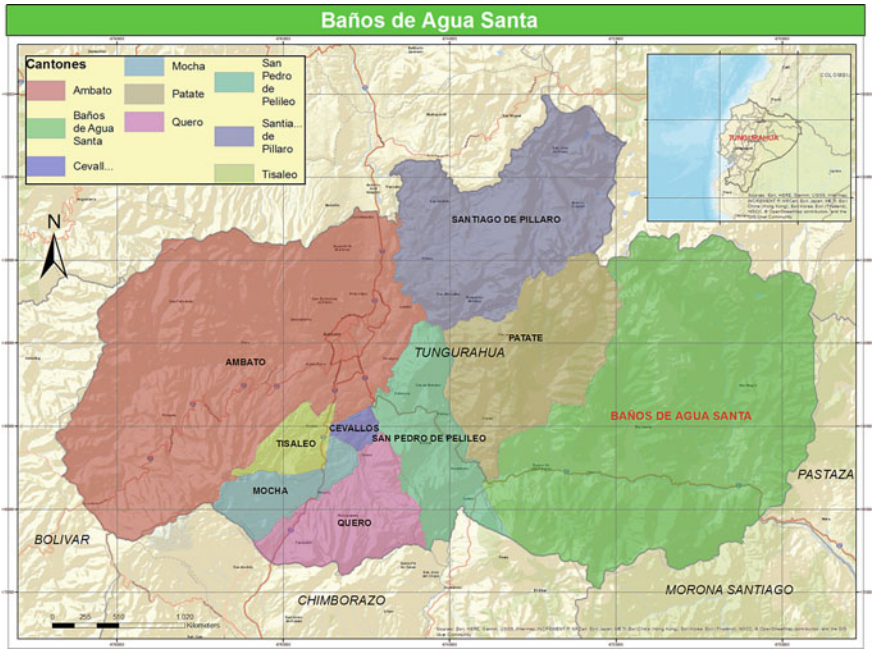

Fig. 1 Location of the Canton Baños de Agua Santa

3 Methodology

A comparative study of Multi-criteria Decision Methods was carried out, which is summarized in Table 1 [9], opting in this study to use the AHP approach taking into account its characteristics, the data that is available and the conditions of the decision-maker. This table compares five MCDA methods that cover three approaches such as the one based on the utility of the information, the one based on ranges and the one based on decision rules. It analyzes research that uses MCDA, although it is carried out for sustainability evaluation, it helps us to evaluate the methods in a general way.

Below are important reasons why the use of the AHP method integrated with GIS is a combination that allows us to provide an efficient solution to the problems addressed in this research:

AHP is characterized by being a compensatory method, in this way it is guaranteed that no criteria/factor and no alternative are discarded [9]. With this characteristic, it is guaranteed that all the criteria/factors selected by the tourist are valued and that all the lodging establishments of the city under study have the option of being selected by a certain tourist.

The AHP in its methodology has an internal process to test its validity. Allowing it to be redefined as many times as necessary until reaching a valid selection process so that the decision-maker [3], who in this case is the tourist, can repeat/debug the process until you find a valid option for applying the methodology and for yourself.

AHP is a method considered difficult, but it has a high coverage in tools which have a quality graphic representation [3], which makes AHP an understandable and easy process to perform, and can also be implemented in Most widely used GIS programs such as IDRISI, ArcGIS, and QGIS.

The AHP allows to work with uncertainty (ignorance of the work environment) which is necessary [9], since the decision-maker is the tourist who does not know a certain jurisdiction. Being the tourist a general user who wants to value his decision to feel satisfied with the place where he will stay. It is necessary to highlight the importance of the respective training that must be provided to the decision-maker so that he/she chooses his/her own preferences adequately with the pre-established criteria/factors.

The AHP-GIS methodology presented in this document asks tourists to select the criteria/factors among the pre-established, which best suit their accommodation needs and in turn are required to establish ranges of values according to the Saaty scale [25]. That is, to compare in pairs of criteria/factors providing values (weights) to each of these pairs.

With the criteria/factors selected by the tourist, vector layers are generated according to the defined values (weights) on Saaty scale. These vector layers during the process are transformed into raster layers whose evaluation is given at the cell level according to the user's preferences. Finally, the AHP method is applied using the raster calculator, in order to have the best option at the census sector or census sector level. Then, on the selected census sector or sectors, accommodation establishments

Table 1 Comparison of multi-criteria decision methods

Comparison criteria domain		Comparison criteria	MAUT	AHP	ELECTRE	PROMETHEE	DRSA
Scientific soundness	Related to input data	Use of qualitative and quantitative	Possible	Possible	Possible	Possible	Possible
		Life cycle perspective	Possible	Possible	Possible	Possible	Possible
	Related to calculation method	Weights typology	Trade-offs	Importance coefficients Trade-offs	Importance coefficients	Importance coefficients	Not needed
		Threshold values	Not possible to possible	Not possible	Possible	Possible	Possible, obtained from the decision
		Compensation degree	Full	Full	Null	Partial Full	Null
		Uncertainty treatment/Sensitivity analysis	Possible	Possible/Partially possible	Partial/Possible	Possible/Partially possible	Possible
		Robustness	No rank reversal is possible	Rank reversal can occur	Rank reversal can occur	Rank reversal can occur	Possible for the choice and ranking problems
Feasibility		Software support and graphical representation	Software available with some graphical capabilities	Software available with good graphical capabilities	Software available but with poor graphical capabilities	Software available with good graphical capabilities	Software available but with poor graphical capabilities
		Ease to use	High to Low	NHigh/Medium/Low	Low	Medium	High
Utility		Learning dimension	Difficult	Difficult to Possible	Difficult	Simple with scenario analysis	Difficult

Note Adapted from Consistency in the Analytic Hierarchy Process: A new approach, 15 May 2006

are placed with their price per person or any other variable of interest for the tourist to make their final decision.

To analyze the effectiveness of the proposed methodology, a test was carried out with the help of the computer tool developed AHP-SIG, applying it to 20 tourists visiting the city of Baños de Agua Santa. These people were staying in some establishments in the city and they were encouraged to carry out the test in order to observe the results that it produced. Of these 20 tourists, 14 were domestic tourists and 6 were foreign. The majority of visitors from the city of Baños de Agua Santa were Ecuadorians from the Sierra 12 region since they were on vacation at the dates the tests were conducted and 2 from the Litoral region.

Three processes were carried out in the study:

The first is the operation carried out for the tourist census, in this the tourist entities that issued the information requirements to be collected were MINTUR, INEC, the Tourism Chamber, and the main universities in the jurisdiction. The criteria/factors used were defined with these actors, so that they are selected and evaluated by tourists according to their preferences.

The second process is the integration of the alphanumeric bases from the censuses with the census cartography. The INEC 2010 census mapping is found in the WGS 1984 UTM Zone 17 South coordinate system at a scale of 1: 50,000. The bases of the Population Census and Economic Census are in REDATAM format [8], REDATAM Process version 5 was used to extract the information to be transformed. The tourist base is in SQL Anywhere 10, native SQL was used to extract the information to transform. Once the information was extracted at the geographic level of the census sector, it was joined to the cartography at the same level using ArcMap 10.1.

The third process presents the tourist as the decision-maker, according to the AHP method, the problem was decomposed hierarchically defining the basic levels, the first the objective, the second the criteria/factors, and the last the alternatives as shown in Fig. 2. The tourist according to their needs chooses the criteria/factors. Each criterion/factor generates a vector layer according to the values (weights), assigned by the decision-maker, which in our case is the tourist, an expert in their preferences. The weights are assigned based on the distance to the selected census sector or sectors, according to the chosen parameter.

These vector layers during the process are transformed into raster layers whose valuation is given at the cell level. The AHP method is applied to obtain the best option at the census sector level. On the selected census sector or sectors, the lodging establishments are presented with some additional variable for the tourist to make their final decision (See Fig. 2).

To validate the selection, the AHP method's own validation process was used with certain modifications proposed by Alonso and Lamata [3]. This form of calculation is simpler and computationally efficient since the traditional method generates too many calculations.

The calculation method of Alonso and Lamata [3] was used in investigations such as [1, 2, 12, 29, 30].

According to Alonso and Lamata [3] the equation to calculate the Consistency Range (CR) is

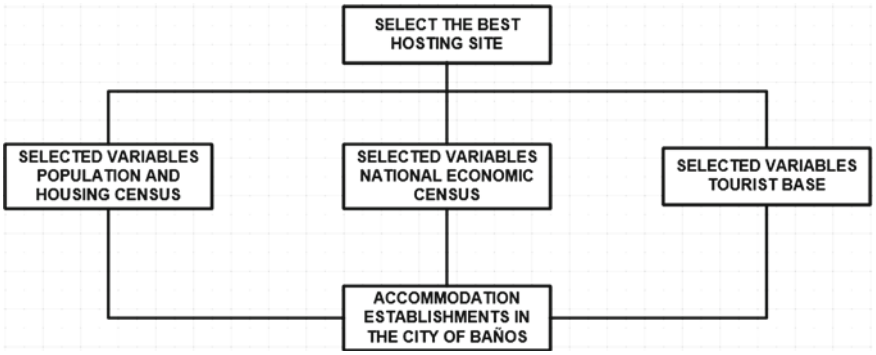

Fig. 2 Hierarchy applied in the accommodation selection process

$$CR = \frac{CI}{RI} \tag{1}$$

where

CR = Consistency Range.
CI = given matrix consistency index.
RI = Random matrix consistency index.

For the calculation of CI, the following equation proposed by Alonso and Lamata [3] was used:

$$CI = \frac{(t-n)}{(n-1)} \tag{2}$$

where

n = Number of parameters.
t = Represents the weighted score for each row of the matrix.

t is calculated as follows:

$$t = \frac{(matrizponderada/matrizpesos)}{n} \tag{3}$$

where

matrizponderada = Multiplying the original matrix by the weight vector.
matrizpesos = Initial weight vector.
n = Number of parameters.

The methodology was automated using an application for Windows environments called AHP-SIG. The database design was done in Sybase PowerDesigner

16.1.0.3637 [27], for the database PostgreSQL 9.4 [24] was used, Sybase PowerBuilder 12.5 for the interface [26], MapObjects 2.3 from Environmental Systems Research Institute (ESRI) to display mapping in the interface [11] and Python 2.7 with ArcGIS 10.1 libraries for batch processing of geographic operations.

4 Results

The application of the AHP-SIG tool was made to 20 tourists over 18 years of age visiting the city of Baños de Agua Santa (National tourists 70%, 10% from Germany, 10% from the Netherlands and 10% from the United States). These tests were carried out randomly in the accommodation establishments near the Sanctuary of the Virgen de Agua Santa (Hotel Acapulco, Hostal Los Nevados, Hotel Alborada, and Hotel Achupalla), both to observe the way of understanding the process as well as to analyze the results obtained. With the execution and obtaining of results with the preferences of each tourist, the validity of the methodology was tested as well as the operation of the developed tool.

From the set of variables previously selected through meetings with institutions related to Tourism in the province of Tungurahua, whose origin comes from the Population and Housing Census 2010, the National Economic Census 2010, and the Tourist Census carried out. They were analyzed in the test with tourists, who ratified the understanding of their meaning and objective for all the variables used in the Population and Housing Census as well as the Tourist Census. But in the variables from the National Census Economic little acceptance of the variables is observed, this due to the non-daily use of this type of information, which is economic information related to productive activities, which indicates that different variables of this census should be included in a future version, with which they would get better results (50%). The variables of the Population and Housing Census and the Tourist Census are in common use in a home or on a trip, for this reason their acceptance and higher percentage of use.

Regarding the evaluation of the pairs of criteria/factors using the Saaty scale [25], the majority of tourists accept (80%) the same, the rest of tourists (20%) mention percentage scales, but it would not be applicable to the model.

For the validation of the methodology, the procedure that follows was explained to the tourist and that the system would reject if it found a matrix with an initial tendency, to which 60% agreed, but 15% disagreed in validating your options as they think that it is not necessary to do so. 25% disagree, mentioning that what was valued by them should be respected initially, despite the fact that it was explained that it is necessary to do it to be sure that the answer is valid.

5 Discussion

There was a tendency for tourists to select variables from the Population and Housing Census, chosen in all the processes carried out. This confirmed the importance of choosing the criteria/factors to make a correct decision and just as important is that the decision-maker is familiar with each of these [25].

It should be borne in mind that different tourists who face the same decision and that even if they use the same criteria/factors, when using the proposed methodology they can reach different conclusions [10], this because each one of them evaluates based on their preferences, the important thing is that each of them satisfied with the decision.

To apply the AHP-SIG methodological proposal in another jurisdiction, the following points should be taken into account:

- The questions that appear in a population census is a standard of questions worldwide [22].
- The universe of the National Economic Census included jurisdictions with 20,000 or more inhabitants, so the jurisdiction to apply must have this number of inhabitants, if you want to include these variables.
- The tourism research was carried out in the Tungurahua province and can be executed in any jurisdiction, although as mentioned it is possible to include or exclude the variables of a certain research, but the developed system must be parameterized accordingly.
- The cartography used is the public cartography of the INEC at the census sector level, where there are jurisdictions throughout the country Ecuador. Several statistical institutes have cartographic information at the census sector level and make it available to the public.
- The tools used must be configured, especially the access to the PostgreSQL database and the location of the cartography next to its temporary processing directories.
- The use of AHP is standard with a variation in the validation methodology that is proposed by Alonso and Lamata [3].
- Additional research information may be included, but these should have results at the census sector level.

The proposed methodology and supported by the developed tool allows to incorporate additional variables and of diverse origins. The key to the AHP methodology is the inclusion of criteria/factor weightings based on the tourist's own objectives, and being a compensatory method, does not rule out any option, thereby ensuring the participation of all criteria/factors and lodging alternatives.

In the implementation of the methodology in which through spatial analysis together with the public information used. It is possible to clearly identify census sectors in which tourists according to their requirements should stay, it is also clear to identify the sectors census in which you should not, in order to feel satisfied with

your accommodation and this becomes a factor for your return to the jurisdiction where you stayed.

Regarding the main objective of the research, which is the generation of a methodology for the optimal selection of a hosting site based on public information. This was accomplished through the generation of cartographic models. The adaptation of alphanumeric and geographic information of public origin. The evaluation of the results and the development of a computer tool that integrated these processes. The methodology, as discussed in this section, can be used for similar selection processes for site selection.

The criteria/factors proved to be adequate, even when tourists had a higher tendency in the criteria and factors of the Population and Housing Census and Tourist Census. This being understood because they are variables referring to a trip, home, and person that are of daily use for a person, the detail of these variables converted into criteria/factors. Additional variables of the Tourist Census as price per person, if the accommodation includes breakfast or not, from the Population and Housing Census, people by age ranges, and from the National Economic Census, the existence of shopping center-type establishments can be included without modification in the system.

In the methodology, the pairwise comparison of the criteria/factors is essential to obtain a satisfactory result [25], even being comparisons between criteria/factors of different origin and nature, and whose evaluation is subjective for the tourist decision-maker, the methodology generates geographic and mathematical processes that trigger the selection of sector/sectors objects of preference. The methodology has and was implemented within the tool that automates it, the validation process of the resulting matrix of criteria/factors, thereby guaranteeing the quality of the result.

Currently there are applications that implement AHP, such as QGis, ArcGIS, and Idrisi Selva, but it was decided to make a tool of their own to facilitate tourist use and to personalize according to the requirements of the proposed methodology.

The cartography used, since it is cartography used in research such as the Population and Housing Census, the National Economic Census, the Living Conditions Survey, the Income and Expenditure Survey, and the various investigations carried out by INEC and of public origin. The processing of the variables together with these layers was carried out using Python scripts without presenting difficulties either due to their weight and quality. Even the display of the result layer presented no problem for MapObjects that was used for it.

With what has been indicated and through the use of the proposed methodology, it is possible to obtain the target census sector (s), and it is emphasized that being a compensatory methodology does not rule out any criteria/factor or any alternative (lodging establishment) (See Fig. 3).

In the present study, experts have not been used for decision-making, but the results have shown that the methodology is valid for the stated objective, which is the Selection of a hosting site. A tourist is the expert on his own preferences.

The methodology developed presents potentialities in this type of decision, it must continue to be refined to include criteria/factors of various and diverse investigations that are carried out in a given jurisdiction, the new variables would increase the

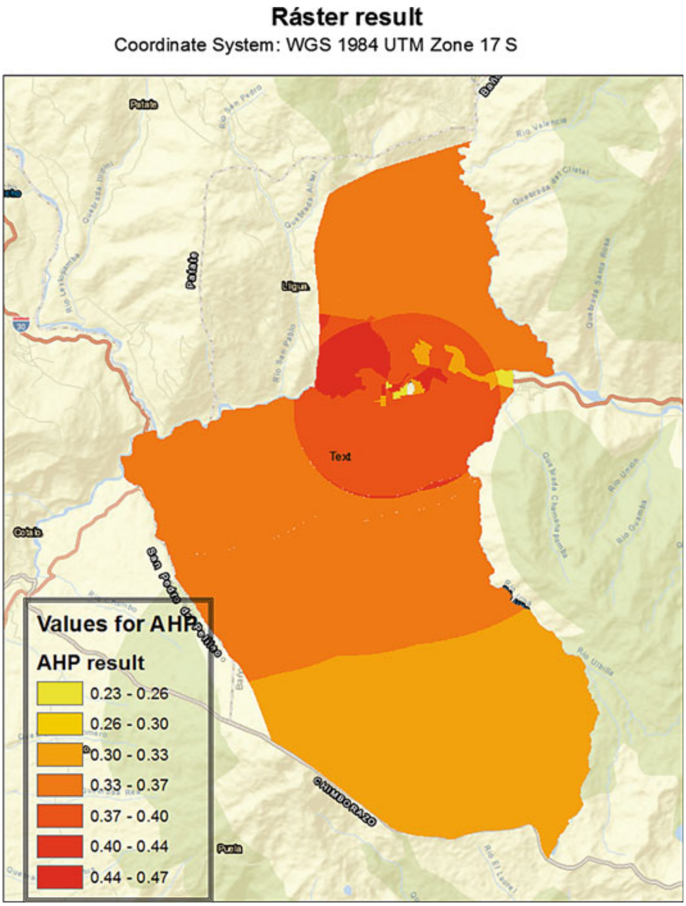

Fig. 3 Raster result of an example of the application of the methodology

perspective of the tourist to make their decision. It is recommended to carry out this study in languages that allow Web and GIS integration.

The process of selecting a lodging site integrates multiple criteria/factors for a tourist, the techniques or tools such as GIS and MCDA individually have certain limitations to provide a complete solution, so when integrating these limitations they are eliminated by providing the tourist with a innovative approach to decision-making. The proposed methodology uses only distance as a geographic factor, in future research geographic factors will be diversified and the application developed will be migrated to the web.

6 Conclusions

The pre-established variables between the MINTUR, the Chamber of Tourism, the representative Universities, and the INEC are the correct ones since they were accepted.

Both the scale and the AHP validation method facilitated the development of the investigation and allowed tourists to redefine the evaluations of each pair of criteria/factors until finding a valid matrix.

The cartography used provided reliability. The proposed methodology to integrate public census information and tourist information with the AHP multi-criteria method and GIS techniques, demonstrated that it is possible to select a census sector or census tracts that contain the best lodging site for a given tourist, according to their needs.

The previously selected variables proved to be optimal in providing the tourist with a wide range of usable characteristics for their selection process. And the ranges used in them in a similar way were easily interpreted by tourists by standardizing the use of the spatial parameter of distance to evaluate them.

The proposed methodology improves its applicability, depending on the good definition of preferences by the tourist, as well as the correct transfer of these preferences to maps. The methodology carried outcomes to provide a selection of the best hosting site at the census sector level, this due to the level of cartography used, it could be reached at the block level using the proposed methodology.

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Decision Support System for the Location of Retail Business Stores

Naysha Loo, Carlos Hernandez, and David Mauricio

Abstract Within the natural cycle of retail companies, there is the stage of expansion where one of the most critical and high impact processes is the process of selecting the location for new stores. So it is necessary to make the most appropriate decision, which allows in the medium and long term to have fewer risks and losses, and higher profits and sales. This work proposes a Decision Support System for the location of retail stores, which will provide entrepreneurs with available, updated, and relevant information on retail stores, public services, and influxes of people. In addition, the system allows to project and compare for two or more new store locations, the critical indicators: average monthly ticket, monthly influx, total monthly sale, demographic density, amount of competences. To validate the proposed system, 5 case studies were carried out on real stores in Lima, the results obtained for a 6-month projection show high precision in the projection of the indicators, reaching on average 98.64%, 97.29%, and 96.61% for the average ticket, the influx of customers and the total amount of sales, respectively.

Keywords Location · Predictive · SAP analytics cloud · Business analytics · Decision support system · Site retail selection

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M. V. García et al. (eds.), *Advances and Applications in Computer Science, Electronics and Industrial Engineering*, Advances in Intelligent Systems and Computing 1307,
https://doi.org/10.1007/978-981-33-4565-2_5

1 Introduction

The retail sector has been constantly growing in recent years, thanks to the large investments that have been made in both technology and business models. This large-scale growth situation reveals one of the key points of the success desired for each company: the decision-making process in the expansion process. The importance of decisions on the location of facilities is justified for two main reasons: these decisions involve considerable immobilization of long-term financial resources and affect the competitive capacity of the company [4]. Likewise, factors have emerged to make the selection of sites increasingly complex, such as accelerated expectations, globalization, environmental aspects, greater availability of labor, public services, and among others [6]. On the other hand, despite of the information that the Internet makes available to the user, it does not necessarily facilitate the process of selecting locations, on the contrary, it can increase lethal risks in the future. Given all the before mentioned aspects, comes the need to reduce the risk each time the company must make this important decision, for which it must have a series of indicators that show the location in question as a great opportunity to increase the profitability of the company.

This need has already been identified in other studies, where they provide some proposed solutions. There is a semi-supervised learning model, Affinity-based Popularity Inference (API), which can predict the popularity of a new retail store location, based on a group of characteristics of locations near the location of query, this model only works if there are shops adjacent to the one of interest [8]. Another solution proposal found was an application of methods and algorithms that helps to facilitate the process of selecting retail sites and sales prediction, a method based on the similarity of five algorithms for the determination of characteristics in the location of retail places [11, 19].

In the contributions found, the minimum essential variables for calculating vital indicators in the making of expansion decisions are not contemplated. Likewise, the main opportunity for improvement is to use the company's historical data to provide feedback through predictive analysis. Given this, this project includes variables that make up the relevant indicators for decision-making, as another solution alternative. In the same way, the contribution will innovate with the predictive analysis of the historical data of the company, which will analyze the successes and mistakes that have been given overtime to make the comparison with the new candidate locations to a new installation.

Predictive analysis is another trend that all companies are going to have to take. What it is about is knowing how to find out how we can have real-time dashboards that talk about the things that are going to happen and not the ones that happened [5]. This paper presents a Decision Support System for the location of retail stores, through which the process of locating new stores will be optimized and facilitated. For this, a data model will be implemented to be integrated with the SAP predictive tool—SAP Analytics Cloud, there will be used the dashboards that it makes available, the internal algorithms it contains, and other generic functionalities.

The article is distributed as follows: Sect. 2 describes the literature review about of methods and algorithms for retail store location selection, Sect. 3 describes the decision support system for retail store location, Sect. 4 presents the validation of the purpose system, finally, the conclusion follows in Sect. 5.

2 Literature Review

Through the application of methods and algorithms, the process of retail store location and predicting sales is facilitated.

A similarity-based method is proposed for the prediction of sales and the use of five algorithms with R programming, for the determination of characteristics in the location of retail sites [19]. Thanks to the data provided by the society commerce and the services according to its location, relevant information can be obtained that supports the commercial, strategic, and operational decisions in a company. A unified computing framework is proposed that captures the location of a company and con-textual information in geographic agglomerations for performance prediction called Business Performance Prediction Framework based on location [5]. There is a methodology to produce the result from data collection, data preparation, and extraction technique to determine the optimal business location selection. The article's framework begins by determining several places as possible changes for a category C store or a specific brand of store chains B. Google Maps data can be found to find the specific place where attributes and type of business that registers in particular places, for a later analysis [10, 13]. There is a unified method based on minimizing the distance from the candidate branch to the most successful branches, considering the notion of success of each branch to attack the complexity of the bank location selection process. To start, you should specifically define a category of branches, then you must select a criterion focused on the main objective of the company to find the best site in relation to this criterion. Next, a vector of the most significant characteristics for each branch is created, which are then evaluated under a numerical score [1].

It seeks to guide retail chains to improve the selection of new commercial locations and build general market development policies. It presents a hybrid model—PCA Model (Principal Component Analysis)—BP (Backward Propagation network), consisting of a module for the evaluation of spatial accessibility and another module for estimating market potential. A benchmarking was performed on the RMSE (Mean Square Error) between the PCA—BP and other tools for the selection of retail sites, the results were as follows: Decision tree (0.301), OLS (0.162), and PCA–BP (0.065) [16]. By combining geographic information systems (GIS), Decision-making Systems (DSS), and the Multi-Criteria Decision-making Method (MCDM), a synergistic effect is generated that contributes to the efficiency and quality of the spatial analysis for the selection of industrial sites. The model developed allows a decision to be taken in ten steps, with the generation and evaluation of alternatives using IMS and MCDM methods for the selection of industrial sites [12].

To build a predictive analysis solution, the tools used by other projects' predictive models are analyzed. In this way, it achieves, through research, an analysis of tagged locations for a new convenience store location. The convenience store location analysis is also achieved, using the Geographic Information System (GIS) and the Support Vector Machine to predict the independent cases' class label [2, 17]. Similarly, providing a proposal that optimizes the process of choosing a good location for a new store, using a Demand-driven Store Placement Framework (D3SP), practical features and models to classify candidate locations is given, as well. Thus, it uses supervised regression models to predict the number of clients and range learning models to classify candidate locations directly [18]. It is worth mentioning that artificial neural net-works are capable of handling nonlinear representations and easy learning, they are flexible for the recognition of patterns, time series, and images, it has a considerable speed compared to other models, adjustments can be made once the model is created. In such sense, predictive model for car insurance claims is proposed, using MATLAB that provides a series of tools that facilitate the creation of this kind of models [3, 20].

3 Decision Support System for Retail Store Location

The proposed Decision Support System for Retail Stores Location (DSS-RSL) helps reduce the risk in the selection of locations for retail stores, making use of the benefits of Business Analytics, predictive algorithms, and ISO/IEC 25012 and ISO/IEC 25024 standards. The system allows companies to consult locations of interest and calculate a list of indicators that feed on the company's demographic, geographic, and internal data; thus, based on the selected locations, the user can compare the indicators that the model has shown as results for each of them. Each of the components and relevant factors of the DSS were analyzed, so that they can interact correctly with each other: Data preprocessing, Data product quality for ingestion, Predictive algorithms, and Display on dashboards (see Fig. 1).

In the preprocessing of the data, the elements and fundamentals used by the system to feed on information and respond to functional requirements were analyzed: internal data sources, external data sources, data processing, data cleaning, and data loading. Likewise, to ensure the quality of the ingested data, we applied the data quality model offered in ISO/IEC 25012 and ISO/IEC 25024, it has fifteen quality characteristics represented, classified as system dependent, system inherent, and shared. However, for the data model terms, the characteristics that apply to the scope of the Project were selected only:

- Inherent characteristics of the system: Regarding the ability that the data quality possesses to meet the requirements. The characteristics are as follows:
  - Accuracy
  - Completeness
  - Consistency
  - Topicality

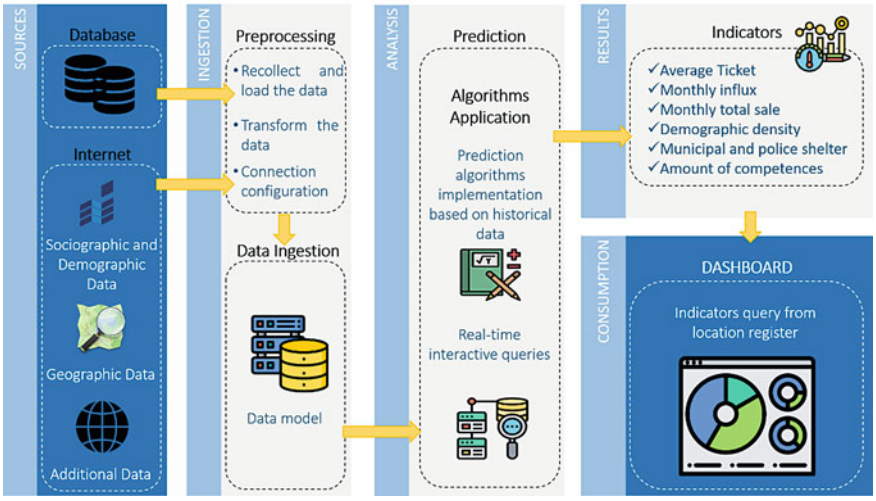

Fig. 1 DSS-RSL model

- Shared characteristics: Regarding those that depend on both the system and the established requirements. The characteristic is as follows:
  - Understandability

3.1 Variables and Indicators

Table 1 shows the set of variables that make up the data model, demographic data about age, gender, employment, and other relevant factors to the installation of a retail store, as well as security, population density, and square meter price data. The objective of the model is to calculate the functional indicators that will be displayed as a result of the user's query. Likewise, the system allows to extend the model and record additional indicators to the user needs and that can be calculated based on the referred data. Table 2 shows the list of functional indicators that the DSS-RSL proposed displays.

3.2 Implementation

In order to implement the DSS-RSL, the following steps were followed:

1. Design of the relational data model: Where the Erwin Data Modeler tool is used.

Table 1 Variables for decision-making

Variable	Description	Source
Age average	Average age of the inhabitants of the district	Ruff, Akhund & Adjoian [14]
Female population	Percentage of female inhabitants in the district	Ruff, Akhund & Adjoian [14]
Male population	Percentage of male inhabitants in the district	Ruff, Akhund & Adjoian [14]
Education level	Average educational level of the inhabitants in the district	Own source
No. of people per household	Average number of inhabitants per household in the district	Own source
Consumption per household	Average consumption in soles per household in the district	Own source
Rate of employment	Percentage of employed inhabitants in the district	Own source
No. of shops	Number of stores nearby to a specific location	Own source
Coverage radius	Coverage radio in meters of the sociographic information entered	Lin, Chen & Liang [9], Vasileiou, Loukogeorgaki & Vagiona [15]
No. of police officers	Number of security forces close to a specific location	Own source
Theft to establishments	Number of thefts nearby with respect to a specific location	Fowler [7]
Square meter price	Average price of the square meter with respect to a specific location	Own source
Project	Name of the construction project in the area	Own source
No. of properties	Number of project properties	Own source

Table 2 Indicators for decision-making

Id	Indicator	Description	Source
I1	Average monthly ticket	Average amount of consumption per customer	Own source
I2	Monthly influx	Average number of customers in the month	Fowler [7], Chang & Hsieh (2018)
I3	Total monthly sale	Average total sales amount	Ruff, Akhund & Adjoian [14]
I4	Demographic density	Number of people per square meters in the area	Fowler [7]
I5	Amount of competences	Number of nearby establishments of the same item	Fowler [7]

2. DB Implementation: Designed in 2012 SQL Server from an exclusively used machine as a server.
3. Extracting information: Necessary sources data to feed the model through Web Scrapping techniques.
4. Connection configuration: SAC must be configured in order to connect it to the DB server.
5. Software download and installation: Apache Tomcat and JRE (Java Runtime Environment).
6. Components configuration: Configuration of SAPCP (SAP Connector Cloud) and SAP Analytics Cloud Agent.
7. Creation of SAC model: There must be created a model in SAC for the data loading that DB server contains.
8. Automatic loading programming: For the instantaneous interaction of DB data from SAC.
9. Creation of an analytical application in SAC: It works as an interface for the end user to interact with the tool, by means of consultation and indicators visualization through forecast functionalities.

3.2.1 Components

– Sources: The DSS-RSL model uses as data sources the user enterprise's DB, an official institute's data that shows demographic data, data from www.Urbania.pe web page about construction projects and Google Maps for establishments information.
– Ingestion: The extracted data is consolidated, processed, and prepared to be inserted in the DB SQL Server 2012 engine.
– Analysis: All collected information is analyzed by the SAC Algorithm, which includes four phases: Trend's hypothesis, cycle detection, stochastic detection, and final selection model (see Ref: https://www.sapanalytics.cloud/resources-your-guide-to-time-series-forecasting/).
– Results: The DSS-RSL model calculates the list of indicators considered as relevant for the decision-making on the location of retail stores.
– Consumption: The end user consumes the dashboards that SAC allows to show from the query that has taken place.

4 Validation

4.1 365M

365M is a Peruvian firm that began operations with a convenience store in Lima Metropolitana at the end of 2014, and currently has 5 stores, where an available

Fig. 2 Query interface

service is offered 365 days a year and 24 h a day. 365M billed $1.3MM in 2018 and it is in an expansion process. The problem of location of a new store involves a tedious and diffuse work, which involves the collection of data, indicators, and analysis, and that can last 21 days. Many times, this process does not contemplate some data that could be relevant to the decision-making process, which can be then negatively impacted in the business development.

4.2 Implementation of DSS-SRL in 365M

To implement the DSS-RSL in 365M, the necessary data was extracted from its servers, using scripts that were then executed in the DSS' DB. Then, we only proceeded to access the SAC tool from the web, from where the user could make the query, as shown in Fig. 2, and see the dashboards with the indicators (see Fig. 6).

4.3 Experiment

The experiment conducted to validate the proposed DSS consists in five cases. Each case consists of the withdrawal of a store, to predict the functionality indicators in the location of the withdrawn store for the months of January–May of 2019, using the data from January–December of 2018, and finally compare the predicted indicators with the real indicators from the removed store. 365M has five stores installed in Lima, Peru (a, b, c, d, and e). The experiment was conducted simulating the removal of each of the five stores for the months January–May of 2019.

– Case 1: stores b, c, d, and e.
– Case 2: stores a, c, d, and e.

– Case 3: stores a, b, d, and e.
– Case 4: stores a, b, c, and e.
– Case 5: stores a, b, c, and d.

4.4 Results

Indicators I1, I2, and I3 have been considered since the study company only has historical information on them. The results obtained were compared with the actual data of the company in line graphs by the indicator in Figs. 3, 4, and 5.

The current process of Location Selection on 365M includes five activities: define an expansion opportunity, visit and rate the location of interest, evaluate the market and generate an order of implementation. These activities require three, two, fourteen, and two days, respectively, to perform, the implemented DSS is oriented to support

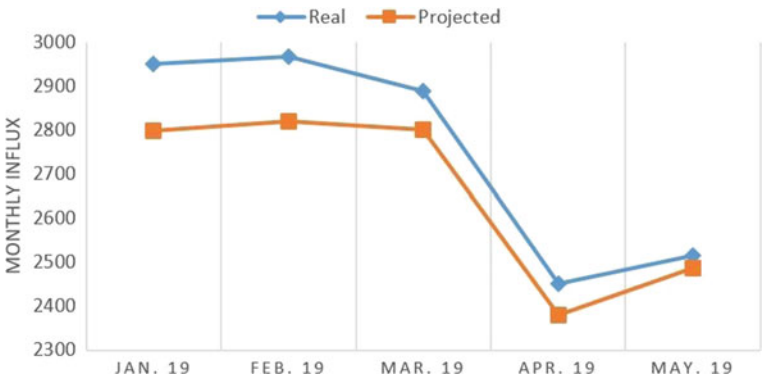

Fig. 3 Average monthly ticket real and projected (I1)

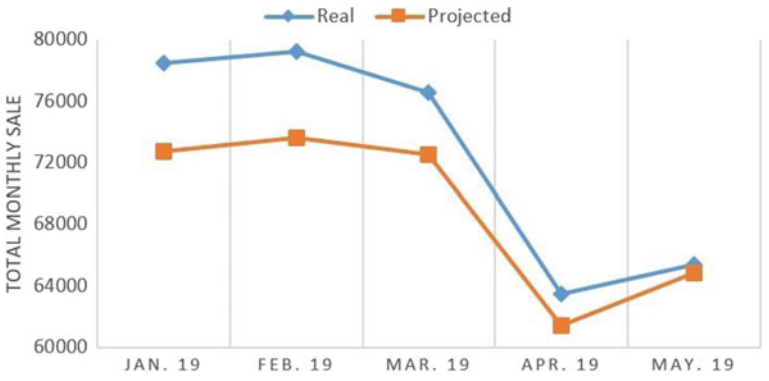

Fig. 4 Monthly influx real and projected (I2)

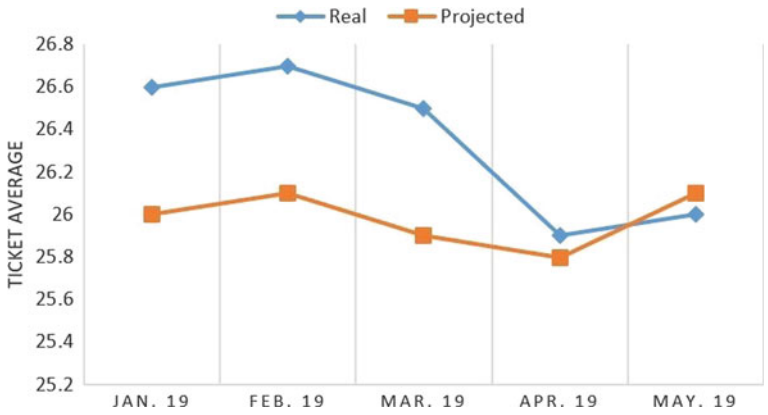

Fig. 5 Total monthly sale real and projected (I3)

Table 3 Activity market evaluation

	Conservative scenario	Optimistic scenario
365M DSS-RSL	7 days	0 (few minutes)

Table 4 Average error

Id	Case 1 (%)	Case 2 (%)	Case 3 (%)	Case 4 (%)	Case 5 (%)
Ticket average	1.23	1.02	1.04	1.58	1.89
Monthly influx	2.96	2.59	2.54	2.67	2.79
Total monthly sale	3.91	3.38	3.1	3.42	3.04

the Market Evaluation activity, Table 3 shows the time that the activity would take using the DSS.

Also, the error percentage of the indicators was calculated in each case of the experiment, as can be appreciated in Table 4.

5 Conclusions

This work has developed a DSS called RSL for the selection of retail store locations, which is based on the prediction of indicators for decision-making, where considers demographic, sociographic, geographic, and company data, likewise, it presents visualization tools that facilitate understanding and interaction with the end user for a better analysis.

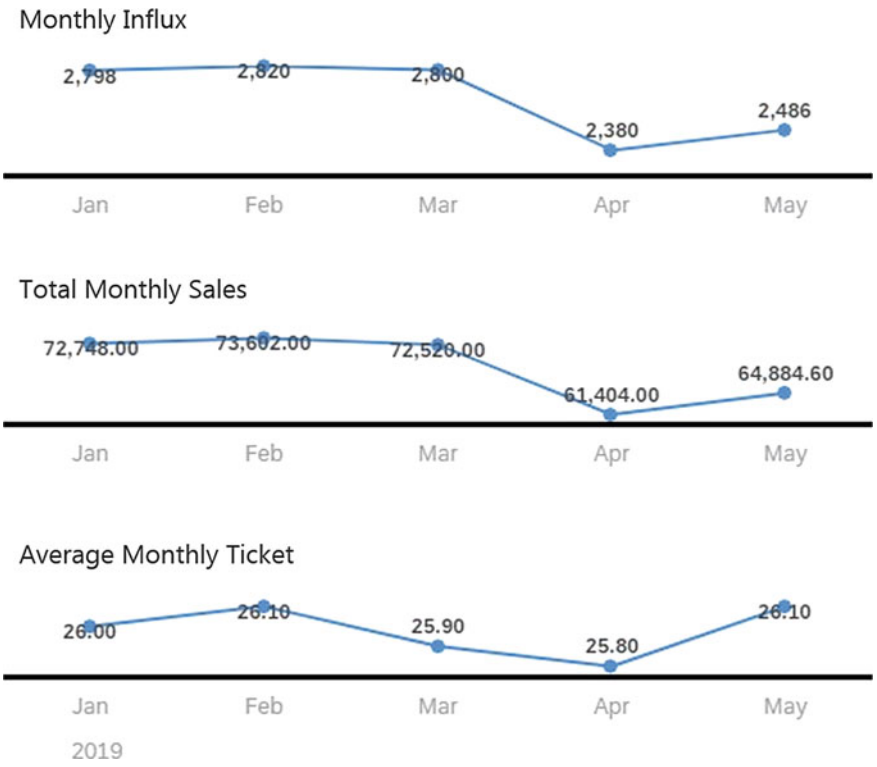

Fig. 6 Dashboards with indicators

The experiment conducted in an expanding retail company shows the effectiveness of the proposed DSS by obtaining an error margin average of the data projected and actual data less than the 1.36% for ticket monthly average, 2.71% for the monthly influx, and 3.39% for the monthly sale. In addition, it is shown that the time for obtaining market data, estimating indicators, and predicting them from days to minutes is reduced (See Fig. 6).

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TCO App: Telemonitoring and Control of Pediatric Overweight and Obesity

Diana Huapaya, Diego Marin, and David Mauricio

Abstract Continuous monitoring of the body condition of an overweight pediatric patient is of utmost importance for the success of his or her treatment. However, this represents a challenge after the first consultation because many parents present problems of time to attend the controls in the office, in addition to lack of tools to support monitoring from home, thus causing a high rate of dropout. There are telemonitoring applications for people with obesity that send data in real time, but they are focused on adults; they do not consider pediatric patients or their parents as agents of change. For this reason, TCO is presented as a mobile application for telemonitoring and control of overweight and obesity in pediatric patients, which facilitates the specialist in the communication, follow-up, and orientation of their patients through family members or caregivers, considering anthropometric indicators, automatic monitoring through rules, prescription of the food plan, and recommendation of foods and dishes of the season and region. A case study was carried out with two groups of 16 overweight and obese pediatric patients, one of them using TCO. The results show that the dropout rate was reduced by 38%, and both body mass index and average waist circumference improved by 4% and 3%, respectively. In addition, family members who did not dropout were surveyed, and satisfaction was obtained between "High" and "Very High" in the use of the application as an aid to monitoring and compliance with treatment.

Keywords Telemonitoring · Control · Obesity · Overweight · Children

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M. V. García et al. (eds.), *Advances and Applications in Computer Science, Electronics and Industrial Engineering*, Advances in Intelligent Systems and Computing 1307,
https://doi.org/10.1007/978-981-33-4565-2_6

1 Introduction

Pediatric obesity is a public health disease associated with having twice the risk of cardiovascular disease, type 2 diabetes, psychological problems, and early death in the future [20]. It is also a risk factor for COVID-19 [36]. In 2016, 124 and 213 million children were diagnosed as obese and overweight, respectively. According to the World Health Organization (WHO), there will be more children and adolescents struggling with obesity than with malnutrition in 2022 [8].

The tracking of overweight patients after the first consultation has become a challenge. Since specialists do not have periodic information on the progress of the patient regarding their anthropometric data (weight, height, waist circumference), they can't identify if the treatment provided is working or not [10]. Also, many parents allege a lack of time to accompany their children to their periodic checkups, as well as a lack of tools to support them [35]. This causes a high early dropout rate without presenting improvements. Remote monitoring (telemonitoring) is a viable alternative to solve these issues.

On the other hand, the World Health Organization (WHO) raises among its strategic objectives to reduce childhood obesity, promote the development of technological solutions that facilitate the periodic control of body weight, and that bring together various components, focusing on the patient's family [1, 31]. Telemonitoring solutions are currently in development for overweight people that contribute to overcoming distance and time barriers by sending data in real time to health providers. These applications will make it possible to assess the patient's condition [28]. However, these solutions are focused on adults and other chronic diseases. Thus, no evidence of telemonitoring using anthropometric data has been found in overweight and obese children, counting on their parents as agents of change. On the other hand, there are mobile applications to support parents in the control of pediatric overweight and obesity, which also include videoconferences with specialists [23], however, these applications do not allow periodic monitoring or evaluation of the status of the pediatric patient.

Therefore, in this paper, we propose a TCO App, a web and mobile application for telemonitoring and control of overweight and obesity in pediatric patients. TCO considers three profiles: the nutritionist, the pediatric patient, and the patient's family. The application allows the family member to register data such as weight, to be sent in real time to the nutritionist who receives alerts/notifications of the results and statistics. This way, after an evolutionary analysis, the dietitian can record or modify the diet plan, send comments, receive feedback, schedule sessions, have videoconferences, and maintain dialogs through a chat. The application is also based on monitoring rules that propose recommendations, depending on the results of the patient, for the family member to evaluate. In this way, the child adapts to the nutrition plan and weight improvement challenges are suggested for the child to apply.

This article is organized into five sections. The second section presents the literature review on telemedicine solutions, telemonitoring models, and existing mobile applications that support the control of pediatric overweight and obesity. In the third

section, the proposal for a telemonitoring and control of pediatric overweight and obesity application is detailed. In the fourth section, we present the validation performed through a case study at a health center in Lima, Peru. Finally, the fifth section culminates with the conclusions and results obtained from the validation.

2 Mhealth for Obesity in Pediatric Patients

MHealth is the use of mobile devices, telecommunications, and technology to promote education, remote monitoring, and communication for health care [26]. In [35], it is shown that 76% of overweight pediatric patients abandon treatment after 6 months, alleging a lack of time to attend checkups and a lack of tools to support their treatment from home. This problem is highlighted by the World Health Organization (WHO), which suggests that the development of telemedicine and mHealth, in that sense, should include parents or caregivers of children as agents of change during the treatment of patients [1, 30]; only in this way could be overcome the barriers of face-to-face visits, long distances and insufficient resources [18, 27].

In [20], a video conferencing program was implemented via mobile. On the other hand, in [33], a short messaging service (SMS) was used. Both showed improvements in parental satisfaction, considering these tools as effective, economical, and convenient. A survey in Pennsylvania perceived the need to have a web or a mobile application to increase the effectiveness of a successful program (accessibility, suggestions, recipes) [19, 24], and with this objective, parents of obese children could use these tools as a support for the treatment of their children [22]. Consequently, various mobile applications are in development.

In Table 1, an inventory of mobile applications to support the control of overweight and obesity in pediatric patients, with the participation of parents, is presented. This table includes characteristics such as profiles, anthropometric indicators (physical dimensions of the body at different ages and its comparison with reference standards [25]), patient ages, specialist interface, informative content, patient management module, appointments, reports, and videoconferences.

The tools present various characteristics, contents, as well as the use of video conferences. In addition, they use indicators such as the Body Mass Index (BMI), Waist Circumference (WC), and the Body Fat Index (BFI), which is considered effective in measuring overweight and obesity [29, 34]. However, specialists do not have an interface for monitoring. Therefore, most specialists send their comments through e-mails or social networks. In addition, the recommendations provided by the applications are usually generic and the only weight measurement is performed before and after the patient's intervention. Likewise, these applications do not include remote monitoring that is essential for this type of diseases [11], on the contrary, for other diseases such as diabetes in adults, it has presented good results [38]. (See Table 1).

Table 1 App for the support and control of overweight and obesity in pediatric patients

Characteristics	MiniStop [32]	TeenPower [37]	Time2bHealthy [23]	AimBe [27]
Profiles	Family	Family	Family	Family, patient
Anthropometric indicator	BFI, BMI	BMI, WC	BMI	BMI
Patient ages	4–5	12–16	2–5	10–17
Specialist interface	No	Website	No	No
Informative content	Foods	Foods, exercises, tips, recommendations, chat, notifications	Foods, exercises, tips, recommendations, screen time, notifications, e-mail reminders	Foods, exercises, tips, recommendations, notifications
Patient management	Yes	Yes	Yes	Yes
Appointment management	No	Yes	No	No
Videoconferences	Yes	Yes	Yes	Yes
Report management	Yes	Yes, dashboards	No	Yes

3 TCO App

3.1 Model

A telemonitoring and control model of pediatric overweight and obesity is proposed, which allows remote monitoring automatically through rules and manually by a specialist, it also considers the prescription and participation of a family member or caregiver.

The family member registers the pediatric patient's data in the application, where the overweight and obesity indicators (A. Capture) are calculated. All of these indicators are registered in a patient database stored in the cloud (B. Registration). Then, automatic monitoring is carried out through the monitoring rules (C. Automatic Monitoring), which, according to the evolution of the patient, automatically generate recommendations for food, exercises, and recipes. In critical cases, the specialist will be informed of the patient's status via the application. Periodically, the specialist will evaluate the patient's evolution (D. Manual Monitoring), and if necessary, will prescribe a treatment (meal plan and recommendations), through the prescription module (E. Prescription), which is sent in real time to the family member for posterior application to the pediatric patient (See Fig. 1).

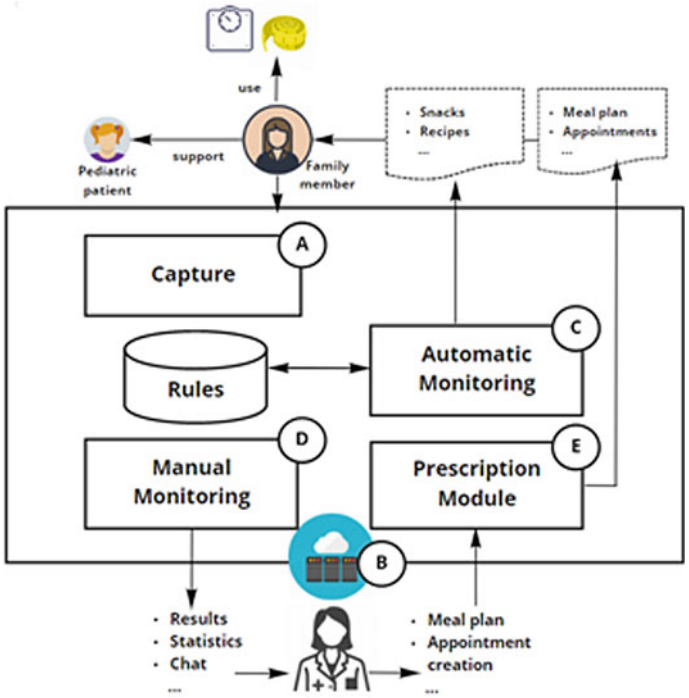

Fig. 1 TCO model

Table 2 Profiles that intervene in the TCO model

Profile	Description
Family member or caregiver of the patient	A family member or caregiver of the overweight or obese patient who performs the measurements of anthropometric data and manages the application of the treatment to the patient
Pediatric patient	An overweight or obese child whose indicators are evaluated and whose treatment is provided through their family member or caregiver
Specialist (nutritionist)	Nutrition professional also called a dietitian, who provides treatment and follow-up to overweight and obese pediatric patients

The profiles that intervene in the TCO model are the family member, the specialist (usually, a nutritionist), and the pediatric patient (see Table 2).

Table 3 BMI and its interpretation for children from 12 to 15 years old, adapted from [17]

Age	Ideal	Normal	Overweight	Obesity
12	17.5	15.8–19.9	20.0–23.5	23.6–30
13	18.2	16.4–20.8	20.9–24.8	24.9–3.7
14	19	17–21.8	21.9–25.9	26–33.1
15	19.8	17.6–22.7	22.8–27	27.1–34.1

A. Capture

The family member, following the indications of the specialist (via Videoconferences) or the application (which uses the home protocol of the Centers for Disease Control and Prevention [27]), enters the following data in the application: weight in kilograms or pounds, height in meters, waist in centimeters, and other data such as age, gender, and region. Then, on the mobile device, the calculation of the Body Mass Index (BMI) is obtained from the formula: weight/(height x height) [3], which, together with the waist circumference, are the indicators used to identify the nutritional status of the patient.

B. Registration

The captured data is stored in a database on a cloud server. Among the stored data is the historical Body Mass Index (BMI), Waist Circumference (WC), ideal weight (final goal), corrected weight (short-term goal), recommendations (exercise videos, recipes, and snacks), reports, meal plan, comments, messages, and scheduled appointments.

C. Automatic Monitoring

Automatic monitoring is done by using rules that are based on the body mass index, waist circumference, regions, and seasons.

Body Mass Index (BMI). The following weight categories have been considered: ideal, normal, overweight and obese, based on the World Health Organization's (WHO) growth table for children from 5 to 19 years of age. This table includes 410 records differentiated by gender and age [17]. Part of this table is presented in Table 3.

Waist Circumference (WC). The following waist circumference categories have been considered: ideal, normal, overweight and obesity, based on [21], for children from 2 to 18 years of age. This table includes 35 records differentiated by gender and age. Part of this table is presented in Table 4.

Regions. It refers to the regions that share the same physical and ecological characteristics, to take advantage of the food produced in each region. For example, in Peru, there are the coastal, Andean, and Amazonian regions.

Table 4 Waist circumference for children from 12 to 15 years old, adapted from [21]

Age	Ideal	Normal	Overweight	Obesity
12	67.4	63.5–74.3	74.4–84.8	+84.8
13	69.5	65.4 –76.8	76.9–88.2	+88.2
14	71.5	67.2–79.4	79.5–91.6	+91.6
15	73.5	69.1–81.9	82–95	+95

Seasons. It refers to the climatic seasons, which are useful for suggesting seasonal fruits and vegetables, as well as recipes based on these; since their nutritional properties remain intact, and they are usually cheaper. For example, in autumn, some of the coastal region's seasonal fruits are the following: strawberries, pineapples, granadillas, tangerines, oranges, and grapes.

Monitoring rules have the following structure:

$$\text{If} \ll \text{combination (BMI, waist circumference, region, season.)} \gg \text{Then} \ll \text{recommendation} \gg$$

The combination is a result of the conditions for the four parameters. The recommendations refer to the suggestions given that correspond to a combination (for example, diets, food, exercises, advice, among others). Below is an example of a monitoring rule

If BMI and waist circumference result in obesity, the patient's region of residence is in the coastal region and the season is fall, then, only recommendations for foods that are lower in fat and sugar are shown, according to the National Heart, Lung, and Blood Institute Information Center (NHLBI) [16], recipes and snacks adapted to the foods that are most frequently produced in the autumn in the coastal region of that country.

D. Manual Monitoring

The results of the automatic monitoring, along with the evolution statistics, reports, and alerts are updated with each data capture in the specialist interface. The specialist can also access video calls and usage analytics for future decision-making through a PC or laptop.

E. Prescription

If deemed necessary, the specialist modifies the meal plan, schedules virtual appointments, sends recommendations or comments to the patient interface.

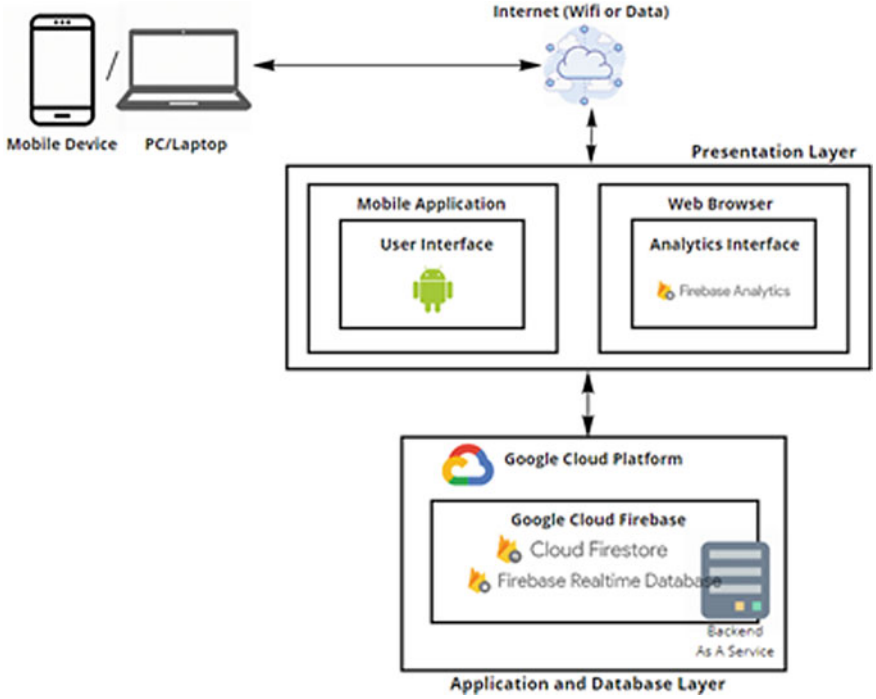

Fig. 2 Integration architecture for TCO App development

3.2 Development of the Application

The architecture used for the development of the TCO application was based on a cloud Backend as a Service model. The interface was programmed for Android devices. In Fig. 2, the integration architecture with the logical and physical components used is shown.

3.2.1 Application and Database Layer

A Mobile Backend as a Service (mBaaS) platform was chosen to link the application to backend storage in the cloud. This platform was also chosen because it allows user management, push notifications, and integration with social networks [13], which accelerates product development. The mBaaS platform used is Firebase, which is part of the Google Cloud, from which we used.

Cloud Firestore. It is a NoSQL database that allows data to be easily stored, synchronized, and consulted [4]. Here the information of the application was stored through collections and documents like the identifiable data of the users (names, surnames,

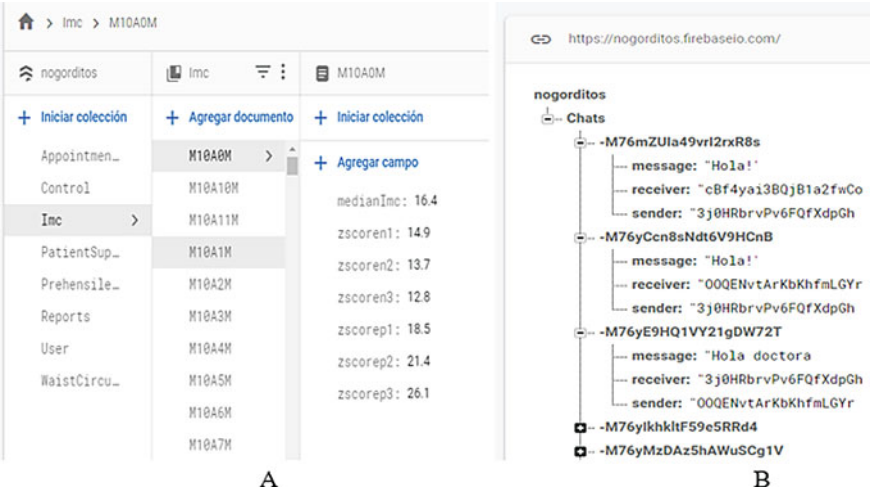

Fig. 3 Firebase: **a** Cloud firestore to store the application rules; **b** Firebase realtime database for the application messages

age, etc.), the information of the registered nutritional controls, reports, diets, and the monitoring rules.

In Fig. 3, a part of the collection of BMI growth tables [17] mentioned in Sect. 3.1 is shown. Documents were stored according to the gender and age of the patient, considering the following nomenclature: M = "Man", W = "Woman", A = "Years", M = "Months". For example, "M10A0M" is equivalent to a male patient of 10 years and 0 months. In each document, the fields corresponding to the percentiles that define whether the patient is overweight or obese were saved.

Firebase Realtime Database. It is a NoSQL database that stores and synchronizes messages between users in real time [6]. It was used for the integrated chat between the specialist and the family members. In Fig. 3, the different messaging transactions are displayed, which are broken down into the content of the message, the identifier of the sending user and that of the receiving user.

3.2.2 Presentation Layer

TCO App was implemented for Android devices because it is the predominant operating system with 70.68% of users worldwide [14], thus Android Studio 4.0.1 was used. The application is compatible with Android version 6.0 (marshmallow) and later. From this android version, is the most used according to StatCounter [12] covering 84.90% of users who use Android worldwide.

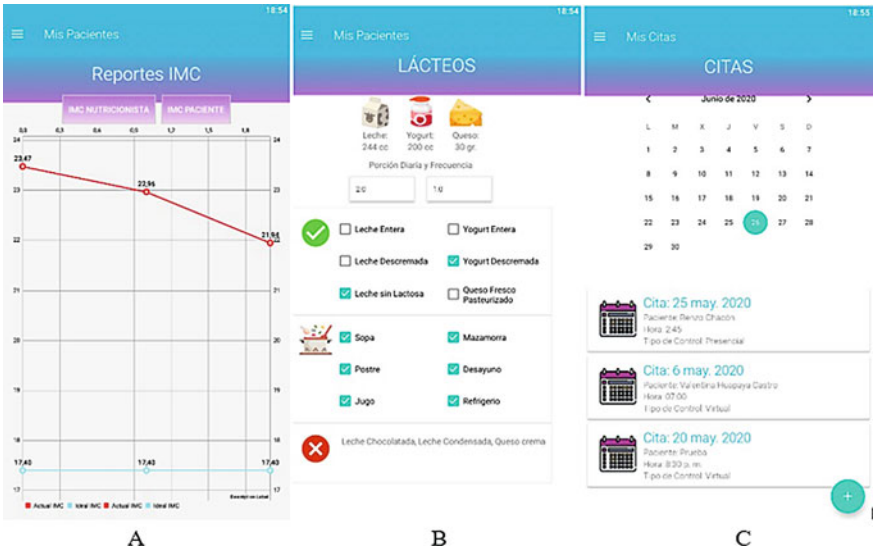

Fig. 4 TCO functionalities for the specialist: **a** Monitoring; **b** Prescription and **c** Agenda

The programming was done with java using the Model View Controller (MVC) pattern so three different parts were obtained for the information classification, the interface, and the system logic. This allows the application to be maintainable and robust, as well as offering greater speed by being able to work on each part in parallel and reusing the views. Also, Google Analytics for Firebase was integrated as a web interface to display statistics on the use of the application.

TCO has interfaces for the pediatric patient's specialist and family member profiles. The functionalities for the specialist are monitoring through the report of the patient's improvement, prescription of the meal plan, consultation schedule, among others. In Fig. 4, an example of BMI monitoring is shown through a patient's reports, her diet plan with the selected allowed foods, and the appointment schedule. The family member's functionalities include the registry of checkups, such as weight, waist circumference, consultation of personalized recommendations, among others.

On the other hand, to monitor the use of TCO, Google Analytics was used, which allows identifying the most used functionalities, geographical areas of use, among other functionalities. In Fig. 5, the most used sections of the application and the country where most sessions are held are shown.

Fig. 5 Google Analytics: **a** Most used functionalities, **b** Geographical areas of use

4 Validation

To validate the TCO App, a case study was conducted in Peru, a country that presented 19.3% of childhood obesity in the year 2018 [15].

4.1 Case Study

TCO App was validated in a nutritional office in a hospital in Lima, Peru, focused on pediatric care, which attends children from 5 to 16 years old, where they treat diseases such as obesity. In the office, approximately 20 children a month are cared for by a nutritionist who specializes in overweight and obesity. Monitoring is done in person when patients attend their medical appointment, which, on average, is monthly. Control and calculations are carried out manually and then transferred to the medical record system. The medical prescription is delivered to the family members in physical documents. Regarding the meal plan, it does not include typical dishes from the patient's region. Also, there is a high dropout rate and little improvement in the child's disease.

4.2 Adaptation of Rules

The parameters of the BMI, WC, region, and season established for the monitoring rules were adapted for the Peruvian population. There are 3 geographic regions that cover the territory: Coastal (Southeast to Northeast), Andean (Linked to the Andes mountain range), and Amazonian (part of the jungle) [9] In addition, the autumn season (the period between March 21 and June 21), 50 snacks, 90 fruits and vegetables, and 50 recipes were considered, with which 84 rules are obtained.

These rules were obtained from public sources such as the Ministry of Health [7], the National Heart, Lung, and Blood Institute Information Center [16], and all the images of the application interface were obtained from the Envato Elements platform [5] by paying an annual license fee. Some of these rules are shown below:

R01. If (Result of BMI Overweight + Result of WC Overweight) then (A green approval symbol is displayed and shows the message: "You are in your best nutritional state. Maintain your healthy style").

R02. If (Result of BMI Overweight + Result of WC Overweight + Coast Region + Autumn) then (It is recommended to consume or acquire oranges, tangerines, strawberries, papayas, peaches, granadilla, apples, avocado, mango, soursop, etc., prepare recipes such as chicken liver or rice with chicken and snacks that include bread with an omelet, orange soda, hard-boiled eggs, etc. [2, 7]) (See Fig. 6).

R03. If (Result of BMI Obesity + Result of WC Obesity + Amazon Region + Autumn) then (It is recommended to consume or acquire aguaymanto, camu camu, star fruit, cocona, aguaje, taperiba, pineapple, blanquillo, granadilla, soursop, mango, etc., prepare recipes such as chicken juane or caigua stuffed with ground meat and

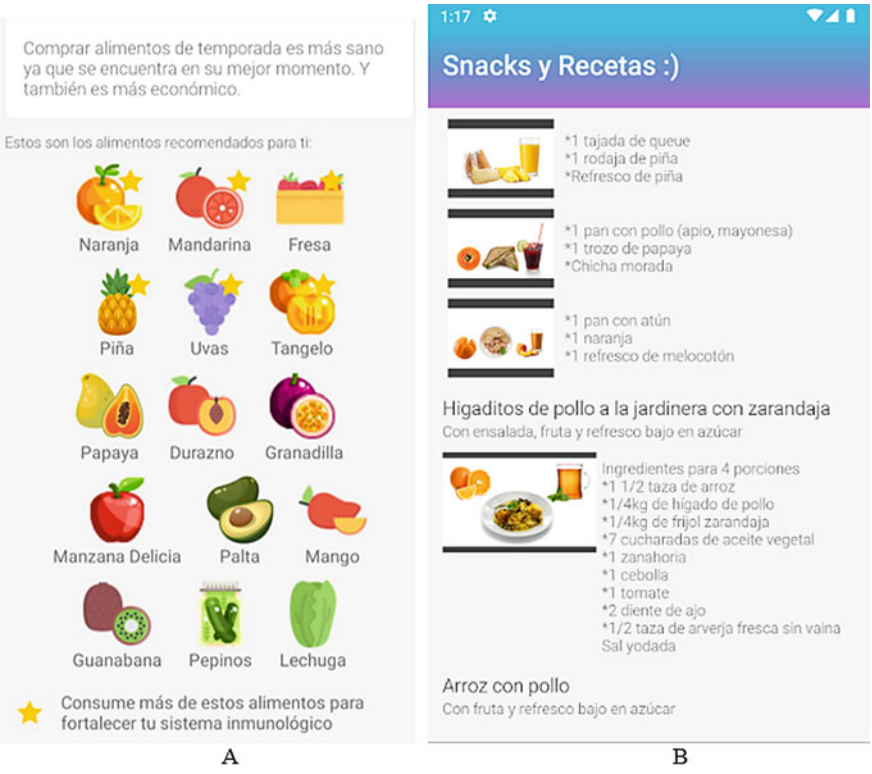

Fig. 6 **a** Fruits and vegetables recommendations, **b** Snacks and recipes

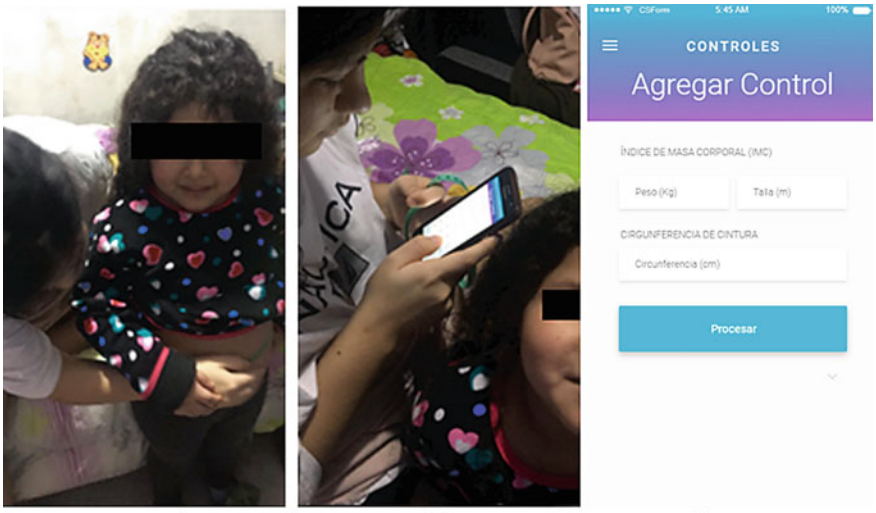

Fig. 7 Measurement registry by parents: **a** overweight child; **b** Registration, **c** Registration interface

snacks that include inguiri with chicken, passion fruit soft drink, parboiled green banana, etc. [2, 7]).

4.3 Experimentation

Two groups of 16 patients were formed. The first group performed the traditional treatment (face-to-face visits and without an application) while the second group used the TCO App. In both cases, the trial period was eight weeks. For the other group, the father of the family was asked to record patient data every week (See Fig. 7). The fathers were trained in the use of the application modules and the proper form of measurement using the scale and measuring tape. Regarding the patients, it was considered that they did not present complications or were diagnosed with genetic disorders. Then, the informed consent was requested from their respective parents about their participation in the study.

4.4 Metrics

The dropout rate (patients who discontinue treatment), the BMI, and WC were determined before and after the intervention. Lastly, a questionnaire with questions about the use of the application (see Table 5) was presented to the parents of the TCO group.

Table 5 Usability and utility questionnaire

N	Questions
Q1	How much did the app help you monitor your child's overweight/obesity?
Q2	Do you think that the suggestions provided helped you to comply with the treatment?
Q3	How easy was it for you to use the application?
Q4	How useful do you think the "TCO App" is?
Q5	How often would you use the app to monitor and control your child's overweight/obesity?
Q6	Would you recommend this application to other parents to monitor and control their children's overweight/obesity?

The questionnaire's alternative responses followed the Likert scale (0: not at all, 1: very little, 2: a little, 3: moderately, 4: high; 5: very high).

4.5 Results

As can be seen in Fig. 8, the number of relatives and patients in both groups decreased over the weeks (dropout), which is usual in many treatments such as diabetes, hypertension, and other chronic diseases [28]. Some parents were called in order to ask the motives of the dropout in treatment. In the traditional group, parents commented that they did not have time to go to the hospital, the lack of results (note that the problem did not reduce), and few food options made them lose their motivation. On the other hand, in the TCO group, the lack of time and issues with their internet connection were mentioned. In the end, the dropout rate for the traditional group was 63%, while in the TCO group it was 25%. Ergo, TCO shows a dropout reduction of 38%.

After eight weeks, in the TCO group, the average BMI and WC improved by 6% and 4%, respectively; while the traditional group had improvements of 2% and 1% (See Table 6). Therefore, the group with the application obtained better results,

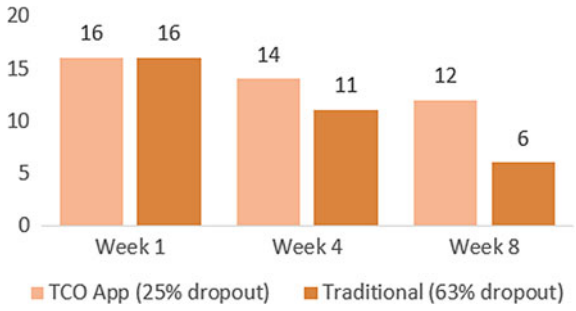

Fig. 8 Reduction in dropout rate

Table 6 Results of the overweight indicators

Indicator	Traditional		TCO APP	
	Before	After	Before	After
BMI average	21.23 kg/m^2	20.87 kg/m^2	21.63 kg/m^2	20.26 kg/m^2
WC average	72 cm	71.7 cm	73.9 cm	71 cm
BMI improvement	2%		6%	
WC improvement	1%		4%	

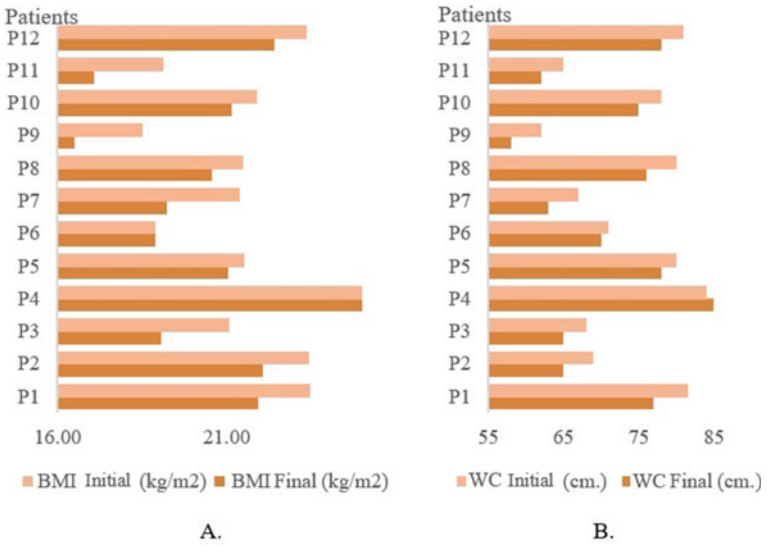

Fig. 9 BMI and WC for the TCO group, at the beginning and end of the study: **a** BMI; **b** CC

specifically, a 4% reduction of the BMI and a 3% reduction of the WC. Similar progress results were obtained in [29], where different behavior change techniques were applied in combination to nutritional interventions, obtaining as the main finding after 6 months an average difference of 0.53 kg/m^2 BMI and 1.45 kg weight between the groups that were part of their intervention compared to a control group to which they didn't apply tests. Therefore, it is considered that, at the same time of validation, the results for TCO improve in comparison to those obtained. As additional data, there were significant improvements in 83% of patients in the TCO group. Also, those with higher BMI and WC were the patients who decreased their weight and girth the most when completing the validation (See Fig. 9).

The questionnaire (see Table 5) was applied to the relatives of the patients who remained in the TCO group (one of the parents was responsible for two patients). This way, the results obtained are shown in Table 7. The results show that 100% responded with "High" and "Very high" to questions about aid to monitoring (Q1), compliance with treatment (Q2), and perception of utility (Q4). On the other hand,

Table 7 Questionnaire results

Family member	Questions					
	Q1	Q2	Q3	Q4	Q5	Q6
F1	5	5	4	5	4	5
F2	4	5	5	4	4	4
F3	4	5	3	5	4	4
F4	5	5	3	5	5	5
F5	5	5	4	5	4	5
F6	4	4	4	5	4	4
F7	5	4	4	5	5	5
F8	4	4	4	5	4	5
F9	5	5	5	5	4	5
F10	5	4	3	5	5	5
F11	4	5	4	4	4	4
Average	4.55	4.64	3.91	4.82	4.27	4.64

regarding usability, the average responses for ease of use (Q3) and frequency of use (Q5) are between "High" and "Very high". When asked, "Would you recommend TCO (Q6)?" 100% responded with "High" and "Very high".

5 Conclusions

In this work, TCO was developed, a mobile application for telemonitoring and control of overweight in pediatric patients that facilitates the communication, monitoring, and guidance of their patients through family members or caregivers. The Android application was built on Firebase, a backend as a service model in the cloud that allowed quick development avoiding application and database server configuration, as well as making user management and push notifications easier. TCO considers anthropometric indicators that help to control and monitor, it performs automatic monitoring through rules established by the specialist, allows the prescription of a meal plan by the nutritionist, and recommends seasonal food and dishes from the region.

A case study was performed in a nutritional clinic of a health center in Lima, with two groups of 16 overweight and obese pediatric patients, one of them used the TCO application and the other followed traditional monitoring. The results show that the dropout rate was reduced by 38% for the group that used the application in relation to the traditional monitoring group. Additionally, the TCO group improved its average BMI and WC by 6% and 4%, respectively, while its counterpart had improvements of 2% and 1%. That is, TCO helped reduce dropout and improved treatment results.

In addition, a survey was conducted among the pediatric patients who did not abandon the treatment, obtaining results on the satisfaction aspect, between "High" and "Very High" to aid monitoring, compliance with treatment, and the perception of the utility, results that are repeated for the aspects of ease and frequency of use. Furthermore, 100% of respondents would recommend using TCO for monitoring and treating overweight and obese children.

For future works, it is proposed to develop a knowledge acquisition module that allows the automatic monitoring rules and the recommendations according to the context of the area and season to be kept up to date. Also, an integration between the application and the patient's digital medical history is proposed.

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Topical Part: Electronics Engineering

Feature Evaluation of EMG Signals for Hand Gesture Recognition Based on Mutual Information, Fuzzy Entropy and RES Index

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Abstract In the field of hand gesture recognition based on electromyography, the selection of features is still a matter of research because the accuracy of feature evaluation techniques depends on the distribution underling a feature space. Currently, there are a lot of kinds of features, so a selection method is required in order to find an optimal feature subset. The selection of features can be done based on either classifier methods or statistical measurement indexes. On one hand, the use of classifier methods takes considerable time, consequently, they are computationally expensive. On the other hand, the use of a statistical index allows to select features based on properties, and they are less expensive in terms of time and computational costs. In this context, this study analyzed different statistical indexes to discover optimal feature subsets and predicts which one may have the best performance in terms of classification and recognition accuracy. For this purpose, four indexes were analyzed: the sum of RES (separation and compactness index), the sum of Fuzzy Entropies, and both of these indexes divided by the mutual information of feature subset. These index values were calculated for 10 different feature subsets obtained from nineteen time-domain features which have been investigated by many researchers for extracting useful information from an electromyography signal. The feature subsets

This work has been supported by the Corporación Ecuatoriana para el Desarrollo de la Investigación y la Academia (CEDIA) and Escuela Politécnica Nacional.

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M. V. García et al. (eds.), *Advances and Applications in Computer Science, Electronics and Industrial Engineering*, Advances in Intelligent Systems and Computing 1307,
https://doi.org/10.1007/978-981-33-4565-2_7

were implemented in four classifiers (Artificial Neural Network, k-nearest Neighbors Algorithm, Support Vector Machine, and decision trees) to find the best statistical index which tries to quantify the suitableness of the feature space. Each tested index in this work was analyzed in terms of classification and recognition accuracy for each machine learning algorithm.

Keywords Hand gesture recognition · Electromyography · Feature evaluation · Fuzzy entropy · Mutual information · Myo armband sensor

1 Introduction

Surface electromyography (EMG) is a noninvasive method which carries the actual information of voluntary movement without problems of occlusion or light changes [13]. It is widely used in many engineering and clinical applications such as control of leg prostheses, characterization of low back pain and hand gesture recognition [5, 23, 29, 47]. An important aspect of an EMG hand gesture recognition system is the gathering of EMG signals to identify various gestures. This system consists of the following stages: (1) data acquisition, (2) preprocessing, (3) feature extraction, (4) classification, and (5) post-processing. In this paper, we focus on feature extraction because it plays an important role to increase the classification accuracy. It is important to note that if the classifier does not have an appropriate input, the system cannot provide good performance. The main purpose of feature extraction is to obtain distinctive and non-redundant features that represent accurately the gesture [33].

Feature extraction can be done in time, frequency, and time-frequency domain [16, 22]. However, in order to reduce the computational cost [18], this study was focused only on time-domain features which do not require additional signal transformation due to these features are calculated based on raw EMG time series [37]. For this purpose, nineteen time-domain features have been chosen based on the literature review of hand recognition systems [9, 39, 40, 46]. These are: mean absolute value (MAV), wavelength (WL), zero crossing (ZC), slope sign change (SSC), average amplitude change (AAC), log detector (LD), root mean square (RMS), difference absolute standard deviation value (DASDV), myopulse percentage rate (MYOP), Willison amplitude (WA), simple square integral (SSI), variance of EMG signal (VAR), modified mean absolute value (MMAV), modified mean absolute value 2 (MMAV2), maximum fractal length (MFL), enhanced mean absolute value (EMAV), enhanced Wavelength (EWL), mean value (MV), and standard deviation (SD).

Since EMG signal is a complexity, nonstationary, and nonlinear signal [1], finding an optimal feature set for a classifier is not an easy task because the problem of grouping features is combinatorial. For instance, choosing the best subset of 5 features among a total set of 10 will require 252 experiments, meanwhile the best subset of 10 features among 100 will require 1.7310e+13 experiments. For this reason, several studies have focused on two main methods to develop an EMG recognition system:

(i) classification accuracy and (ii) statistical criteria [21]. These methods are selected to improve the accuracy of classification and recognition through the elimination of irrelevant features [10, 11, 25, 26]. The first approach has a major disadvantage because evaluating a feature set (chosen by the researcher's experience) with each classifier will take a long time to reach a high recognition performance (trial and error) [34].

The second approach tries to quantify the suitableness of a feature space [28]. Therefore, several studies use methods based on a statistical criterion for feature evaluation such as: Fishers linear discriminate index [45], Bhattacharyya distance [24] and Davies-Bouldin index [44]. However, none of them focus on determining which index is the most efficient for selecting an optimal EMG feature subset. As a solution to this problem, we analyze the use of RES index and fuzzy entropy (FE) to compare different feature subsets and predict which one may have the best performance. Furthermore, the mutual information (MI) is also taken into account for this proposal. RES index is based on the distance between two scatter groups (Euclidean distance) and the variation of samples in the same group (standard deviation) [26].

This index is characterized by its low computational cost and easy implementation [15]. For its part, fuzzy entropy is a measure of information content which is used to determine a suitable feature set for classification systems and to evaluate the separability among features [8, 19]. This index is a variation of Shannon's entropy, and it is measured by calculating membership values of occurring elements. Finally, mutual information defines the dependency of each given feature set in order to reduce redundancy and improve the classifier performance, as is presented in [2].

In this paper, we want to determine if the proposed indexes are effective metrics to improve the performance of hand gesture recognition systems using EMG signals. The indexes are: (i) sum of RES index (sRES), (ii) sum of fuzzy entropy (sFE), (iii) ratio of RES index and mutual information (RESMI), and iv) ratio of fuzzy entropy and mutual information (FEMI). For this purpose, ten sets of random features corresponding to each statistical index were chosen among nineteen time-domain features from a total of 524287 ($2^{19} - 1$) combinations.

Once the ten feature sets for each index have been found, they are used to design the recognition systems. In this case, four popular machine learning classifiers are implemented to determine which index provides better accuracy in classification and recognition. Classification will be understood as the problem of identifying the corresponding class of a given gesture, regardless of its time of occurrence. Whereas recognition involves assigning to every signal point a label, taking into account the time of the gesture occurrence. The evaluation protocol follows the guidelines proposed in [48].

The algorithms were k-nearest neighbor (k-NN), feed-forward artificial neural network (ANN), Support Vector Machine (SVM) with polynomial kernel, and decision tree [4, 7, 14, 20] and the selected gestures were the same gestures recognized by the proprietary system of the Myo Armband (wave-in, wave-out, fist, open, pinch). To find the best feature set of each index, 50 users were used, while another group of 50 users was used to evaluate the classification algorithms.

The results of this study will present the usefulness of the EMG feature extraction based on statistical indexes. The organization of this paper is as follows: Section 2 presents the dataset and methodology. Section 2.5 discusses the experimental results. Finally, the conclusions are presented in Sect. 3.

2 Dataset and Methodology

2.1 Dataset

In this research, EMG signals are measured using the MYO Armband sensor. These signals are collected through 8 bipolar channels with a sampling frequency 200 Hz. In addition, this device has an inertial measurement unit of nine-degrees of freedom (accelerometer, gyroscope, and magnetometer) and haptic feedback. The sensor was placed in the right forearm of each user and EMG data was transmitted via Bluetooth to the computer. This placement was established according to Rhodes et al. [32] to get the most accurate motor unit potentials of the muscles. To build the dataset, the users performed 50 repetitions of each gesture (wave-in, wave-out, fist, pinch, and open), including the relax gesture which belongs to the class no-gesture, resulting in a total of 300 samples per user. Each repetition was recorded during 5 s following a continuous sequence of 3 positions: relax, gesture, and relax.

Once the data collection process for 100 users was carried out, the fifty samples for each gesture were divided into 50% for training and 50% for testing. Most of the users were university students between 21 to 29 years and the gender proportion was 70% for male and 30% for female. EMG data from fifty users were used to find the EMG feature subsets and the other fifty users were employed to evaluate the classification and recognition of the four machine learning algorithms. The proposed gestures are shown in Fig. 1.

Fig. 1 Hand gestures recognized in this paper

2.2 Features

The proposed features were selected due to their simplicity and promising performances in previous works to recognize hand gestures [3, 27, 28, 39]. The nineteen time-domain features are described as follows:

Mean Absolute Value (MAV) is a function that returns the average of the absolute value of the EMG signal amplitude. Wavelength (WL) represents the cumulative length of waveform over time [38], Zero Crossing (ZC) calculates the number of times that the values of EMG signal crosses zero [40]. Slope Sign Change (SSC) describes frequency information of the EMG signal, as the number of times that the slope changes from positive to negative or vice-versa [35]. Average Amplitude Change (AAC) indicates the average of the number of changes of the amplitude in a time span signal [3]. Log Detector (LD) points out a good estimation of the exerted force [41]. Root Mean Square (RMS) describes the muscle force and non-fatigue contraction [17]. Difference Absolute Standard Deviation Value (DASDV) is the standard deviation absolute value of the difference between the adjacent samples [30]. MyoPulse Percentage Rate (MYOP) represents the mean of myopulse output in which the absolute value of EMG signal exceeds the pre-defined threshold value [40].

Willison amplitude (WA) is used as an indicator of the firing of motor unit potentials [27]. Simple Square Integral (SSI) is represented as the sum of square values of EMG signal amplitude. Modified Mean Absolute Value 1–2 (MMAV 1–2) are variations of MAV feature by assigning the weight window function [42]. Maximum Fractal Length (MFL) gives a measure of the strength of contraction. MFL has the logarithmic scale, making it less sensitive to noise [6]. Mean Value (MV) is the average value of the EMG signal amplitude. Standard Deviation (SD) measures the dispersion of the EMG signal. SD indicates how the data are scattered respectively to the average. In addition, the following two features, enhanced mean absolute value (EMAV) and enhanced wavelength (EWL), were taken from [40], and they allow us to analyze mainly the information content at the middle region of the EMG signal. In addition, the researchers in [12] reported which MAV and RMS features gives a better quality in class separability viewpoint.

2.3 Feature Evaluation Indexes

The indexes used to select EMG feature subsets are: sum of RES index (sRES), sum of fuzzy entropy (sFE), ratio of RES index and mutual information (RESMI), and ratio of fuzzy entropy and mutual information (FEMI). sRES index is evaluated in order to know if the recognition error decreases when the value of RES index increases. RES can evaluate the distance between several scatter groups (separation index) and directly address the variation of feature in the same group (compactness index) [34].

The RES index uses the ratio between the Euclidean distance (ED) and the standard deviation (SD) to determine the performance of the time-domain features [31]. A good quality in class separation means that the result of classification accuracy will be as high as possible. In other words, the best performance of classification is obtained when the ED value is high, and the SD value is low. Therefore, the RES index should be large in order to obtain better performance. Reference [15]. The definition of the RES index is as follows:

$$RES_{index} = \frac{ED}{SD} \tag{1}$$

In (1), the ED is calculated as the root of the square differences between coordinates of a pair of classes in a $n-$dimensional Euclidean space (8 channels). The Euclidean distance can be expressed as

$$ED = \frac{2}{K(K-1)} \sum_{p=1}^{K-1} \sum_{q=p+1}^{K} \sqrt{\left(\overline{f}_1^p - \overline{f}_1^q\right)^2 + \cdots + \left(\overline{f}_8^p - \overline{f}_8^q\right)^2} \tag{2}$$

where $\overline{f}$ is the mean EMG feature corresponding to each channel, p and q are gesture numbers (waveIn = 1, waveOut = 2, fist = 3, pinch = 4, open = 5, noGesture = 6) and K is the total number of gestures ($K = 6$). Furthermore, SD is represented as

$$SD = \frac{1}{IK} \sum_{i=1}^{I} \sum_{k=1}^{K} s_i^k \tag{3}$$

where s_i^k is the standard deviation corresponding to each EMG feature, i is the channel number ($1 \leq i \leq I$, $I = 8$) and k is the gesture number ($1 \leq k \leq K$, $K = 6$). It is important to mention that the EMG features from each channel of all gestures were normalized (from 0 to 1). The sRES of a feature subset is obtained by adding the RES index of each feature belonging to the same subset, as follows:

$$sRES = \sum_{n=1}^{N} RES_{index_n} \tag{4}$$

where RES_{index_n} is the RES index of a feature, n is the feature number ($1 \leq n \leq N$) and N is the total number of features belonging to a feature set.

For sFE index, fuzzy sets are used to improve the estimation of the entropy. The measuring of the fuzzy entropy is different from Shannon entropy since fuzzy entropy has fuzziness uncertainty, while Shannon entropy has randomness uncertainty [19]. In this research, fuzzy entropy is calculated for each feature f_i and is determined as follows:

1. Given a universal set of elementary values $\mathbf{x}_h$ in the feature dataset as $\mathbf{X} = \{\mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_h\}$, where h is the total number of patterns.
2. Let $C = \{wi, wo, op, fi, pi, ng\}$, where $wi, wo, \ldots, ng$ represent the six gesture classes: "wave-in", "wave-out", "open", "fist", "pich" and "no-gesture", respectively. Each feature in the data is separated into six classes.
3. $SC_i(\mathbf{x}_h)$ describes a set of elements of class i from the universal set $\mathbf{X}$.
4. The fuzzy set uses the matching degree to classify the features. Thus, matching degree class q is calculated as follows:

$$P_q = \frac{\sum_{h \in SC_{i(\mathbf{x}_h)}} \mu_{f_i}(h)}{\sum_{h \in \mathbf{X}} \mu_{f_i}(h)} \tag{5}$$

   where $\mu_{f_i}(h)$ is the mapped membership degree of the element $\mathbf{X}_h$ with the set $SC_i(\mathbf{X}_h)$.
5. The fuzzy entropy, belonging to the class q, is represented as

$$FE_{C_q}(f_i) = -P_q \log P_q \tag{6}$$

6. The total fuzzy entropy of feature f_i is the sum of fuzzy entropy values of all classes, as follows:

$$FE = \sum_{q=1}^{K} FE_{C_q}(f_i) \tag{7}$$

   where $K = 6$, representing the six gesture classes of this proposal

The sFE of a feature subset is obtained by adding the FE index of each feature belonging to the same subset, as follows:

$$sFE = \sum_{n=1}^{N} FE_n \tag{8}$$

where FE_n is the FE index of a feature, n is the feature number ($1 \leq n \leq N$) and N is the total number of features belonging to a feature subset.

In this paper, the mutual information (MI) index was used in order to evaluate the "information content" of each feature subset. Mutual information analyzes the relevance of different feature subsets and the mutual dependencies. The estimation of the mutual information for continuous variables was calculated through Information Theoretical Estimators Toolbox (ITE). This package is an open source and multi-platform toolbox which is able of estimating entropy, mutual information, divergence, association measures, cross quantities, among others [36]. The mutual information of the d_j-dimensional components of a feature data $\mathbf{X} = \{\mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_h\} \in \Re^d \left(d = \sum_{j=1}^{h} d_j\right)$ is:

$$\mathbf{I}\left(\mathbf{x}^1,\ldots,\mathbf{x}^h\right)=\int_{\Re^{d_1}}\cdots\int_{\Re^{d_1}}df\left(\mathbf{u}^1,\ldots,\mathbf{u}^h\right)\log\left[\frac{df\left(\mathbf{u}^1,\ldots,\mathbf{u}^h\right)}{\prod_{j=1}^{h}df_j\left(\mathbf{u}^j\right)}\right]d\mathbf{u}^1\cdots d\mathbf{u}^h \tag{9}$$

where df is the joint density function of $\mathbf{X}$ and df_j is its jth marginal density. As it is known, $\mathbf{I}\left(\mathbf{x}^1,\ldots,\mathbf{x}^h\right)$ is non-negative and is zero, if and only if the $\left\{x^j\right\}_{j=1}^{h}$ variables are jointly independent. The criterion which estimates the mutual information of a feature set is Hilbert-Schmidt independence criterion (HSIC). This criterion was chosen after several tests on different independent datasets. HSCI presented more exact values than Kernel Canonical Correlation Analysis (KCCA) and Kernel Generalized Variance (KGV).

The relationship of sRES and sFE with MI for a feature set is the most suitable approach for estimating dependency between features. This approach has the capacity to show the uncertainty of a feature set and is defined as follows:

$$RESMI=\frac{sRES}{MI} \tag{10}$$

$$FEMI=\frac{sFE}{MI} \tag{11}$$

Therefore, ten random feature subsets are generated for each index. The method applied to select the EMG feature subsets is shown in Sect. 2.4.

2.4 Selection of the Feature Subsets

To evaluate the proposed features, 50 users were used in this stage. Five random samples of each gesture were chosen corresponding to each user. Therefore, 250 samples for gesture were analyzed. Then, the samples were segmented in order to have only the section with the muscle activity. After that, the segmented signal is divided into windows with a length of 15 and a stride of 15 points. Each window is filtered with a sixth order Butterworth low pass filter 75 Hz, and finally the 19 features are extracted. The results of each feature were concatenated to evaluate their performance.

Subsequently, ten random feature sets are chosen from a total of 524287 ($2^{19}-1$) combinations based on sRES, sFE, RESMI, and FEMI indexes. The combinations were selected maintaining the same separation interval for each index. From the combinations obtained for each index, the four classifiers (ANN, SVM, k-NN, decision trees) were designed. The architecture of the four classifiers was described in Sect. 2.5.

2.5 Hand Gesture Recognition Systems

The experiments were designed to evaluate the classification and recognition accuracy using different index values over four different classifiers (k-NN, ANN, SVM, and decision trees). The recognition systems used an user-specific approach as a common hand gesture recognition architecture. In other words, the system was trained and tested for each user. The result corresponding to each system consisted of the average of the results of the tested users. In addition, this architecture employed a sliding window approach with a window size of 15 and a stride of 15 points. For this case, an EMG sample, represented by a matrix 1000×8, will have 66 nonoverlapping windows of size 15×8. The system analyzes one window at a time, ignoring future information temporally. With this approach, the model simulates a real-time functionality. In our experiments, a total of 50 users were tested.

The preprocessing applied to the current window is identical to the preprocess used for calculating the indexes. The nineteen features were extracted from the filtered window. In this context, the filter employed was a sixth order Butterworth low pass filter 75 Hz. Then, 10 different feature subsets were tested for every index (in total, 40 different subsets). After extracting the feature subset to the filtered window, a feature vector is obtained through concatenation. This feature vector represents the classifier input and was normalized to range 0 to 1. The training set for the classifiers was generated from labeled feature vectors of all windows of the repetitions in the training group of a user. Approximately 9900 examples were concatenated corresponding to a user's model. This number was obtained from the 150 samples (training samples) and each sample contains 66 nonoverlapping windows.

The user model was evaluated over the 150 samples of the test group (testing samples). Similarly, sliding windows were generated and the same preprocessing was applied. For each analyzed window, the user model returns a class prediction (one category of the classes described in Sect. 2.1) forming a vector of predictions. In addition, a post-processing to filter spurious predictions is applied. This post-processing consists of replacing the current prediction with no-gesture when it is different from the previous one. The predicted class of a sample is the most common class (without considered no-gesture) among the vector of predictions.

The architecture of the hand gesture recognition system was maintained for all experiments, and only the type of classifier was changed. In this paper, the classifiers were ANN, SVM, k-NN, and decision trees.

Regarding the ANN, a hidden layer of 5 units with tansig as activation function was selected. Its output layer has softmax, and the loss function is cross-entropy. The number of hidden units was chosen to fulfill the condition that the training examples must be much larger than the number of weights. In this proposal, the worstcase scenario appears when a feature subset is composed of all the proposed features. It means that the neural network will be composed of 152 inputs (19 features by 8 channels). The corresponding number of weights in a neural network with 152-5-6 neurons would be 801. With this neural network size, the condition is fulfilled for the worstcase scenario (9900 training examples for a user model $\gg$ 801 weights).

For its part, SVM was designed based on a third order polynomial kernel, and the decision trees have 2 minimum observations per leaf. Finally, k-NN algorithm uses 10 neighbors for its decision. This value was selected as a close integer value to $log_2(N)$, where N is the size of the classifier training set.

As a result, 120 classifiers were developed (40 classifiers for each index) with different EMG feature subsets (Appendix A). Each classifier is evaluated in terms of classification and recognition. The measurement of these metrics is described as follows: A classification will be correct when the label returned by the hand gesture recognition model (i.e., prediction) matches the target's label. This approach does not take into account the time and order of the labels [43]. A classification result is obtained employing a sliding window to create a vector of predictions. This vector of predictions is analyzed to get an equivalent unique prediction as a classification result. If this prediction matches the true label, the classification is correct. On the other hand, the recognition evaluation compares a vector of predictions with the current instant of time corresponding to gesture occurrence (i.e., ground truth) [48]. This vector of predictions is valid if it has just one segment of the same consecutive labels. Otherwise, the overlapping factor is not calculated, and the recognition is declared as incorrect. The recognition is correct when the overlapping factor is greater than a given threshold. Equation (12) represents this comparison through the ρ overlapping factor.

$$\rho = 2 \cdot \frac{|A \cap B|}{|A| + |B|} \tag{12}$$

where A and B are the sets of time instants when it exists muscle activity. Set A and set B corresponds to the ground truth and the vector of predictions, respectively. In addition, $|A|$ and $|B|$ are the size of each set.

The objective of the experiments in this paper is not aimed at showing high recognition precision values. On the contrary, our analysis aims to evaluate each feature subset and determine a quantitative measure for the feature extraction.

3 Results and Analysis

In this Section, the results of the four feature evaluation indexes described in Sect. 2.3 are presented. The experiments were carried out over a new set of 50 users. This set of users is different from the set used to calculate EMG feature subsets. The results of classification and recognition accuracy of the four classifiers are compared and illustrated in each chart. The figures show the average accuracies among the set of 50 users used in the evaluation. Figures 2 and 4 show the performance of the four classifiers for all selected features subsets according to sRES and sFE index. In addition, Figs. 3 and 5 describe the performance of the four classifiers for ten features subsets for RESMI and FEMI, respectively.

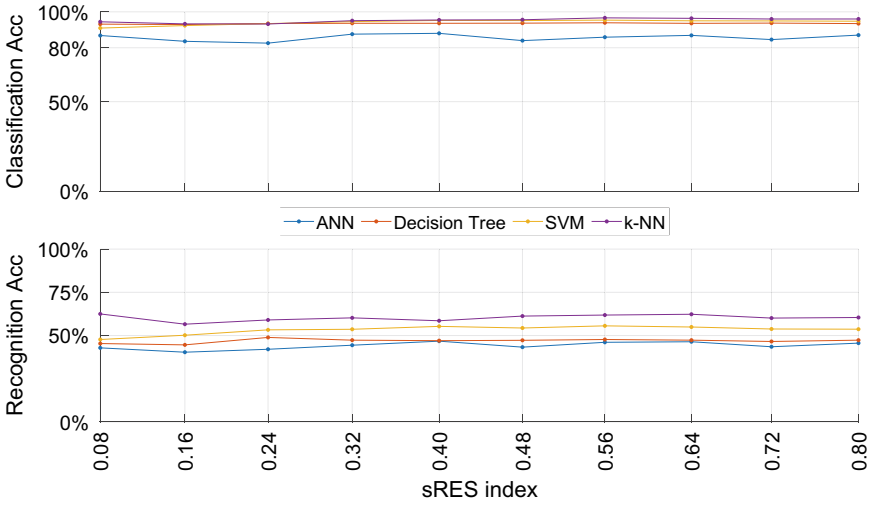

Fig. 2 Classification and recognition accuracy of the four classifiers evaluated on different values of the sRES index (the sum of the RES index)

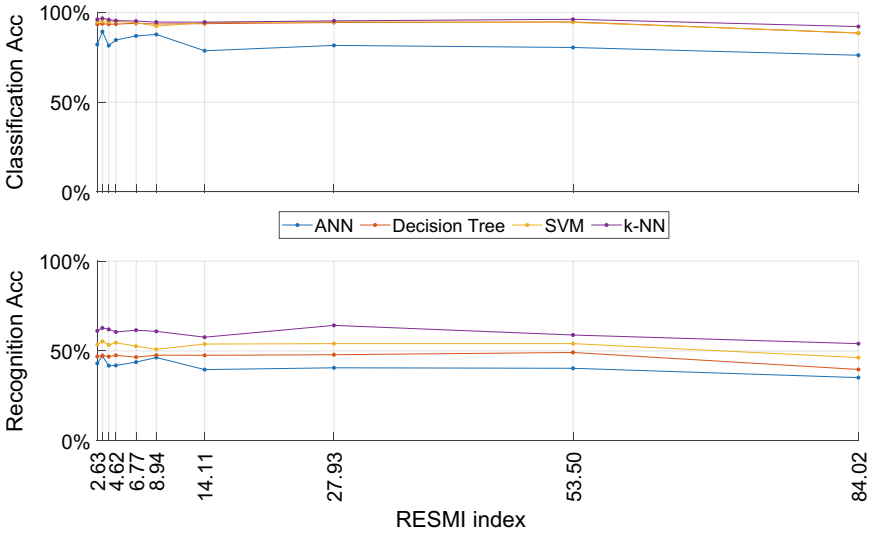

Fig. 3 Classification and recognition accuracy of the four classifiers evaluated on different values of the RESMI index (the sum of the RES index divided by the mutual information)

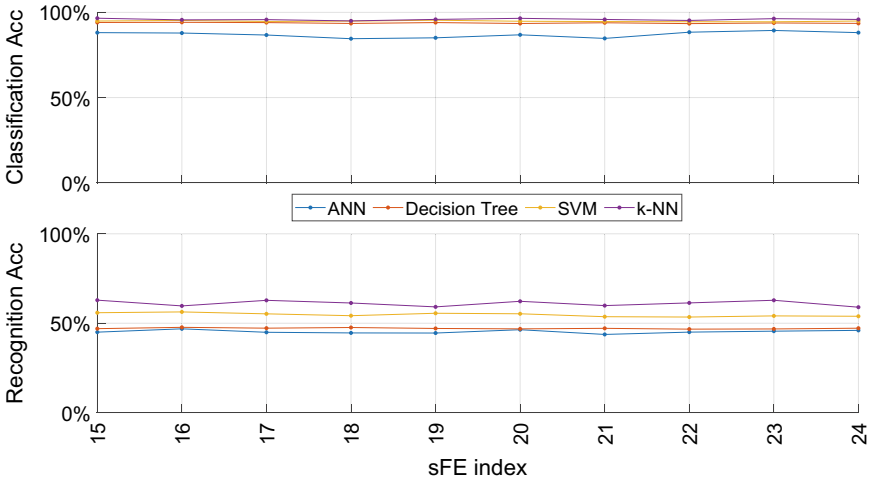

Fig. 4 Classification and recognition accuracy of the four classifiers evaluated on different values of the sFE index (Fuzzy entropy)

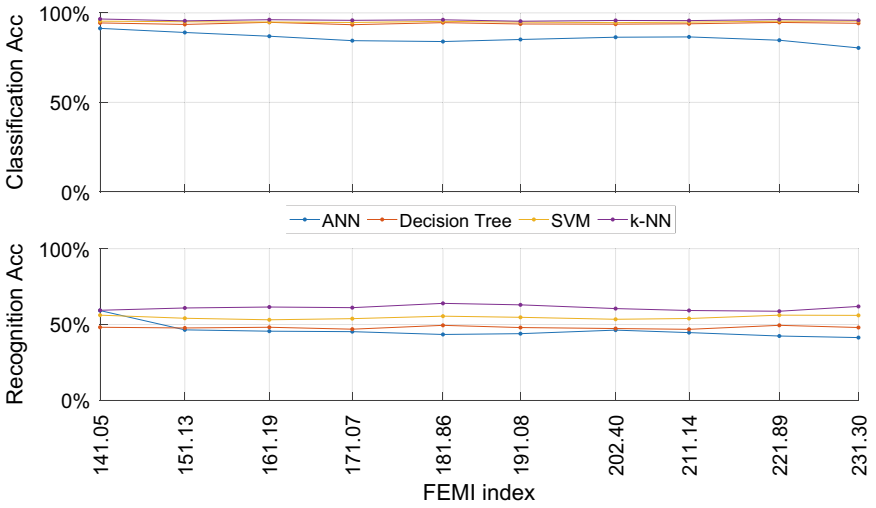

Fig. 5 Classification and recognition accuracy of the four classifiers evaluated on different values of the FEMI index (Fuzzy entropy divided by the MI)

As can be noted, k-NN had the best performance on most of the tested EMG feature subsets for classification and recognition. On the contrary, ANN got the worst performance in our metrics. A possible explanation for this finding could be the ANN limited network complexity. The complexity of the network was chosen to fulfill the criterion that training examples should be much larger than the number of parameters in the network.

It is also important to note that for any model, classification accuracy is higher than recognition. As mentioned in Sect. 2.4, the evaluation of recognition considers the alignment of a valid vector of predictions with the ground truth. A vector of predictions is valid when there is only one class predicted, and its appearance is contiguous in the vector of predictions. Instead, classification analysis only considers the most common class without considering no-gesture. Even in some cases where the vector of predictions contain erroneous predictions, the classification may be correct as long as the true class predominates. This fact implies that the maximum recognition accuracy cannot be higher than the classification accuracy in a hand gesture recognition model. Based on the information obtained from the experiments, the classification accuracy is above 90% in most of the cases, but recognition is between 50% and 60%.

A surprising result is the relationship between the performance metrics (classification and recognition) with the feature evaluation indexes. The tendency that may have been expected would be an increment of the performance while increasing feature index. However, the results of our experiments do not show a clear tendency on any of the feature evaluation indexes tested, either in classification or recognition.

Under the hand gesture recognition architecture defined, the chosen classifier configurations and the feature indexes evaluated, we can assure that the performance of the model remains constant. The feature evaluation index depends directly on the selected feature subset, meanwhile the performance metrics are affected by every stage of the hand gesture recognition model. Varying the feature evaluation index implies varying the feature subset, thus the feature vector input of the classifier will change. Obtaining a similar result with completely different feature sets (e.g., a subset with 2 features against a subset of 19 features) would be counterintuitive. As a result, our findings indicate that the selected feature indexes are not fit to the problem of hand gesture recognition using EMG, and that the prepossessing and post-processing stages play a significant role in classification and recognition accuracy.

4 Conclusions

The EMG signals provide a large set of features that can be selected for hand gesture recognition systems. However, the selection of a subset of features that provide us an optimal recognition accuracy without consuming considerable time and computational resources is challenging. In this context, the present work analyzed 4 indexes for evaluating the performance of subsets of features and their relation with the classification and recognition accuracy: (1) the sum of RES (sRES), (2) the sum of RES

divided by the mutual information (RESMI), (3) the sum of fuzzy entropies (sFE), and (4) the sum of fuzzy entropies divided by the mutual information (FEMI).

The results of this study demonstrate that the variation of the 4 indexes does not imply necessarily a significant variation of the classification and recognition accuracy. Our findings suggest that, for the problem of real-time hand gesture recognition based on EMG, changes in the data acquisition, preprocessing, and post-processing modules could have a more significant impact on the accuracy rather than changes in the combination between the classifiers and the selected features. Similarly, although most of the feature selection techniques are heuristic, they do not necessarily assure the best performance in terms of accuracy.

These findings are not conclusive but open a hypothesis that needs more experimentation and, potentially, it would initiate a new front for research in an area that is mainly focused on tuning the hyper-parameters of the classifiers.

Acknowledgements The authors gratefully acknowledge the financial support provided by the Corporación Ecuatoriana para el Desarrollo de la Investigación y la Academia (CEDIA) and by the Escuela Politécnica Nacional (EPN) for the development of the research project PIE-CEPRA-2019-13-Reconocimiento de Gestos.

Appendix: EMG Feature Subsets

See Tables 1, 2, 3 and 4

Table 1 EMG feature subsets for the sRES index

Id	# features	EMG feature subset	sRES
1	2	EWL, ZC	0.078
2	4	DASDV, EWL, MV, WAMP	0.159
3	7	MAV, MV, MYOP, SD, SSC, WAMP, ZC	0.238
4	8	EWL, MFL, MMAV2, MV, MYOP, SD, SSC, WL	0.318
5	9	DASDV, LD, MFL, MMAV, MV, MYOP, SD, VAR, WL	0.401
6	12	DASDV, EMAV, MFL, MMAV2, MV, MYOP, RMS, SD, SSC, SSI, VAR, ZC	0.481
7	12	AAC, EMAV, EWL, LD, MAV, MFL, MMAV, SD, SSC, VAR, WAMP, WL	0.559
8	14	AAC, DASDV, EMAV, EWL, LD, MMAV, MMAV2, MYOP, RMS, SD, SSC, SSI, WAMP, WL	0.642
9	16	AAC, DASDV, EMAV, LD, MFL, MMAV, MMAV2, MV, MYOP, RMS, SD, SSI, VAR, WAMP, WL, ZC	0.718
10	18	AAC, DASDV, EMAV, EWL, LD, MAV, MFL, MMAV, MMAV2, MV, MYOP, RMS, SD, SSC, SSI, VAR, WAMP, WL	0.801

Table 2 EMG feature subsets for the RESMI index

Id	# features	EMG feature subset	RESMI
1	19	AAC, DASDV, EMAV, EWL, LD, MAV, MFL, MMAV, MMAV2, MV, MYOP, RMS, SD, SSC, SSI, VAR, WAMP, WL, ZC	2.629
2	12	DASDV, EMAV, EWL, MAV, MFL, MMAV, MMAV2, SD, SSC, WAMP, WL, ZC	3.171
3	17	AAC, DASDV, EMAV, EWL, LD, MAV, MMAV, MMAV2, MV, MYOP, RMS, SD, SSC, SSI, VAR, WAMP, ZC	3.856
4	14	AAC, DASDV, LD, MFL, MMAV, MMAV2, MV, RMS, SD, SSC, SSI, VAR, WAMP, WL	4.617
5	8	DASDV, EMAV, EWL, MMAV, MV, SD, SSC, WL	6.773
6	9	AAC, MAV, MMAV2, MV, SD, SSC, WAMP, WL, ZC	8.940
7	6	AAC, DASDV, EWL, LD, MV, SSI	14.106
8	5	EWL, LD, MAV, SSC, VAR	27.934
9	3	AAC, MMAV, SSI	53.502
10	2	MMAV2, WAMP	84.022

Table 3 EMG feature subsets for the sFE index

Id	# features	EMG feature subset	sFE
1	8	EMAV, WL, ZC, RMS, MMAV, MMAV2, WAMP, MFL,	14.995
2	8	EMAV, WL, RMS, AAC, MYOP, WAMP, MFL, MV,	15.995
3	9	WL, ZC, SSC, RMS, DASDV, MMAV2, MYOP, SSI, VAR,	16.995
4	9	EMAV, SSC, RMS, AAC, LD, MMAV, VAR, WAMP, MV,	17.995
5	10	EMAV, WL, MMAV, MYOP, SSI, VAR, WAMP, MFL, MV, SD,	18.995
6	11	EMAV, EWL, WL, ZC, RMS, AAC, LD, MMAV2, MYOP, VAR, SD,	19.995
7	11	EWL, MAV, WL, RMS, AAC, DASDV, LD, MMAV2, MYOP, MFL, MV,	20.995
8	11	EWL, WL, ZC, SSC, DASDV, LD, MMAV, MMAV2, MFL, MV, SD,	21.995
9	12	EMAV, EWL, WL, ZC, SSC, RMS, AAC, DASDV, MMAV, MMAV2, WAMP, SD,	22.995
10	13	EWL, MAV, AAC, DASDV, LD, MMAV, MMAV2, MYOP, SSI, VAR, MFL, MV, SD	23.995

Table 4 EMG feature subsets for the FEMI index

Id	# features	EMG feature subset	FEMI
1	13	EWL, WL, ZC, SSC, RMS, AAC, DASDV, MMAV, MMAV2, MYOP, SSI, MFL, SD	141.045
2	15	EMAV, EWL, MAV, WL, ZC, AAC, DASDV, MMAV, MMAV2, MYOP, SSI, VAR, MFL, MV, SD	151.134
3	18	EMAV, EWL, MAV, WL, ZC, RMS, AAC, DASDV, LD, MMAV, MMAV2, MYOP, SSI, VAR, WAMP, MFL, MV, SD	161.192
4	16	EMAV, EWL, MAV, WL, ZC, SSC, RMS, DASDV, LD, MMAV2, MYOP, SSI, VAR, WAMP, MFL, MV	171.065
5	13	EMAV, EWL, MAV, WL, ZC, RMS, DASDV, MMAV, MYOP, SSI, VAR, WAMP, SD	181.855
6	12	EMAV, EWL, MAV, WL, ZC, RMS, MMAV2, MYOP, VAR, MFL, MV, SD	191.079
7	18	EMAV, EWL, MAV, WL, ZC, SSC, RMS, AAC, DASDV, LD, MMAV, MMAV2, SSI, VAR, WAMP, MFL, MV, SD	202.401
8	13	EMAV, EWL, MAV, WL, ZC, AAC, LD, MMAV, MYOP, SSI, WAMP, MV, SD	211.141
9	8	EWL, WL, ZC, RMS, DASDV, MYOP, VAR, WAMP	221.886
10	11	EMAV, EWL, MAV, RMS, AAC, MMAV2, MYOP, SSI, VAR, WAMP, MFL	231.305

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Challenges of Implementing Cleaner Production Strategies in the Food and Beverage Industry: Literature Review

Rodrigo Valle Espinosa, Maria Soto, Marcelo V. Garcia, and Jose E. Naranjo

Abstract Cleaner production (CP) represents a set of strategies in favor of the environment, productivity, and the optimization of manufacturing processes from a holistic point of view that includes the whole life cycle of the product, proactive, preventive, and environmentally friendly strategies through which water consumption is reduced, emissions, waste and the sustainability of the production chain is achieved. In general terms, the implementation of cleaner production strategies in the food and beverage industry represents a saving of 35 % of total costs; the accelerated growth of environmentally conscious markets has forced the industry to implement CP strategies in accordance with the particular line of business, with the aim of remaining competitive in markets where actions on environmental care are becoming increasingly important. This paper presents a qualitative systematic review of the literature (SRL) on the implementation of CP strategies in food and beverage industries and the challenges in applying them, analyzing scientific articles from the last five years, from relevant bibliographic databases (Scopus, ScienceDirect, IEEE Xplore, SpringerLink) synthesized particularly in five proposed topics. From the results obtained, it is concluded that the implementation of cleaner production strategies in the food industry represents an opportunity factor for the sector, not only by combining its actions with the sustainable development objectives for 2030, but also by reducing operating costs and optimizing production lines.

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M. V. García et al. (eds.), *Advances and Applications in Computer Science, Electronics and Industrial Engineering*, Advances in Intelligent Systems and Computing 1307,
https://doi.org/10.1007/978-981-33-4565-2_8

Keywords Cleaner production · Sustainability · Food industry · Eco-efficiency · Beverage industry

1 Introduction

The productive model developed in the twentieth century operated under the criterion that natural resources were unlimited, for years factories managed productive systems that today are ecologically unsustainable. Man used natural resources without any kind of supervision because it was believed that nature was capable of absorbing waste and regenerating itself without affecting the biosphere [28]. Today's fiercely globalized and competitive twenty-first-century markets demand not only a greater variety of products at a reduced cost, shorter delivery time, and perfect quality, but they prefer these products to be ecologically sustainable. This changing scenario requires a new manufacturing paradigm [4].

The main environmental problems presented by industries are energy consumption and the generation of liquid and solid waste and emissions [22, 38]. To minimize environmental impact and increase competitiveness and business economy, industries use strategies of cleaner production (CP) that through technological innovation allows the reduction of manufacturing costs [21, 23].

CP allows energy to be saved, resources to be reused, the quantity of waste and unwanted emissions to be reduced and the consumption of raw materials to be reduced, and is understood as a model of industrial development based on the principle of reasonable use of resources. CP achieves the reduction of post-operational costs of waste management [38]. There are several strategies used by the CP to achieve its industrial innovation process. Among the strategies used are good operating practices, input substitution, improved process control, modification of equipment and machinery, technological changes, product restructuring, internal recycling, generation of products from waste [8, 23]. One of the productive sectors benefiting from these strategies is the agro-industrial sector. The relationship between the agricultural sector and the industrial sector favors the application of CP since it allows the closure of production cycles through the reuse of by-products [9, 38].

Agro-industry is an important part of the economy of South American countries, using as its main resources (inputs) raw materials from the exploitation of land, water, and energy to obtain products and waste (outputs). Due to the inadequate use and/or dumping of the waste generated, negative impacts are caused to the environment and, therefore, to human health [19]. Beverage and liquor companies are part of the agro-industrial sector and also play a key role in the consumption of non-renewable resources, mainly water and energy [34]. The proportion of energy used differs in each country, yet a pattern is observed where the energy consumed by agro-industry in developing countries is generally very high. For example, in African countries, energy consumed by the agro-food chain can contribute up to 55% of national consumption, a high value compared to 15.7% in the United States [1].

In this context, many governments and trade companies recognize the importance of energy-saving practices [34]. CP drives energy savings through well-distributed lighting design [17] and the use of alternative energy such as biomass which is a type of energy produced from plant and animal waste [10]. Another energy alternative is the use of heat pumps that allow the use of waste heat from thermal processes, including drying, cooking, evaporation, among others [1].

Additionally, the implementation of CP in the beverage industry allows for the reduction of the water footprint, benefiting the conservation of the biosphere especially considering that freshwater has become a scarce and overexploited natural resource in many parts of the world, threatening widespread irreversible environmental change and harmful impacts on human well-being [11]. In short, the CP has a practical approach that allows environmental and economic benefits to be balanced in an integrated manner. Replacing production and waste management processes with environmentally friendly operations is a challenge for beverage and liquor companies [20]. Countries such as Canada and Nigeria, the world's leading malt beverage producers, have joined the challenge of a CP [7, 20].

In order to preserve the environment, it is necessary that more companies join this initiative, the following is a bibliographical review that summarizes the results obtained and the main problems presented in the beverage industries when adapting to a cleaner production system, in addition the obtained results will serve to motivate to the agro-industrial companies to optimize the use of raw materials, water, and power resources, focusing the benefits not only from the environmental point of view but also the economic one.

This document is made up of five sections. Following the introduction, section two presents the methodology applied for the selection of articles and for the analysis of the data obtained. In section three is the bibliographic review, the research works analyzed are of implementation, therefore, in this section the results obtained in different companies when adapting to a CP system are presented. Section four contains a critical analysis of the articles analysed, emphasizing energy saving and water reuse, and finally concludes in section five.

1.1 Methodology

For this bibliographic article, we use the methodology of qualitative systematic review, proposed in [31, 32]. Based on this method, a strict review process was carried out to compile scientific publications that were later evaluated under a qualitative approach. In order to answer the questions raised in this research, the first one was What are the problems presented in the food industry when applying CP strategies? and the second one was What are the results obtained by the beverage and liquor industries when changing their processes to CP operations?. In Fig. 1 an outline of the protocol used to obtain relevant data is presented.

Within the databases, the most relevant key terms were generated: cleaner production, renewable energy, food industry, and ecologically sustainable production

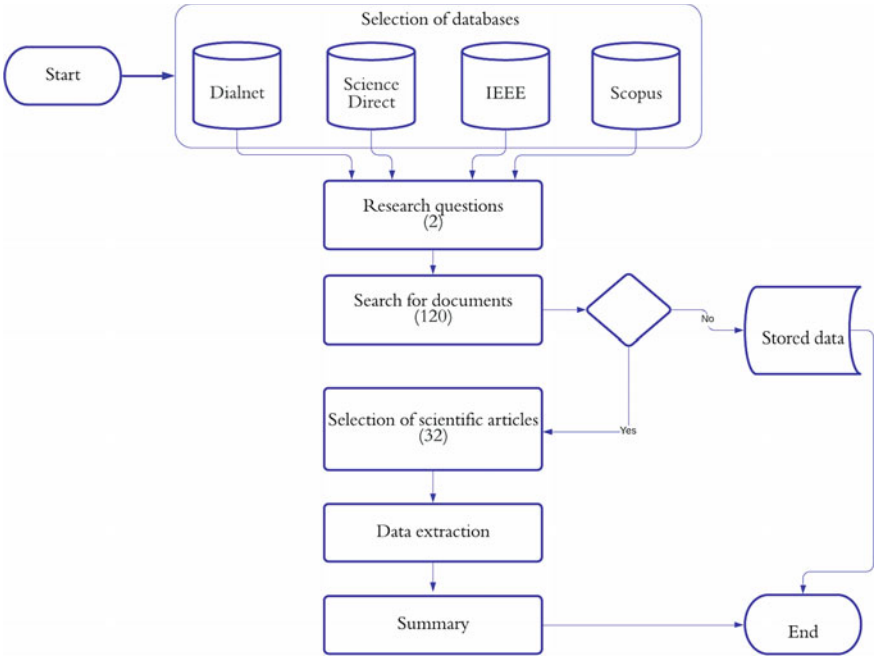


Fig. 1 Scheme of systematic qualitative bibliographic review

(see Fig. 2). Search criteria were applied prioritizing articles on cleaner production implementation in food industries, publications that have the endorsement of academic peers and papers published in the last five years in English language were chosen. A total of 120 articles were reviewed, of which 49 belonged to Science Direct, 37 to Scopus, 31 to IEEE, and 3 to Dialnet.

For the selection of articles and/or publications, the title was reviewed, followed by the abstract of the publication, to determine the degree of connection they presented with the questions posed in this literature review. When the relationship was high, the conclusions were read and then the introduction was added to the selection of publications that were subsequently analyzed. The 32 articles selected were summarized by answering the questions posed. The bibliographic manager Zotero was used to organize the information collected and the presentation format chosen was Springer.

Based on the data presented in the bibliographic review, a discussion was held consisting of a critical analysis of the progress made, recommendations for future research, and the author's own criteria were issued. The analysis was prioritized in terms of the CP strategies proposed to reduce energy consumption, and the strategies proposed to minimize the water footprint generated by agro-industrial companies dedicated to the production of beverages and liquors.

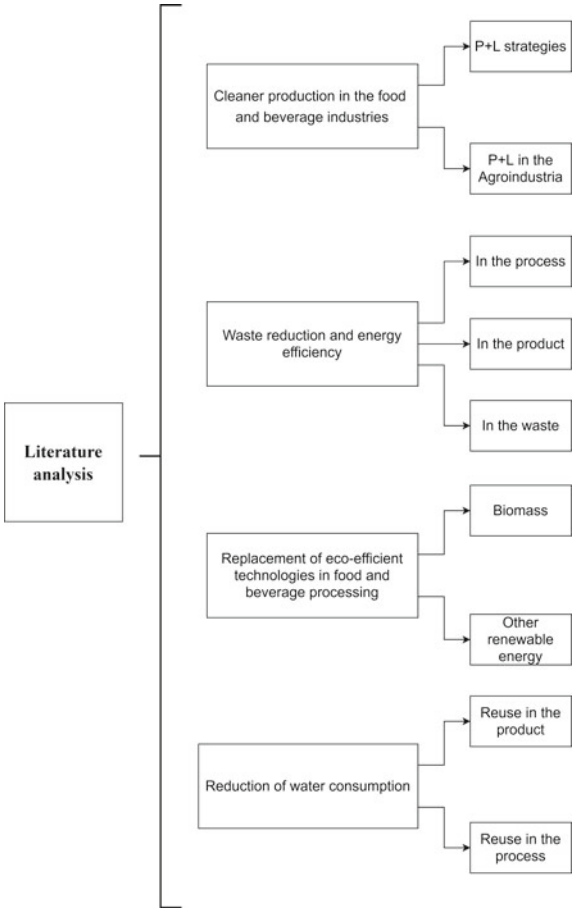


Fig. 2 Literature search relevant topics

2 Literature Analysis

In the case of the food industry, cleaner production (CP) opportunities can be applied by minimizing the loss of raw materials, improving energy efficiency, reducing water consumption, improving cleaning and maintenance practices, improving packaging processes, and properly separating waste; a review of the literature on some strategies applied in the industry is presented below.

2.1 Cleaner Production in the Food and Beverage Industries

Cleaner production represents a proactive and preventive industrial approach to the environment by seeking integrated process and/or product solutions that are both

environmentally and economically efficient ("eco-efficiency"). The pioneers in this field were the large process industries in the United States of America (from the late 1970s), but until the early 1990s, cleaner production was generally recognized as a valuable approach for large and medium-sized enterprises in all industrial sectors [6].

The definition of cleaner production adopted by the United Nations Environment Programme (UNEP) [29] is "The continuous application of a preventive environmental strategy integrated into processes, products and services to increase overall efficiency and reduce risks to humans and the environment".

ANFAB [3] presents in context that cleaner production strategies are the continuous application of integrated policies and preventive environmental methodologies applied to processes, products, and services to increase overall efficiency by 30% and business competitiveness, therefore, the application of these strategies is indispensable in the food and beverage processing industry.

For the food industry, cleaner production (CP) opportunities can be applied by minimizing the loss of raw materials, improving energy efficiency, increasing water consumption efficiency, better cleaning and maintenance practices, improvements in packaging processes and proper waste separation.

Guo et al. [13] argue that the food and beverage industry is potentially a green industry, and the waste is safe and bio-friendly. However, these wastes can pose serious environmental problems if not properly managed. Nooi-Loo [25] states that, worldwide, a large percentage of total wastewater effluent is released by food processing companies without any treatment.

In addition, they point out that, specifically the alcoholic beverage industry whose main process is alcoholic and acetic fermentation; in Malaysia, by 2018 they contributed 35% of total industrial wastewater effluents, representing the fifth most polluting industry in the country, so the implementation of environmental mitigation strategies is essential for the beverage industry, based on government initiatives and corporate environmental awareness. Currently, there is a great demand for research on factors influencing the adoption of environmentally friendly technologies in the food and beverage industry. This concept is supported by Bates et al. [5], who suggested that research within the food and beverage industry should be intensified to improve waste treatment efficiency, and to minimize waste in food processing and manufacturing operations. Fryer [12] considers that from the consumer's point of view the application of cleaner production strategies in the alcoholic and non-alcoholic beverage industry does not represent a focus compared to food safety strategies, however, the continued growth of green markets and environmentally conscious consumers represent an important starting point in the adoption of eco-friendly production strategies. Henningsson et al. [14] describe how waste minimization can be as successful in the alcoholic beverage industry as in other industries that are often considered more polluting. Thirteen companies made annual savings of 1.1 million in the Eastern Angola Beverage Industry Waste Minimisation Project. These alcoholic beverage production companies reduced annually: raw material use and solid waste production by 1,400 tons; carbon dioxide (CO2) emissions by 670 tons; and water use by 70,000 cubic meters.

Abidin et al. [2] state that there are common non-regulatory aspects around the world that are the main limitations when it comes to implementing cleaner production strategies in the food and beverage industry, which are characteristics of environmental technology, communication networks, and efficiency of eco-friendly technologies, which must be adapted to the national reality and the line of business of each company. On the other hand, the most influential factors when implementing cleaner production strategies are focused on socio-political environmental aspects, the demands of the interested parties, the regulatory pressure, and the external governmental and legislative international pressure. In Latin American countries, there are no clear policies of incentive for the adoption of cleaner production strategies, but in contrast isolated public-private initiatives that support their implementation, however, in several countries these initiatives are more consistent than in others, based on their relationship with technology and their adoption processes. These characteristics include the relative advantage it offers compared to implementation costs, its complexity and compatibility with production processes, and how the results of the innovation are presented [24].

According to ANFAB [3], in Ecuador, starting in 2017 the food and beverage industry has deployed several initiatives to implement cleaner production strategies that allow for the optimization of production processes and care for the environment. Hence, the need to continue searching for alternatives such as technology substitution in production processes, leveraging on tax exemptions, incentives and government certifications (green dot, do good, do better) and private credit lines with preferential interest rates for industries with ecological initiatives.

2.2 Waste Reduction and Energy Efficiency

Wu y Low [35] propose a cleaner production alternative for the alcohol production and fermentation industry by recycling distillery residues (stillage) and using ultrafiltration with a ceramic membrane, which increases the average yield of ethanol production by 8.8% thus eliminating the stillage treatment stages using conventional biological treatment processes, such as anaerobic digestion and activated sludge stages currently used in the industry, reducing waste in 92% of the production process.

Notarnicola et al. [26] emphasize that, in the agro-industrial production chain, significant amounts of food-grade material are rejected from the production line because of unsatisfactory quality or out of standard for visual, physical, microbiological, or compositional (chemical or biochemical) reasons.

Reducing the use of raw materials carries the greatest potential for financial savings because this source reduction approach exceeded by more than two orders of magnitude the corresponding savings in landfill costs in an analysis in the UK alcoholic beverage industry in 2015. This reinforces the importance of companies identifying source reduction opportunities, rather than end-of-pipe solutions and the relatively low cost of disposal to the beverage industry.

Currently, with the aim of maximizing waste reduction the food and beverage industries are applying the methodology of life cycle assessment (LCA), which provides the organizational framework to holistically assess the environmental impacts of products and production systems. According to Özbaya and Demirer [37], the use of LCA in the environmental management and sustainability of the food and beverage industries has grown rapidly in recent years, as shown by the growing number of published documents on LCA methodology and case studies, which amounted to more than 4,500 in 2019 in Europe alone, focusing on the reduction of energy consumption or energy efficiency in the LCA chain.

Ikemoto et al. [16] state that the food industry includes many energy-intensive operations such as sterilization/pasteurization, drying, and even refrigeration of products during distribution, storage, and retail. All of this dictates the need to minimize energy consumption as a key element, so it is not feasible to consider only processing operations in isolation from the entire supply chain.

2.3 Replacement of Eco-Efficient Technologies in Food and Beverage Processing

Hyde et al. [15], through analysis of their success case in the East Angolan alcoholic beverage industry, describe that changes in alcoholic beverage processing technology brought significant savings in labor, materials, and services. Procedural changes often focus on processes, material handling, and staff training, and with a low associated capital cost, these results represent the key to success in implementing cleaner production strategies.

Jones [18], through their analysis of the success story of the alcoholic beverage industry in Eastern Angola, describes how changes in alcohol processing technology brought significant savings in labor, materials, and services. Process changes often focus on processes, materials handling, and staff training, and with a low associated capital cost, these results represent a key to the successful implementation of cleaner production strategies.

Rahim y Raman [30] present a study in which the viability of the use of CP strategies in a fruit juice production plant was evaluated. The main objective was to reduce carbon dioxide (CO2) emissions taking into account economic, health, and safety aspects. The analysis showed that the total CO2 emission generated in this plant was 0.07 kg of CO2 per liter of fruit juice, of which 88% was contributed by the combustion of fossil fuel, generating CP options such as the replacement of pasteurization equipment with electric pulses, which after implementation reduced CO2 emission by about 20% through an economically viable investment with a recovery rate of 2 years.

Valle [33] demonstrated that the application of ozone to fruit wine must ensure the quality and safety of the final product, providing, in addition, ideal organoleptic characteristics perceptible by the consumer, replacing the need for fossil fuels for

the traditional pasteurization process, demonstrating that the ozone injection process eliminates the microbial load present in the product more efficiently, in a conclusive manner.

2.4 Reduction of Water Consumption

The alcoholic beverage industry is one of the largest industrial users of water, despite significant technological improvements over the past 20 years; energy consumption, wastewater, solid waste and by-products, and air emissions remain the industry's main environmental challenges. Olajire [27] presents an analysis that examines the main challenges of the alcoholic beverages industry focusing on these key issues and best environmental management practices that do not compromise final product quality.

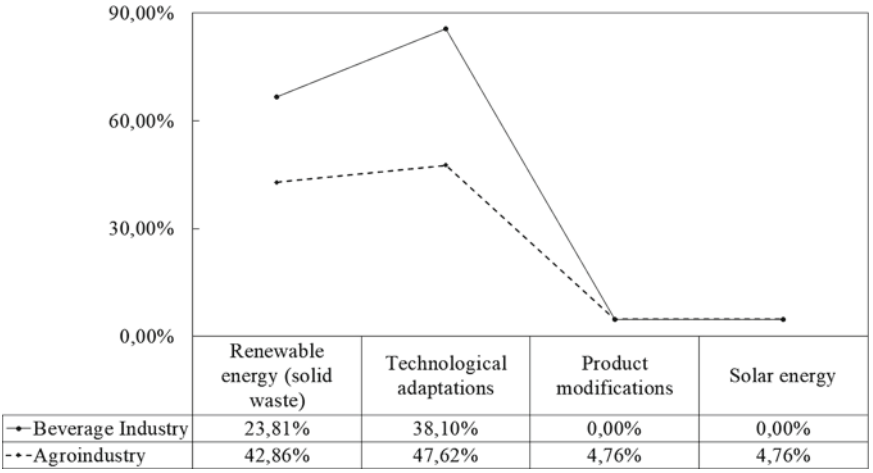
As a result of the work, it showed that technology substitutions in the production of alcoholic beverages significantly reduce process water consumption, air emissions, and solid waste, economically viable for the industries and encouraging environmental awareness through the application of this type of strategies, supporting the need for the development of alternatives such as the one in this paper.

Yi et al. [36], in their research work, carry out an analysis of the growth and competitiveness of eco-efficient food industries that maximize water consumption in their processes, in Heilongjiang province, showing that the general growth trend of the ecological food industry with lower water consumption in its processes and certified by the Chinese government, is likely to increase by 220% by the end of 2018, which makes it clear that the market is increasingly ecologically aware and forces food and beverage companies to be ecologically competitive.

3 Discussion and Analysis of Results

Most CP application articles, depending on the problem, are seeking to solve the use of appropriate techniques. In general, the resource that is sought to be optimized is energy consumption. Figure 3 shows the CP techniques applied in industry to minimize energy consumption. Of the 32 publications analyzed, 21 mention energy optimisation, and one of the most popular strategies is technological adaptation (47.62%), which involves changing machinery for more environmentally-friendly equipment, plants with better distributed lighting, or changes in fossil energy consumption for electrical energy, a high percentage (42.86%) of industries opt for the use of energy resources from biomass or energy sources generated from organic solid waste. Other alternative sources of energy are solar energy and product modifications, which are rare (4.76%).

100% of the articles analyzed with a focus on the reduction of the planet's water footprint agree that it is one of the resources that has been most exploited during the



	Renewable energy (solid waste)	Technological adaptations	Product modifications	Solar energy
Beverage Industry	23,81%	38,10%	0,00%	0,00%
Agroindustry	42,86%	47,62%	4,76%	4,76%

Fig. 3 CP energy alternatives in agroindustry

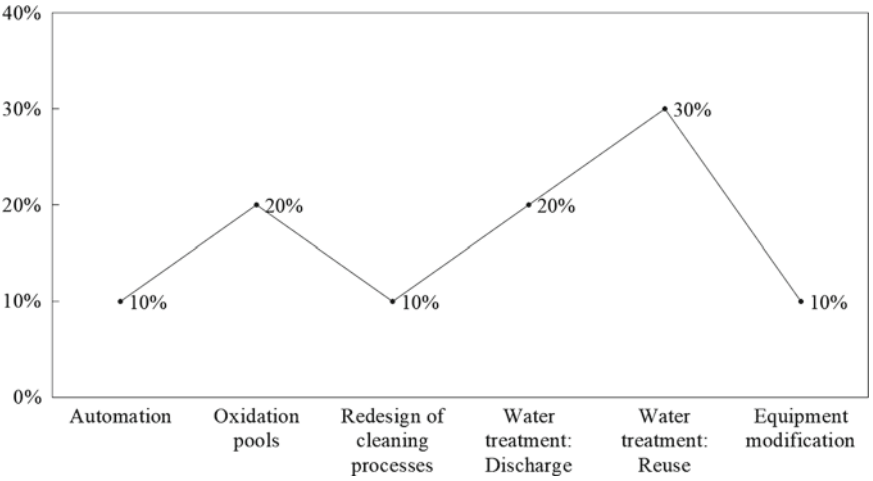


Fig. 4 Water footprint reduction techniques

twentieth century. Of the 32 publications analyzed, 10 apply techniques for reducing water consumption in the drinks and spirits industry. In Fig. 4, the strategies mentioned in the reviewed articles are observed, highlighting that the technique that has had the greatest impact is the treatment of wastewater. The treated water has two destinations, the first is direct discharge to sewers (20%) and the second is reuse in irrigation processes (30%). Other strategies mentioned are the automation of irrigation systems (10%) and the modification of equipment, especially pasteurizers (10%).

The analyzed articles concerning the reduction of the water footprint in food industries propose corrective actions, which seek to reduce the amount of contaminants present in this resource after its use, but few authors propose preventive actions for this resource. There is no talk of reducing consumption at source, nor of modifying the technology of the product; the processes used in the food industry have not changed over the years. Taking into account that in the twentieth century people still worked under the concept that natural resources were unlimited, one can understand the lack of process innovation at that time. With regard to energy consumption, the main problem that companies encounter is the lack of planning with which they start their industries. Most food companies start out as micro-enterprises, with minimal consistency in the installed capacity of the different machines that make up their production lines. As the industry grows, the capacity of these machines does not supply, and companies that generally do not have the resources to carry out re-engineering, make adaptations that, although it is true, are usually more economical in the short term, end up causing greater expenditure of money by consuming greater amounts of energy.

The main energy losses are produced by poor equipment design, lack of insulation materials. Considering the above, it is not surprising that most authors opt for technological modification, such as CP strategies. Many advances have been made in the twenty-first century in the field of CP, but there is still a long way to go.

4 Conclusions and Future Works

This study, through an SLR, analyzed previous work on the implementation of CP strategies in the food and beverage industry, and the challenges the industry confronts when implementing them, including government, legal, and market requirements; most of the works analyzed focused on their strategies on the reduction of water consumption through the reuse and recycling of water resources, in terms of waste reduction strategies focused on the adequate treatment of industrial effluents prior to discharge, however, this strategy is framed in the concept of control at the end of the pipe that does not combine with the objectives of CP, but as an environmental mitigation methodology.

On the other side, the investigation showed that the automation of processes is also a little exploited alternative within the food and beverage industry, compared to the replacement of more efficient equipment and the redesign of cleaning and disinfection processes that are less contaminating and that optimize water consumption, considering that due to health regulations it is one of the most important processes for ensuring the safety of products, taking into consideration that in industrialized countries 30% of all industrial effluents correspond to cleaning and disinfection processes in food and beverage production plants.

The implementation of new processing technologies, as well as the use of waste for energy generation, constituted the most used CP strategies by the food sector, marking a significant difference between the application of these strategies with

respect to the beverage industry, putting in context the opportunity to strengthen the development of future research directed to the beverage industry specifically, in which the water resource is the main component of the final products, considering that of the whole industrial sector it is the least studied business line.

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Design of a Synchronous Generator of Permanent Magnets of Radial Flux for a Pico-Hydropower Station

Estefania Flores, Myriam Cumbajin, and Patricio Sanchez

Abstract The design of a radial flux permanent magnet synchronous generator is presented, which can produce a maximum power of 2 KW at 600 rpm. Once the design was made and its main characteristics determined, the analysis was carried out in MATLAB to observe the behavior of the generator in its operating range. SolidWorks was also used for the elaboration of 3D modeling and finally in ANSYS for its electromagnetic analysis. The objective of this design is that the generator can be installed in a Pico-Hydropower station located in an Ambato–Huachi–Pelileo irrigation channel, in the Tungurahua province in Ecuador. This will allow users to get benefit from electrical energy in difficult access areas. At the same time, when used in the irrigation channel, it will be able to illuminate the channel and thus allow to provide maintenance at any time of the day.

Keywords Irrigation channel · Synchronous generator · Permanent magnets · Radial flux

1 Introduction

The use of unconventional energy resources in recent years has been developed mainly with the intention of reducing the use of fuels [5]. Under this concept, water is one of the resources used, since it satisfies multiple human needs. Conservation

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M. V. García et al. (eds.), *Advances and Applications in Computer Science, Electronics and Industrial Engineering*, Advances in Intelligent Systems and Computing 1307,
https://doi.org/10.1007/978-981-33-4565-2_9

and proper management of this resource is important in the country, since social and production inequalities are closely linked to water access; Additionally, 70% of the electrical energy in Ecuador is of hydraulic origin [9, 18].

Pico-hydroelectric power plants are typically a stand-alone hydroelectric system built to provide electricity to rural communities and are adopted as renewable energy due to their advantages over large hydroelectric plants [16, 17]. With the foregoing, it is said that these systems are the most economical option to supply energy in isolated rural areas.

In this power generation system, it depends a lot on the variation of the water, and this is where generators are used to maintain its level, there are two types of permanent magnet machines for generators [6, 7, 15]; radial flow permanent magnet synchronous machine (RF-PMSM) and axial flow permanent magnet synchronous machine (AF-PMSM). Radial flux permanent magnet machines are conventional machines that have been in use for a long time. RF-PMSM has some advantages of compact structure, higher torque capacity, higher efficiency due to the absence of rotor windings and excitation losses, higher power density than conventional induction machines [2].

Most of the RF-PMSM applications are focused on aerial generators, since the main characteristic of this generator is its constant magnetic field, which is generated by its permanent magnets located in the rotor. If the machine is excited with permanent magnets, the permanent magnet materials have to be selected and the main dimensions of the parts manufactured from these materials have to be determined. Generally, when calculating the magnetizing current for a rotating machine, the machine is assumed to run at no load: that is, there is a constant current flowing in the magnetizing winding [14].

The aim of this project is to make a contribution to the use of RF-PMSM in peak hydroelectric power plants, which may be used as an energy source in rural areas with difficult access, thus achieving that each of the country's areas has access to this basic service. Therefore, a generator has been designed to adapt to the characteristics of a Michell-Banki type mini-hydraulic turbine, in order to provide energy from the flow of the irrigation channel, which provides us with a hydroelectric power plant peak. To carry out this research, the MATLAB and SolidWorld Software is used for 3D modeling and sizing.

2 Related Works

One of the most recent works related to this particular project is the one presented in the article "Design and Fabrication of a Radial Flux Permanent Magnet Synchronous Generator" where it mentions that radial flux direction synchronous generators produce a higher voltage compared to the conventional ones. Among them, in the Axial flow generator, the flow direction is perpendicular to the radius of the machine, so it reduces the output voltage. This generator is designed to produce a voltage of 26 V at a speed of 375 rpm [3, 4, 11].

Table 1 Mechanical dimensioning of the turbine

Parameters	Measurements	Units
Dimensions	916.5 × 796.9 × 237	mm
Weight	33.035	Kg
Revolutions	110	rpm
Torque	26	Nm
Power	22.88	W

It has also been taken into account that permanent magnet synchronous generators (PMSG) have been widely documented in specialized literature as the most suitable for use in low power wind turbines, mainly due to their high efficiency, its high reliability and high power density [8]. In our case, it will be used hydraulically, since in both cases the potential of the air and water currents is used, respectively, transforming the kinetic energy into electricity.

In the article "Analyzing the Power Quality of a RF-PMSG by Considering Different Types of Windings" published in the IEEE magazine in 2019, it is mentioned that the type of winding also directly intervenes in the analysis of the performance of the RF-PMSG generator. Considering this analysis, the impact of the winding on the quality of energy presented by it was considered [20].

Induction and rare earth PMSGs currently have the largest share of the PMSG market. High power density, high efficiency, high reliability, low maintenance requirement are some of the advantages of PMSGs compared to induction and reluctance generators [10, 19]. RF-PMSGs are so versatile generators that study [1, 13], can be found in which they can be related to wind turbines in offshore areas.

3 Formulation of the Problem and Methodology

For the development of the proposed design, the mechanical characteristics presented in the research project carried out in 2019 at the Technical University of Ambato with the title "Design and Construction of a Michell-Banki mini-hydraulic turbine" to be installed in open primary channels were taken into account. They generate mechanical energy. These characteristics are the main guide for making the generator. Those are presented below in Table 1:

The main data obtained for the design of the turbine in question were taken from Lenin Ibañez engineering thesis [12]:

1. Channel width: 1.63 m
2. Total depth of channel: 1.7 m
3. Velocity in the channel: 1.512 m/s
4. Channel flow: 0.0936 m^3/s
5. Accessibility to the canal.

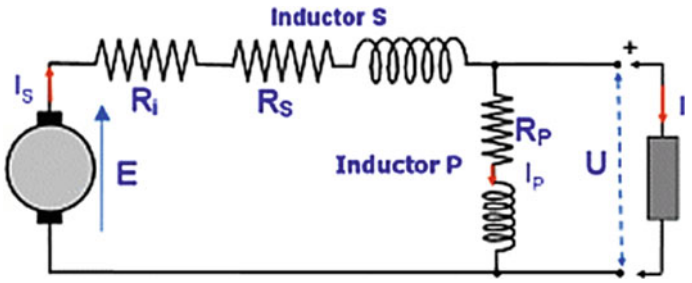


Fig. 1 Equivalent circuit of the generator

Since the number of revolutions is low, a 1:6 gearboxes will be used to work with a total of 600 rpm, which have been taken into account for the elaboration of our generator.

In the circuit of Fig. 1, it is visualized how permanent magnet generators provide electrical energy by induction. In this case, the inductor winding is connected in series with the armature, in such a way that all the current that the generator supplies to the load flows equally through both. Since the current flowing through the inductor winding is high, it is necessary to build them with few turns and a large section in the conductors.

The resultant equations of the equivalent circuit of the generator are (See Eqs. 1, 2)

$$U = E - (R_i + R_s)I_s - V \tag{1}$$

$$U = R_p I_p \tag{2}$$

where
E = Electromotive force (FEM)
I_s = series intensity
$I\,R_i$ = armature resistance
R_s = series resistance of inductor winding
R_p = resistance in parallel
I_p = intensity parallel to FEM
U = tension.

3.1 Theoretical Study

For the theoretical study, the analysis has been carried out considering the book Design of Rotating Electrical Machines [14] which is detailed below.

3.1.1 Pole Pairs

The number of pole pairs is determined by the frequency and the speed of rotation of the rotor in rpm, as seen in Eq. 3.

$$p = \frac{(60 * f)}{n} \tag{3}$$

where
n = speed in rpm
p = number of pairs of poles.

3.1.2 Maximum Energy

The maximum energy is determined by the magnetic characteristics of the permanent magnet, and is given by Eq. 4:

$$E_M = \frac{(B - H)_{max} * V * n_{PMGS}}{2} \tag{4}$$

where
$(B - H)_{max}$: Maximum energy product (kJ/m^3)
n_{PMGS}: generator rotation speed (rpm)
V: volume of the magnet (m^3).

3.1.3 Angular Speed of Rotation

The angular speed of rotation is determined by the frequency of the alternating current and the number of pairs of poles (See Eq. 5).

$$\omega_{PMGS} = \frac{2 * \pi * f}{p} \tag{5}$$

where
p = number of pairs of poles.

3.1.4 Maximum Power

With the values obtained previously, the electrical power by the magnets at a speed of 600 rpm is (See Eq. 6)

$$P = E_M * \omega_{PMGS} \tag{6}$$

Table 2 Initial parameters for the design

Initial parameters	Value	Units
Power	2	KW
Spin speed	600	rpm
Frequency	60	Hz
Voltage	110	V

The design of the neodymium permanent magnet generator was defined with the parameters shown in Table 2. Where a voltage of 110 V is observed, which has been chosen because this is the most commonly used in homes, and the frequency 60 Hz, since at this frequency is the one at which the electrical network works nationwide, the speed of 600 rpm will be provided by the turbine using a multiplier box, in order to obtain a power of 2 KW, which is what is desired ideally.

3.1.5 Number of Slots

To calculate the number of grooves, we have the Eq. 7:

$$Q_s = \sqrt[3]{2 * p * q_s * q} \tag{7}$$

where
p = number of pairs of poles.
q = number of phases.
q_s = number of slots per pole and phase.
So the number of slots that must have is 36.

3.1.6 Total, Number of Coils

To calculate the coils, we used Eq. 8.

$$G = p * q \tag{8}$$

where
p = number of pairs of poles.
q = number of phases.
That is, this time there are 18 coils that will be part of the stator winding.

3.1.7 Number of Coils per Phase

The equation used to calculate this is 9

$$G_f = p \tag{9}$$

where
p = number of pairs of poles.
G_f = number of coils per phase.

The number of coils per phase is equal to the number of poles that the generator has, in this case it will be 6 coils per phase.

3.1.8 Number of Coils per Group

This number gives us how many coils will be inside the slots. (See Eq. 10).

$$U = \frac{Q_s}{2 * p * q} \tag{10}$$

where
U = number of coils per group. For this study case, U = 1.
Q_s = number of slots.
p = number of pairs of poles.
q = number of phases.

The space between connected coils is given by Eq. 11:

$$m = (q - 1) * U \tag{11}$$

where
U = number of coils per group.
m = coil width or pitch. Being m = 2.

Once the main parameters have been obtained, the calculation of the dimensioning of the rotor, stator, and airgap is made, which will serve us for an optimal design. In this case, several free parameters must be taken into account, which can be solved with tables and graphs of previous investigations. In Fig. 2, these main parameters to be calculated are displayed, such as the internal and external diameter of the rotor and stator, respectively, as well as the dimensions of the grooves where the winding is placed (Fig. 3).

The formulas for obtaining each of these calculations are as follows. For the calculation of the internal diameter of the stator core, it is based on the concept of torsional stress of the rotor, where parameters such as mechanical constant and nominal power are presented (See Eq. 12).

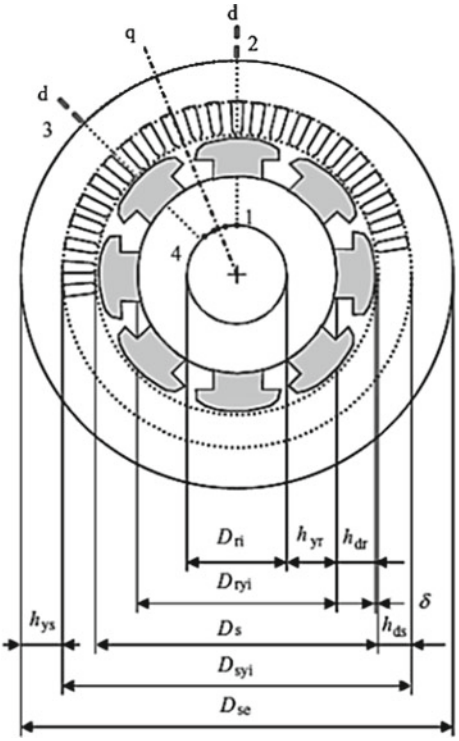


Fig. 2 Equivalent circuit of the generator

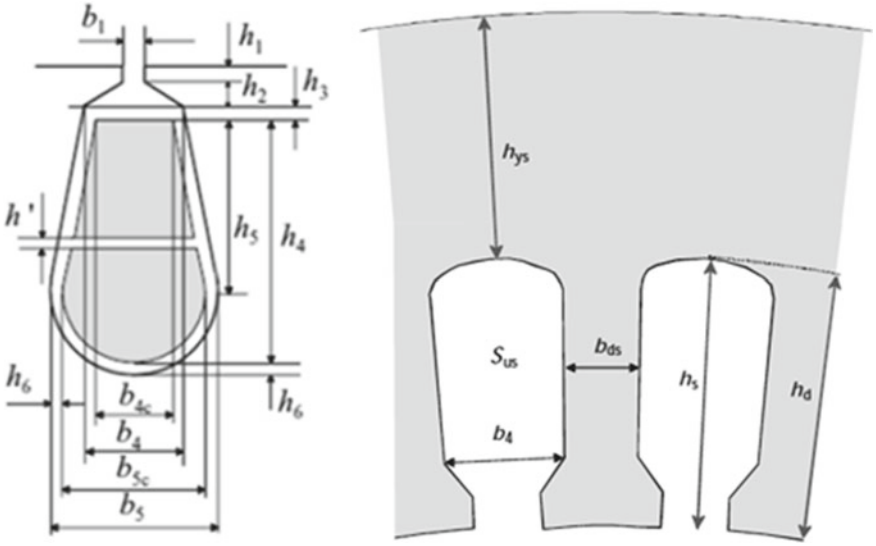


Fig. 3 Equivalent circuit of the generator

$$D_{si} = \sqrt[3]{\frac{P_{nom}}{x * C_{mec} * n_{syn}}} \tag{12}$$

where
D_{si}: Inner diameter of stator core (mm).
P_{nom}: Nominal design power (kW).
x: Relationship between the equivalent length of the machine and the diameter of the iron.
C_{mec}: Output power coefficient or mechanical constant for generators synchronous and asynchronous (kW/m^3).
n_{syn}: Synchronous relationship (s-1).

For each of the parameters that have been requested to obtain the internal diameter of the rotor, it is obtained using the following formulas. The synchronous relationship through the Eq. 13:

$$n_{syn} = \frac{f}{p} \tag{13}$$

To obtain the relationship between the equivalent length and the gap diameter, in standard machines, we applied Eq. 14

$$x = l'/D \tag{14}$$

where
l': Stator equivalent axial length (mm).
D: Diameter of the airgap (mm).

The diameter of the airgap D is equivalent to the internal diameter of the stator, D ≈ Dsi. In the investigative process, Table 3 was obtained. Taking these relationships into account, the second option is our responsibility.

To get the mechanical constant, we used Eq. 15.

$$C_{mec} = \frac{\pi^2}{\sqrt{2}} K_w A \widehat{B}_\delta \tag{15}$$

where
K_w: Winding factor.
A: Linear current density (kA/m).
$\widehat{B}_\delta$: Airgap flow density per pole (T).

For which the value of the linear current density and the flux density is obtained by software, so the gap in the airgap must be minimal.

We can see in Table 3 the relationship between the equivalent length of the machine and the diameter of the iron according to the type of machine that is going to be created, for our case the third option has been chosen since the number of poles with the that we count is greater than 1.

Table 3 l'/D ratios, typical for different electrical machines

Asynchronous machines	Synchronous machines $p > 1$	Synchronous p = 1	DC machines
$x \approx \frac{\pi}{2*p} * \sqrt[3]{p}$	$x \approx \frac{\pi}{4*p} * \sqrt[2]{p}$	$x = 1 - 3$	$x \approx \frac{-0.6}{p}$

And without invalidating any of these parameters, it is obtained that the internal diameter of the stator is D_{si} =0,140 m =140 mm.

Once obtained in diameter and ratio, it is possible to calculate the equivalent length $l' = 45$ mm.

3.1.9 Airgap

An airgap should technically be as small as possible, it can be determined as follows in Eq. 16.

$$\delta = \gamma \tau_p \frac{A}{\widehat{B}_\delta} \tag{16}$$

where
δ: Airgap (mm).
γ: Coefficient for the definition of the airgap.
τ_p: Pole pitch (mm).

The definition coefficient of the airgap is $\gamma = 7 \times 10 - 7$ for outgoing pole generators.

The polar passage is given by Eq. 17:

$$\tau_p = \frac{\pi D}{2p} \tag{17}$$

In Eq. 12, the polar pitch is determined with the internal diameter of the stator.

$$\tau_p = 36,652 \text{ mm} \tag{18}$$

So the maximum space between the iron is $\delta = 1.2$ mm.

3.1.10 Stator Core Outer Diameter

To solve this parameter, we used Eq. 19

$$D_{se} = \frac{D_{si}}{0,63} \tag{19}$$

In this case, the value of 0.63 is the ratio between the external radius of the rotor and the external radius of the stator.

3.1.11 Rotor

To calculate the rotor, we used Eq. 20.

$$D_{re} = D_{si} - 2 * \delta \tag{20}$$

3.1.12 Number of Turns

In the design of this generator, the number of turns is calculated by using Eq. 21

$$W_s = \frac{\sqrt{2} \times E_m}{2\pi f * k_w * \widehat{B}_\delta * \tau_p * l_s * \alpha_i} \tag{21}$$

where
W_s: Number of turns of turns per phase in series.
E_m: Electromotive force per phase (V).
l_s: Actual length of the stator core, being the same effective length (mm).
f: Frequency (Hz).
α_i: Arithmetic average coefficient of the flux density of a pole.

Eq. 21 is used to calculate the electromotive force per phase (V)

$$E_m = 1,1 * V_n \tag{22}$$

And in this case, the calculation of V_n is done taking into account the maximum value to be reached 120 V.

$$V_n = \frac{V}{\sqrt{3}} \tag{23}$$

The framework developed in MATLAB allows us to enter the initial information and thus generate the output parameters. In Fig. 4, we can see the guide screen where the boxes in which it is possible to change the value of the data highlighted, and obtain important parameters such as the number of poles, power that can be generated according to the poles, number of slots and number of coils for generator design. For the case, the data previously presented in Table 2 has been entered.

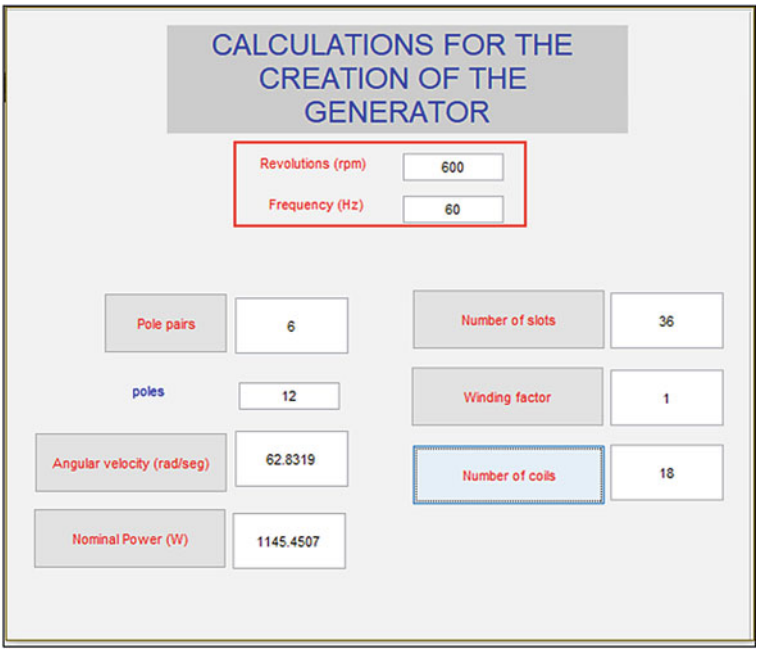


Fig. 4 MATLAB screen where the final parameters are displayed according to the data entered

Table 4 Design specification of generator

Description	Value	Unit
Generator type	Three-phase permanent magnet	–
Nominal speed	600	rpm
Power	2	KW
Number of slots	36	Units
Number of poles	12	Units
Rotor outer diameter	138.8	mm
Stator outer diameter	222	mm
Airgap	1.2	mm
Stator inner diameter	140	mm
Groove depth	18	mm
Tooth width	6.6	mm
Magnet type	NdFeb N52SH	–
Number of coils	18	Units

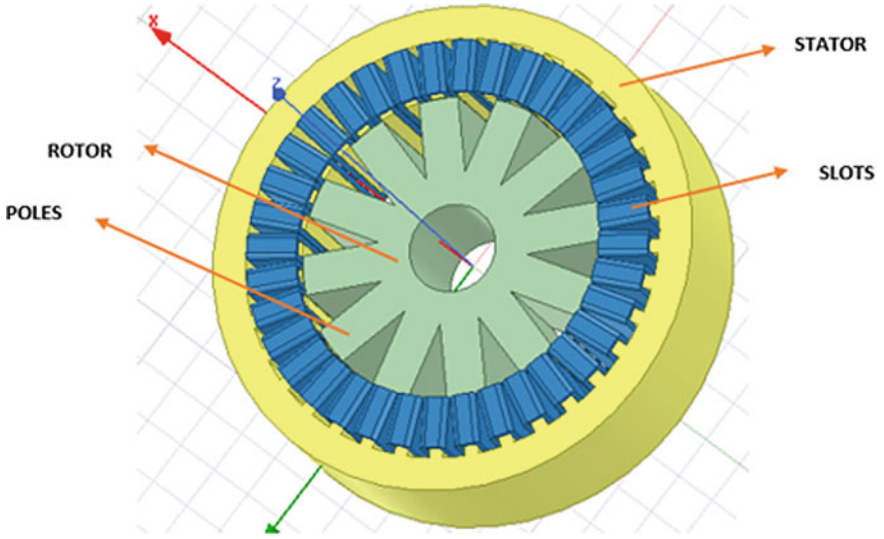


Fig. 5 Model of the generator

4 Design

The design specifications of the calculated generator are presented in Table 4. Where it is important to state that the most important of these are the type of magnet that is going to be used since from this we will use its magnetic field, which generates the torque, the number of pole pairs that affect the voltage, the number of slots and turns of the winding, since with these the current is obtained and finally the speed with which the generator will work. Once the voltage and current data have been obtained, we can consider the power since it involves the magnetic characteristics of the magnet. Taking all these parameters into account, it is modeled and simulated in the software.

Once the necessary specifications for the generator design have been obtained, we use the ANSYS software to obtain the desired structure and in turn perform its simulation. As can be seen in Fig. 4, we find the diagram made with the specifications in Table 4.

In Fig. 5, we find a cut of 30° in which the result of simulating can be visualized the distribution of the magnetic flux in the stator core and the rotor generator.

In Fig. 6, we can see that the value of the flux density of the intensity of the magnetic field in the gears of the stator core varies constantly, the ideal value is 1.0744E + 000 T which indicates that the magnetic field is suitable in generation areas. From the modeling results, it is simulated to obtain the generator output voltage at a speed of 600 rpm.

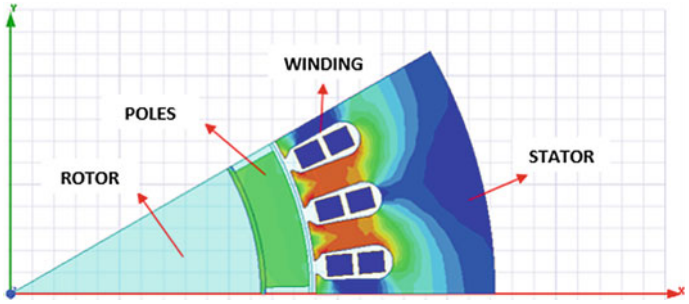
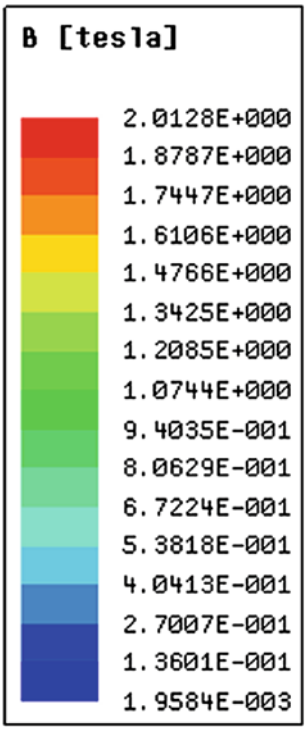


Fig. 6 Magnetic field in one-sixteenth of the generator

Fig. 7 Simulator magnetic field values



5 Analysis of Results

The values reached by the generator are shown in the graphs shown below. In Fig. 7, it can be seen how the current reaches 5 V, which is directly proportional to the rotation speed exerted by the rotor core, which in the case is 600 rpm, this current produced by the generator will always depend on the revolutions that the rotor can reach.

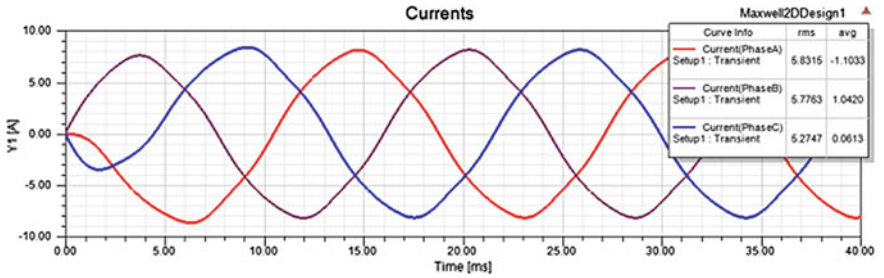


Fig. 8 Generator current

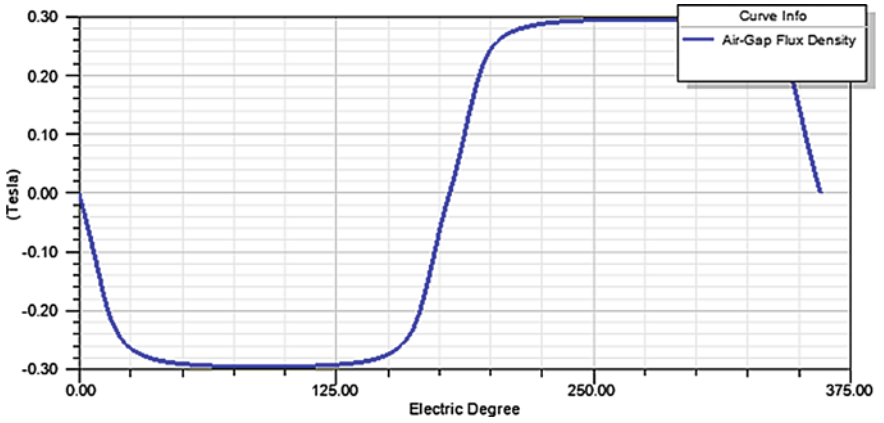


Fig. 9 Gap behavior

In Fig. 8, the process of magnetization and demagnetization of the airgap is observed, the realization of this process shows us that the magnetic poles of the magnets are in the correct position, which shows that the generator is working in good conditions.

Figure 9 shows the phase voltage and the line voltage produced by the generator in the simulation gives us a maximum of approximately 52 V, while the phase voltage reaches approximately 24 V, these values must be verified in real operation.

The results obtained in the simulation process may vary based on the needs. Therefore, we can say that to achieve optimum generator performance, the ideal would be to install the generator in an area where the water speed is sufficient to provide, at most, 5 A in current and 24 V in voltage. These generator features can satisfy loads such as a refrigerator, four light bulbs, and a blender covering 600 W generated (Fig. 10).

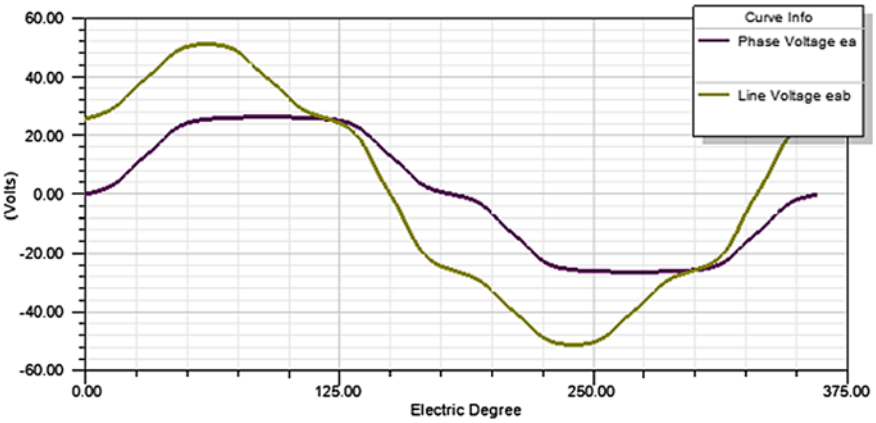


Fig. 10 Evolution of the voltage in the generator

6 Conclusions

The design of this generator is mainly to benefit users in rural Ecuador, and give them the opportunity to have access to one of the main basic services, which is electric power. In the most remote areas, it is common to see hydroelectric power plants, since these are used for irrigation of agricultural production, which is the main occupation in these sectors, which is why cleaning mingas are carried out for their conservation, that is where our design becomes productive because thanks to this the channel is illuminated and makes cleaning more efficient, making it possible to carry it out also.

Acknowledgements The authors thank the invaluable contribution of the Technological University Indoamerica in Ambato—Ecuador, for their support in carrying out this research, in the execution of the project "Estudio de Energía Eléctrica de Baja Potencia en los Canales de Riego como Fuentes Hídricas".

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Smart University: Key Factors for an Artificial Intelligence Adoption Model

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Abstract The emergence of new technologies has brought many advantages to organizations and other sectors, they manage to streamline manual processes and are of vital importance in decision-making. Today many entities decide to make use of emerging technologies that facilitate the work and perform it more effectively, however, the adoption rate is not as high as expected and that is due to a widespread fear due to lack of knowledge of information management and intelligent technologies. It is necessary to analyze the levels and the relationship with the processes where they are involved, that is, how the IT technologies are used and each factor within the university can enrich the university community. The purpose of this article is to present an artificial intelligence adoption model proposal for universities. The IT organizational unit of the universities is in charge of adapting all these "Smart" technologies to the university environment in each of its teachings, research, management, or government facets. The complexity is great, we are talking about very diverse environments with very different needs.

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M. V. García et al. (eds.), *Advances and Applications in Computer Science, Electronics and Industrial Engineering*, Advances in Intelligent Systems and Computing 1307,
https://doi.org/10.1007/978-981-33-4565-2_10

Keywords Adopting smart technology · Artificial intelligence · Characterization · Process · Smart university

1 Introduction

Technology and society are now inseparable partners that offer citizens a new level of services and quality of life in a way that was previously unthinkable. Cities, workplaces, parks, and gardens and, in general, cities are immersed in a technological wave that makes them more efficient, more comfortable, more useful, and, above all, puts them at the service of citizens. This scenario reveals a new social paradigm which, due to its complexity and transversality, has evolved without a general reference model. It is necessary to stop for a moment to think, reorder ideas, establish organizational principles and design models, and architectures that will allow this explosion of ideas, technologies, and services to citizens to be sustained [60]. This growth has generated that today's cities have more needs in terms of education, transportation, health…,etc.; that is, why technologies are emerging to satisfy these needs, the idea is to create sustainable services in the long term, which will improve and facilitate the quality of life of citizens, through the creation of an intelligent city; that is, it seeks to promote the use of sensors that capture information that can later be analyzed to learn from the problems and respond to the needs. The IoT infrastructure is in charge of collecting large volumes of data, and it is the main key when talking about a Smart city.

Innovation and learning are strongly linked. Society is in constant evolution, seen from the notions of knowledge and learning; where the collaborative and networked work of the different institutional actors (and with links external to the organization) allows the consolidation of innovative processes [23].

Advances in technology in recent years have changed student learning behaviors and teaching methods with new methodologies, environments, and resources. This situation has given rise to new challenges: A greater presence and possibility of informal learning, ubiquitous resources with the possibility not only that the student accesses from anywhere to the sources and resources of learning, and in general knowledge, but also that this access, the student, make it helped in learning by the system, with knowledge of their learning situation at the mercy of data on their habits, styles, and ways of learning have. These advances have given rise to several challenges facing today's education systems. These include a broader approach to informal learning, a widening gap in students' prior knowledge of their access to the classroom, and a mismatch between the career options offered to individuals and those demanded by development.

The presence and advance of detection and recommendation technologies are offering great and determining opportunities to develop new learning environments. Intelligent learning is an extremely innovative concept. It is promising, but it poses significant challenges that are key to the development and evolution of the new university emerging from the current disruptions; although it should be noted that these environments also challenge existing and consolidated educational practices,

which have been used for centuries, and push teachers and educational experts out of their comfort zone by making them aware of the limitations of current teaching and assessment practices and the evidence that they can be improved through these new possibilities [31].

Institutions must use tools that connect learning with the use of new technologies, bridging gaps with the outside world by allowing constant communication not only in their educational environment but also with educational systems in other countries. It is important to emphasize that it is not only about leaving the student in front of a screen, where there is no motivation on the part of an instructor or physical relationship with other students, but it is also about unifying education with technology, that is, using tools that facilitate educational processes. An intelligent education is provided by an educational environment supported by intelligent technologies and devices, which seek to be widely adopted in schools and higher education institutions.

Today's universities are widely adopting the technologies and systems but the above-mentioned tools must be explored in a broad way, which allows studying their effectiveness, and which provides improvements in terms of their flexibility and treatment of new and emerging needs of modern society [18].

The transformation from a traditional university to a smart university involves more than using technology, it is about establishing a set between smart education, smart classrooms, smart learning, and smart campus, when the previous concepts are unified, it is possible to talk about smart university. Some universities begin by making changes in certain areas, such as the use of smart cards with NFC, applications with QR codes, which allow entry to certain areas, thus improving security [4]. On the other hand, smart technologies can also be used to create a sustainable energy model, which manages to establish heating and cooling points from renewable energy sources and the implementation of appropriate actions aimed at saving energy [13, 22].

Technological innovations have changed the educational model and the interactions between students and their academic environment to acquire and share knowledge. The emergence of the Smart University concept allows the transformation of the traditional learning process, making use of intelligent technological tools; seeking to meet the needs of students, ensuring effective learning methods [5]. This paper is divided mainly into (i) introduction, (ii) Method, (iii) Characterization of models by intelligent technology, (iv) Proposed model of adoption of artificial intelligence, and finally, conclusions.

2 Method

For the development of this article, the methodology adapted from Petersen [38] is presented in Table 1, which can be further elaborated on in Revelo et al. [14, 49]. The analysis of the results of Dyba et al. [21], which provide a list of important databases in the field of Computer and Engineering Sciences, was taken into account to select the relevant electronic databases and to carry out the search. The following electronic databases were selected: ACM Digital Library; IEEE Xplore; ScienceDirect; Scopus.

Table 1 Summary of implementation of the article's methodology

Phase	Summary
1. Research question	(1) What are the models of smart technology adoption in organizations? (2) What is the application of the smart technology adoption models found in organizations? (3) What are the key factors related to the adoption of IA for universities?
2. Definition of search criteria for primary studies	"Smart technologies adoption"; "IoT adoption"; "cloud computing adoption"; "Big Data adoption"; Big Data AND education; "Artificial Intelligence" AND education; Smart education
3. Definition of the inclusion and exclusion criteria	I1: Articles published from 2015 to 2020 I2: If several items are related to the same study, only the most recent is selected I3: If an article describes more than one study, each study is evaluated individually I4: If there are short and full versions of the same study, the latter is included E1: Abstracts or presentations (grey literature) and secondary studies (systematic reviews /mappings) E2: Articles not in English or Spanish E3: Articles not related to education
4. Classification scheme	They were classified according to smart technologies: Artificial intelligence, IoT, big data, cloud computing, [43]

3 Characterization of Models by Intelligent Technology

Understanding in the current context "Smart Technologies" to the combination of Information and Communication Technologies that include hardware, software, and communication systems capable of acquiring data, analyzing, predicting behavioral trends, and adapting automatically [29]. These technologies play a substantive role in the generation, exchange, dissemination, management, and access to knowledge and are increasingly important and relevant in all areas of social life, but especially in education [59].

The need to learn to manage technologies to strengthen their contribution to society is a consequence of the irruption of technology and globalization, which has generated a change in the role of universities (Artificial Intelligence (AI); cloud computing; Internet of Things (IoT); and Big data), which continue to emerge and make great advances [53]. As smart technologies emerge, it is necessary to have models to measure the level of their adoption by communities to know how an individual feels about using technology: perceptions about the usefulness and complexity that

Table 2 Models of smart technology adoption

Intelligent technology	Adoption model	Document
The Internet of Things	TAM, UTAUT, UTAUT2, TPB, TRA	[1, 6, 7, 12, 19, 26, 28, 30, 34, 52, 55–57]
Cloud Computing	TAM, UTAUT, DOI, UTAUT2	[8, 10, 33, 35–37, 39, 41, 42, 48, 58]
Big Data and Artificial Intelligence	TAM, UTAUT	[9, 51]

impact the level of adoption. These models are summarized in Table 2. According to the literature, the most used and validated is Technology Acceptance Model (TAM). This model uses variables that influence directly the acceptance of technologies, but it is limited since it only uses a part of the attributes perceived by the users to carry out its measurement. In higher education institutions and business environments, the most used model is Unified Theory of Technology Acceptance and Use (UTAUT), because it has variables to better measure the degree of user acceptance, for this reason, it is common to hear that this model has higher explanatory power than TAM. In the articles found on the degree of acceptance of cloud computing, 27.2 % use the TAM model in conjunction with UTAUT or UTAUT2, 13.6% used the TAM model to measure the level of adoption, 9% chose to use UTAUT-UTAUT2, 4.5% studied 3 models at the same time TAM, UTAUT, DOI; while 50% did not record the use of methods for measuring the technology. Among all technologies, TAM and UTAUT are specially used to evaluate the adoption of Big Data.

A review of the literature from 1990 to 2017, 97% of the literature focuses on IoT and AI (more specifically, 55% of the literature focuses on AI and 42% of the studies focus on IoT). However, 3% of the studies focused on cloud computing. This observation allows us to identify that the main technologies used in intelligent cities are essentially IoT and AI, where the integration of artificial intelligence into the IoT network makes it possible to create sustainable and intelligent infrastructure. AI is characterized by being an imitation of human intelligence and capabilities, to build intelligent machines, just as it is a simulation between human intelligence and machine skills, to solve complex problems [46].

4 Proposed Model of Adoption of Artificial Intelligence

Artificial intelligence plays an important role when talking about technology and its adoption in educational entities; it is a component of the development of intelligent learning, thought out intending to break the canons of traditional education. This element has components capable of adapting to each user, managing to establish trends and being able to predict decisions before a particular event, its use lends

itself to students learning according to their needs and requirements, creating an independent learning pace and according to the needs of each individual [45].

In the use and appropriation of any type of technology, certain aspects must be considered that favor or harm its implementation. In these cases, the institution where the technology is to be adopted must have clear ideas about all that the adoption of the technology entails; sometimes there is no planning or assessment before implementation, nor is there any evaluation of the changes that must be faced when using new tools. The use of new technologies brings many advantages if implemented properly and success is achieved when the institution has a high level of technology ownership. Plan and establish actions to improve and stay ahead of the curve.

The change from a traditional university to a Smart University must be carried out step by step, taking into account all areas, one could talk about reengineering to establish that intelligent environment [40], it is a process with initiative, one must analyze all the pros and cons, and at the end determine if the implementation can be done.

A smart university is mainly based on the integration of information technologies into the educational process. The appearance of this concept allows the application of a great number of components that imply the adaptation of the traditional educational model using intelligent information technologies, guaranteeing a collaborative learning environment by layers, fed by data that have a special treatment to generate solutions to the needs raised. It is an environment where technologies can be developed and put into use, it is mainly based on the integration of technologies such as IoT, cloud computing, radio frequency identification, ambient intelligence technology, augmented and virtual reality technology, wireless network sensors among others, these technologies can be examined and applied to create a sustainable evolution. The smart campus can be characterized by its ability to learn about itself and, therefore, be able to self-optimize teaching and learning strategies to operate and improve the performance of the main business and educational functions; it must be able to adapt, detect information, infer from the information obtained, anticipate possible needs that may arise and, finally, be able to organize and restructure itself [3].

One of the key factors to take into account during this process is whether the university's infrastructure is capable of handling the data traffic that is currently generated and if so, to verify whether it will be able to handle the traffic after the data increases in number; the first step is to carry out network planning and forecasting to guarantee the quality of service [2]; after having the data traffic issue resolved, constant improvements must be generated in the disciplines and all areas that the university has. In the area of teaching, university professors must be trained in the use of new technologies. It should be noted that in some institutions, professors carry out cutting-edge research activities, which make them the exclusive holders of knowledge, thus cultivating skills in students such as social behavior and human interaction, communication, teamwork, problem-solving, creativity, lateral thinking, and resilience.

A smart environment goes beyond just infrastructure, new technologies have been widely adopted in schools and specifically in universities, in many cases, these institu-

tions make use of cloud computing and portable devices, with advanced applications in highly interactive frameworks, therefore, one could say that smart universities are emerging, however, smart education is only the top layer, which is intended to reach [17].

The technical architecture of a smart system has illustrated the different technical challenges faced in establishing a smart university; in fact, the development of a smart university that fits the smart city model is characterized by technical specifications that require the integration of innovative technologies, an ICT-based infrastructure, and high-quality data and services.

Artificial Intelligence (AI) is rapidly opening a new frontier in the fields of business, government, education, and society. They are also influencing broader trends in global sustainability [24]. As previously mentioned, artificial intelligence can be focused on different areas, in which it can exercise the function of monitoring systems, processes, quality control, and strategic planning.

In the education sector, this technology can help decipher the difficulties of students, and understand how to help them, improve the imagination of a community and design a new educational experience [16]. Artificial Intelligence (AI) approaches are considered valuable tools, as they can develop and replicate the decision-making process adopted by individuals. Several AI techniques have been used in adaptive educational systems. These include, among others, fuzzy logic, decision trees, neural networks, Bayesian networks, genetic algorithms, and hidden Markov models [11].

Users, sensors, and networks generate huge amounts of data from which governments can develop applications and acquire knowledge using Artificial Intelligence (AI) techniques. Therefore, IoT and AI can enable the development of valuable services for citizens, businesses, and public agencies, in multiple domains such as transport, energy, health care, education, and public safety [25].

In the field of health education, the early application of Artificial Intelligence (AI) technologies has been in those specialties that are predominantly based on images, although it should be noted that it is currently being used in the classroom, where the student can interact with these images in an educational process, i.e., AI is being used as a teacher trainer or mentor, who interacts with the user through virtual and/or augmented reality [54]. Concerning intelligent tutoring systems, it can be said that they have potential advantages, which can be used directly in education [32]. Moreover, solutions, especially in specific treatments, uniquely composed drugs, and personalized therapies. AI is an innovative technology whose main application is for better decision-making in complicated cases [27].

The adoption model proposed for the Artificial Intelligence technology is focused on the Intention of Use factor, on which some elements depend and which will be mentioned below (see Fig. 1).

F1. Performance expectation. The performance expectation is significantly related to the intent of use. The intention to use is directly proportional to the performance expectation. When a higher education institution has broad performance expectations, the Use Intention will also be broad. F1.1 Attitude toward use. This element is directly associated with performance expectations, where both are directly proportional to each other. F1.1.1 Voluntary use. It can be stated that voluntariness is

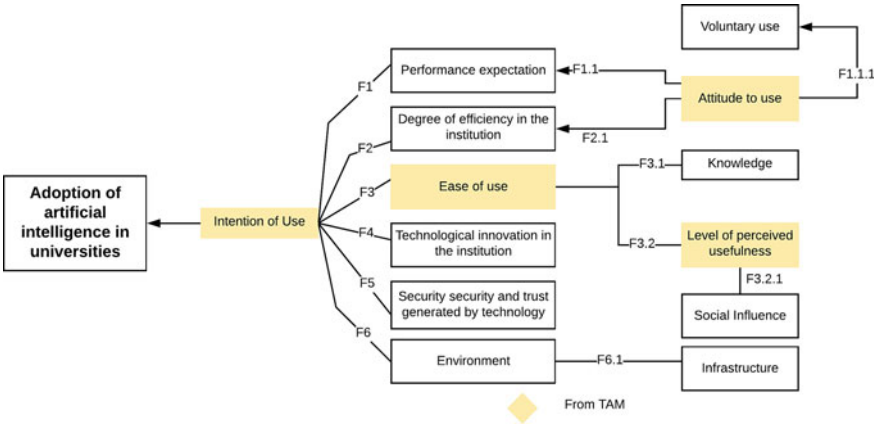

Fig. 1 Model of adoption of artificial intelligence. *Source* Author

directly proportional to the attitude toward use. It is a factor that positively influences the adoption of technology, i.e., when it is used voluntarily, it tends to bring more benefits than when it is used under compulsion

F2. Degree of efficiency in the institution. It refers to the optimal use of resources to perform a certain function, in this case, it could be defined as the efficiency that artificial intelligence has when implemented in a higher education institution F2.1 Attitude toward use. This element is also directly associated with the degree of efficiency. The attitude toward the use of technology is caused by the degree of efficiency it has in carrying out a process

F3. Ease of use. Ease of use according to the definitions above refers to the degree to which a person believes that using a particular system will make less effort to perform their tasks. This is where they come in: F3.1 Knowledge. Directly influences the user's perceived ease of use F3.2 Utility received. It is related to the ease of use because the utilities will be higher as long as the ease of use is good, they are directly proportional. Within this item are F3.2.1 Social influence. It has both a positive and a negative relationship, is linked to the opinions of nearby institutions and can favor the implementation of new technologies as long as the perceived opinions are good, or oppose them if the opinions are negative.

F4. Technological innovation within the institution. Innovation is a fundamental aspect at present and is significantly related to the intention of use. Because of having a positive value in the intention of the use of new technologies, one will want to innovate.

F5. Security and Trust. Being a technology that handles data, its level of adoption will take into account as a measure the security with which they treat that data that directly influences the trust toward the technology

F6. Environment. It has to do with the adaptability for the adoption and implementation of new technology, in this case, the environment refers to the context of higher education HF.1. Infrastructure. It is a favorable point in the context of use.

This technology does not represent a large investment in physical elements and so institutions can access it more easily.

The incorporation of Smart Technologies produces the so-called educational innovation, that is, it integrates new developments that produce changes to improve the learning process. Currently, the term "smart university" is incorporated. The IT dependence in universities in this SU scenario will help and support areas representing an integration of (1) smart and intelligent systems, smart objects and smart environments, (2) smart technologies, several branches of computer science and computer engineering, (3) last generation smart educational systems, agents and software and/or hardware tools, and (4) innovative pedagogy and teaching strategies and learning methodologies based on advanced technologies [47, 50]. Cerdeira and Mendes [15] generated the SU concept which is divided into four thematic axes: Infrastructure; Governance and Management; Services and Education. Where it is not only characterized by the use of written technologies in the infrastructure axis, as suggested by several works, it is remarkable that this axis serves as a support for the other dimensions, mainly in the provision of data and connectivity, governance and management of these institutions. The data generated by these services serve as input for other initiatives, mainly those aimed at campus management, in activities aimed at decision-making [44].

5 Conclusions

The analysis carried out in the literature at an international level and in the experiences shows the existence of strategies by the universities to promote and develop the processes incorporating intelligent technologies. At present, universities face several challenges to developing improvements in their mission, support, and assistance processes, incorporating technology as a support. The key technologies at the international level, according to the review, for a Smart University are Artificial Intelligence and the Internet of Things. These technologies are to improve infrastructure, optimize resources, ensure community access to information. Security, among others.

It is important to recognize the existing dynamics in the subject and the interest that is increasing, the tendency according to the experiences is to include "Smart" technology, at this moment the most applied is Cloud Computing. However, it is still evident the lack of studies and consolidation of information on the current state of technology adoption in universities, as well as an analysis of its contribution to the improvement of their processes. This research was based on the study of the level of adoption of four technologies, one of them is the internet of things, the articles found where this technology was used coincided in using the TAM method to measure the level of acceptance in organizations, secondly, UTAUT is positioned, who have improvements in terms of the number of variables to measure this level, also found information where other models are mentioned as UTAUT2, TPB TRA with the same purpose; On the contrary, artificial intelligence has been adopted in greater proportion by the education and health sectors to improve the quality of teaching,

efficiency in learning and decrease the dropout rate, but in the articles found there is no description of the use of any method to measure the level of adoption of the aforementioned technology, that is to say, there is no result on its adoption by the individuals with whom it interacts daily. It could be said that this technology is on the rise and the measurement of its acceptance is currently being carried out.

One of the distinguishing trends in the global practice of smart education development is the design of smart technologies and their implementation in the educational process. Throughout the text, an attempt has been made to give a current theoretical structure to traditional approaches to technology adoption. It was possible to recognize the existence of internal transitional factors that would allow us to account for how the passage from one level of adoption to another would be, making the traditional view of technology adoption by levels more dynamic. The adoption of intelligent technologies is becoming an increasingly common object of study in research work.

From the top management process, a university model must be defined that includes an IT structure where it contributes value and generates a response to the needs of this model. This goes hand in hand with the trend identified in the review, which highlights the need for alignment and integration of technology with organizational processes, calling for greater interaction with senior management. It is necessary to analyze the levels and the relationship with the processes where they are involved, that is, how the IT technologies are used and each factor within the university can enrich the university community. The IT organizational unit of the universities is in charge of adapting all these "Smart" technologies to the university environment in each of its teachings, research, management, or government facets. The complexity is great, and we are talking about very diverse environments with very different needs.

A new model of university is the goal of this transformation process. Defining it is not an easy task since we do not even visualize clearly what we are aiming at. This transition from the analogical to the digital model must be defined by the Management Teams through vision, identifying those parts of the university service that will be immersed in changes due to digitalization and determining those areas in which the university generates a differential value in its service provision [20].

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Assessment of Supply Chain Performance in an Assembly Company: Evaluation of Evolutionary Algorithms

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Abstract In current globalized markets, companies no longer compete with each other. They now compete with the supply chains (SC) to which they belong. SC optimization allows efficient and effective management of resources. In many cases, optimization goals can conflict with one another. Therefore, the purpose of this work was to evaluate SC performance by comparing three optimization algorithms in a case study with multiple objectives. Two objectives are maximizing profit and maximizing the level of customer service. Also, the modeled problem considers multiple products and periods for two security inventory scenarios (maximum and minimum inventory levels). Evolutionary algorithms were compared: NSGA-II, MOPSO, and MOMA. The NSGA-II algorithm obtained the best result. With a minimum inventory level, NSGA-II presented 97.87% service level and the best benefit. Results show the importance of SC management and its optimization as well as some relevant variables to be considered.

Keywords Supply chain · Multi-objective optimization · Algorithms · NSGA-II · MOPSO · MPAES

1 Introduction

The Supply Chain (SC) has been of great interest in recent years since it encompasses functions such as planning, provisioning, production, distribution, and return.

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M. V. García et al. (eds.), *Advances and Applications in Computer Science, Electronics and Industrial Engineering*, Advances in Intelligent Systems and Computing 1307,
https://doi.org/10.1007/978-981-33-4565-2_11

According to [40], companies now compete not only with each other, but also with the supply chains to which they belong. Because of this, improving the operation of the SC is important for many companies. This is achieved by optimizing variables associated with the supply, production, and marketing of goods and services. However, the existence of numerous decision variables and their complex interrelationships, as well as the limitations specific to each system, make SC a highly complex system [23, 24]. SC research has grown exponentially and points to "optimization and mathematical modeling" as the main research topics [29].

On the other hand, evolutionary algorithms (EA), which are based on the social behavior and natural biological evolution of species, have been one of the most studied optimization methods in the last decade [10, 18]. Considering the complexity of SC and the search for the optimization of both costs and benefits, several metaheuristics have been developed in EA, such as genetic algorithms (GA), particle swarm (PSO), and memetic algorithms (MA). These have yielded solutions that come close to a global one. The Non-dominated Sorting Genetic Algorithm II (NSGA-II) is the GA most applied to SC optimization studies where the total cost of SC is evaluated considering objectives such as "lead time" [24], the level of customer service [10], distribution [1, 39], inventories [14, 32], and SC with a "just in time" (JIT) approach [5, 30]. Optimization by PSO has been demonstrated in a few studies. Some of these studies, in addition to optimizing the cost of SC, have opted to optimize both conventional logistics and inverse logistics in closed SC [4, 18] and, in other cases, have dealt with problems of scheduling [25, 38] and order delays [17]. MA optimization, which is also known as a hybrid algorithm because two or more algorithms are combined, is known to improve algorithms (GA, PSO) in terms of quality of results. In SC, MA have been used to optimize costs, increase chain response capacity [33], and decrease environmental effects [16, 26]. These algorithms have answered various manufacturing, logistics, and assembly problems. However, most of the cases mentioned consider a single optimization objective [1, 16, 27], and few investigations have studied multiple objectives. Fewer still have researched the entire SC, due to the high complexity of testing multiple objectives in this dynamic environment [10, 24, 33, 39].

In SC, the optimization of resources is essential, but many optimization objectives are considered in isolation or are in conflict. Additionally, there are no studies that compare at least three EA and determine which of the EAs perform best. Therefore, this research proposes to combine relevant SC variables that together generate several objective functions that were optimized using three evolutionary optimization algorithms. These algorithms are evaluated using a case study from a television assembly company. Indeed, this work aims to answer the question, "Which algorithm performs better than others in optimizing a SC in terms of time and quality of response?" The remainder of the paper is divided as follows. In the second section, a literature review related to optimization models and algorithms for SC is presented. The third section clarifies the problem statement for optimization, where the variables and criteria of the SC are identified that allow the formulation of two objective functions to be optimized. The fourth section shows the main results obtained, and the fifth section discusses them. The last section articulates the conclusions of the investigation.

2 Theoretical Background

2.1 Multi-objective Optimization Problem

A multi-objective problem (MOP) is one that answers several unknowns that are posed at the same time in a problem. The solution of a multi-objective optimization problem presents a set of optimal solution points known as Pareto Front or Pareto Optimal. This procedure is supported by a dominance analysis to find solutions to the problem. A dominant solution is one in which there is no other solution that improves an objective function without harming at least one of the rest of the objectives [39]. There may also be a solution that is the best, but indifferent (neither dominant nor dominated) with respect to the target values [6]. In general, a multi-objective optimization problem includes a set of n decision variables, a set of k objective functions, and a set of m constraints, where $x = [x_1, x_2, \ldots, x_n]^T$ is the decision vector, while the objective vectors of the decision spaces are X and Y, respectively, and gi are the constraints of the problem functions. Azzouz et al. [2] pose the multi-objective problem according to (1), (2) and (3):

$$Optimize : y = f(x) = (f_1(x), f_2(x), \ldots, f_k(x)) \tag{1}$$

$$Subject\ to : gi(x) = (g_1(x), g_2(x), \ldots, g_m(x)) \geq 0 \tag{2}$$

$$where\ x = (x_1, x_2, \ldots, x_n) \in X; y = (y_1, y_2, \ldots, y_n) \in Y \tag{3}$$

2.2 Optimization by Genetic Algorithms

Genetic algorithms (GA) are principally based on imitating the adaptation and evolution phenomena of species, carrying out transformation and selection processes which simulate natural genetics [22]. The algorithm begins by generating an initial population, which is constituted of individuals who compete for survival. Each individual represents a possible solution to the optimization problem. After an evaluation process, the strongest individuals (parents) are selected, who will have the opportunity to "procreate" new individuals (children), through crossover and/or mutation processes. New individuals will inherit characteristics from their parents or may even improve them; in this way, the initial population evolves, and the cycle is repeated over and over again. Each cycle or loop of the algorithm is known as a generation [34]. The evolution of the population occurs mostly by three processes that are known as genetic operators which are selection, which is responsible for choosing from the population the best individuals to transmit its genetic code to future generations; crossing, which consists of combining or "mating" two individuals (parents) to mix their genetic information to generate new individuals (children); and mutation, which

selects a random individual and changes one or more current genes for new alleles (the value that takes a gene in a certain position) [15, 30].

The evolution of multi-objective GA begins with the GA called Vector Evaluated Genetic Algorithm (VEGA); unfortunately, this technique was not efficient [8]. Then, Goldberg [12] proposed new concepts to treat MOEAs to improve the quality of optimization, and clarified pareto optimality, non-dominated classification, and selection methods for the first time in this field. The early generation of GAs was characterized by the simplicity of their algorithms and the lack of methodology to validate them. The most important are Multi-objective Genetic Algorithm (MOGA), Niched Pareto Genetic Algorithm (NPGA), and Non-Dominated Classification Genetic Algorithm (NGSA). Fonseca & Fleming [11] presented MOGA, which implements a Pareto hierarchy, where the hierarchy of an individual depends on the number of individuals dominating a given population. NPGA focuses on tournament selection based on the dominance of Pareto and "fitness sharing", which is a technique to conserve diversity in GAs [8]. Srinivas & Deb [35] developed NGSA. It has the same MOGA structure and differs in the assignment of the aptitude function. In NSGA, all individuals near the pareto front have high fitness values. Also, a $\sigma share$ distance is defined to measure the degree to which individuals affect their fitness function [8, 32]. The next generation of GA searched the efficiency in optimization. Deb et al. [9] presented NSGA-II. It is based on a technique of "elitist selection" and "crowded tournaments". Elitism consists in ensuring that the individuals with the best value of the adaptation function continue in the following iterations in order to prevent a loss in the adjustment obtained. In the selection by crowded tournaments, the winner of a tournament is judged based on the level that its fitness function contributes to the tournament [32]. Algorithm 1 shows the pseudocode for NSGA-II [9].

Algorithm 1: NSGA-II

```
Create initial random population P0 (N individuals) and evaluate;
Create a population of offspring Qt, by crossing and mutation;
Set Pt = ∅;
while the stopping criterion is not met do
    Join the Pt and Qt populations to create the Rt population;
    Perform a non-dominated classification to Rt, and identify better
    non-dominated Fi fronts;
    while the size of |Pt| + 1 < N, do
        Calculate the agglomeration distance in Fi;
        Sort in Fi in descending order;
        Update Pt, i.e., Pt = Pt ∪ Fi (the best in Fi elements are assigned);
        Apply genetic operators;
    end
end
```

2.3 Particle Swarm Optimization (PSO)

PSO is an evolutionary calculation technique presented by Kennedy & Eberhart [21]. It is a search algorithm based on the simulation of the interaction of social behavior and the grouping of birds and fish [8, 36]. PSO is different from GA because it does not seek the survival of the fittest, so it does not adopt an individual selection process. Instead, it works with a population that is evaluated by one or several adjustment functions. Then the population is updated and the optimal solution is found [19]. The algorithm starts with a group of random particles where each individual is treated as a particle without volume in a multi-dimensional search space and at random speed. Then, a set of particles are "thrown" into a search space with an initial position and velocity. Each particle in that space knows and remembers its position, its best previous position, as well as of your neighbors, and the value of the objective function in that position. In this way, all particles constantly adjust their direction and search speed according to the two best positions [18].

The main PSO terms are: velocity, inertia weight and learning factor [36]. Velocity (v) is a vector that controls the direction in which the particle must "fly" to improve its position. Inertia weight (W) is used to control the impact of the previous velocity history on the current velocity of a particle. Learning factor is composed of two constants: C1 is a cognitive learning factor that simulates the attraction that a particle has toward its success, and C2 is the social learning that simulates the attraction of a particle toward its neighbors. Algorithm 2 shows the pseudocode to solve a particle swarm optimization problem.

Algorithm 2: PSO

```
Initialize swarm (speeds and best positions);
Initialize external record (initially empty);
while the stop criterion is not satisfied (number of iterations or variation
between the current and previous solution) do
    for each particle do
        Select a member of the external registry (if necessary);
        Update speed and position;
        Evaluate new position;
        Update of best position and external registration;
    end
end
```

2.4 Optimization by Memetic Algorithms

Memetic Algorithms (MA) have their origin in the eighties when evolutionary computing was booming, and metaheuristic techniques were used and studied to optimize difficult problems. MAs arise from the combination of concepts and strategies

of different metaheuristics to improve their performance. The term "meme" is analogous to the term "gen" of GA and it is attributed to Dawkins [27]. The MAs are population nature since they have inherited characteristics of the evolutionary algorithms. Memetic Pareto Archived Evolution Strategy (M-PAES) is an algorithm that uses an external file, which generates a new child with a mutated Gaussian operator and selects the next generation based on an uncontrolled comparison of parents and children evaluated in good condition [37]. Algorithm 3 presents the M-PAES pseudocode.

Algorithm 3: M-PAES

```
Generate an initial population P of n random solutions and evaluate;
Place each non-dominated member of P in a global G file;
while the stopping criteria are not satisfied do
    for each solution c in P do
        Create a local file H, initially at 0;
        Fill file H with solutions of G that do not dominate c;
        Copy solution c from P to H;
        Run the local search using the PAES process (c, G, H);
        Replace the improved solutions of c; in P;
        Create an intermediate population (P′) and a ni (initially at 0);
        while neither < n do
            Put the number of test recombinations r = 0;
            while ((c is dominated by G) ∨ (c is at the fullest location on the
            mesh)) ∧ (r <maximum recombination of tests) do
                Randomly select 2 pairs of P ∪ G, recombine to form offspring c;
                Compare c with the solutions in G; Change G with c if necessary;
                if c is dominated by G then
                    discard c and use binary tournament to select a new solution c
                    from G
                end
                Place c in the intermediate population P′;
                Update population P with intermediate population P′;
            end
        end
    end
end
```

Table 1 Indices notation for the mathematical model

Index	Meaning
b	Products
j	Plants
k	Markets
z	Period

3 Statement of the Optimization Problem

3.1 Objective Functions and Constraints Used for SC Optimization

The investigation analyzed three different optimization algorithms that were evaluated using the data from a case study of a television assembly company located in Cuenca, Ecuador. The company name is not mentioned for confidentiality terms. For the same reason, not all the input data for the optimization problem is presented. The SC of the case study is composed of three levels, namely suppliers, assembly plant, and customers; and two stages, production and distribution. It is necessary to determine the best production and distribution combination to meet the demand of customers under the capacity restrictions at each level. Furthermore, it is important to optimize the inventory levels that the company maintains at the end of each period, especially the security inventory. The SC is integrated by six suppliers (S1–S6) that supply more than 170 items. There is a television assembly plant (P1) which in the study period (2017) assembled 14 television models. The distribution of SC is limited to five distribution centers (DC) that represent 82% of annual sales (DC1–DC5). For the problem statement, the following assumptions were considered: The number of suppliers, plants and distribution centers, the demand for each distribution center, and the plant capacity are known. The supply capacity of the suppliers is considered infinite, i.e., that the suppliers can meet the demands of the plant completely. Furthermore, in the provisioning stage, there is no selection of suppliers, so this term can be simplified in the objective function, and customers receive products from a single distribution center. On the other hand, the indices used to identify products and the parts or levels of the problem posed are described in Table 1.

The input data come from information gathered about the company, corresponding to the costs associated with SC and the system capacity constraints (see Table 2).

Decision variables or output variables of the proposed optimization problem are depicted in Table 3.

The variables in Tables 2 and 3 were determined through a systematic review. The objective functions for the optimization problem were generated with the previous information. Equations (4) and (6) allow to maximize the utility of SC and maximize the level of customer service respectively.

Table 2 Mathematical model notation

Notation	Meaning
CM_{bjz}	Unit cost of raw material supplied to assemble b in plant j, in period z
CE_{bjz}	Assembly cost (conversion) of product b in plant j, in period z
CT_{bkjz}	Unit cost of transporting product b from plant j to market k, in period z
CI_{bjz}	Unit cost of maintaining inventory of product b in plant j, in period z
PV_{bk}	Sale price of product b in market k
D_{bkz}	Demand for product b by customer k, in period z
I_{b0}	Initial inventory level of product b, in period $z = 0$
pt_{bj}	Time required to produce a unit of b in plant j
tt_{jz}	Time available to produce at plant j per period z
SS_{bjz}	Safety stock of product b in plant j, in period z

Table 3 Decision variables notation used in the mathematical model

Variable	Meaning
P_{bjz}	Total quantity of product b assembled in plant j, in period z
PD_{kbkz}	Quantity of product b shipped from plant j to market k, in period z
I_{bjz}	Quantity of final inventory of product b in plant j, in period z

3.1.1 Objective 1: Maximize Profit (Max P)

$$Max\ P = \sum_{z}\sum_{j}\sum_{k}\sum_{b}\left(PD_{bkjz}\cdot PV_{bk}\right) - TC \tag{4}$$

$$\begin{aligned} TC = &\sum_{z}\sum_{j}\sum_{b}\left(PD_{bjz}\cdot\left(CM_{bjz}+CE_{bjz}\right)\right)+ \\ &\sum_{z}\sum_{j}\sum_{k}\sum_{b}\left(PD_{bkjz}\cdot CT_{bkjz}\right)+\sum_{z}\sum_{j}\sum_{b}\left(I_{bjz}\cdot CI_{bjz}\right) \end{aligned} \tag{5}$$

3.1.2 Objective 2: Maximize Customer Service (Max CS)

$$Max\ CS = \left(\frac{\sum_{z}\sum_{j}\sum_{k}\sum_{b} PD_{bkjz}}{\sum_{z}\sum_{k}\sum_{b} D_{bkz}}\right)\cdot 100 \tag{6}$$

Equation (4) constituted the difference between sales (first term) and total cost (TC), second term. In turn, the total cost (5) is made up of the total cost of raw material, plus the cost of assembly, the cost of distribution and transportation of the products, and the cost of maintaining inventory at the end of a period in the plant. Equation (6)

represents the level of customer service as a ratio between the products distributed and their demand. The problem to be optimized requires customer service levels high or greater than 90%. On the other hand, the restrictions that were identified for the case study are presented below in Eqs. (7)–(11).

Constraints:

$$\sum_{b} pt_{bj} \cdot P_{bjz} \leq tt_{jz}; \forall b, j, z \tag{7}$$

$$\sum_{j} PD_{jbkz} \leq D_{bkz}; \forall b, j, k, z \tag{8}$$

$$I_{bjz} = I_{bj(z-1)} + P_{bjz} - \sum_{k} PD_{bjkz}; \forall b, j, k, z \tag{9}$$

$$I_{bjz} \geq SS_{bjz} \tag{10}$$

$$P_{bjz}, PD_{bjkz}, I_{bjz} \geq 0 \tag{11}$$

Constraint (7) ensures that the total time required to produce the products b does not exceed the total available time of plant j at each period z. Constraint (8) limits the quantity of products b shipped to market k at each period z, i.e., is not greater than the demand. Constraint (9) is a final inventory balance equation of product b at the plant j at each period z. Constraint (10) indicates the minimum inventory of product b that must be kept in the plant j at the end of each period z. Finally, constraint (11) indicates the non-negativity of the decision variables, which must take a value greater than or equal to 0.

3.2 *Input Data for the Optimization Model in SC*

The information used for this study corresponding to the 2017 period is presented in Table 4. It was obtained from the work carried out by [13, 31].

Other input data for the optimization model are D_{bkz} and PV_{bk} as indicated in Table 2. However, they are not presented due to the terms of confidentiality with the company. In addition, maintaining a safety inventory is required SS_{bjz}, which is calculated using the standard deviation of the product (Z) and the number of standard deviations, Eq. (12). For a service level of at least 95%, a number of standard deviations (Z) of 1,645 is obtained. The replacement time is considered one month, and the inventory at the beginning of each period I_{b0} as zero (0) due to the limitation in the provisioning information.

$$SS = Z \cdot \sigma_{dLT} \tag{12}$$

Table 4 Unit time and costs, by television model

Model	Raw material cost CM_{bjz}	Assembly cost CE_{bjz}	Inventory holding cost CI_{bjz}	Transport cost CT_{bkjz}	Assembly time pt_{bj}(min)
1	$ 358.59	$ 14.77	$ 6.29	$ 4.00	12.058
2	$ 522.93	$ 15.20	$ 6.29	$ 5.00	12.435
3	$ 446.95	$ 12.82	$ 6.29	$ 5.00	12.435
4	$ 174.44	$ 10.83	$ 6.29	$ 3.00	8.272
5	$ 269.41	$ 17.08	$ 6.29	$ 3.00	8.272
6	$ 349.17	$ 15.51	$ 6.29	$ 3.00	12.167
7	$ 401.06	$ 15.13	$ 6.29	$ 5.00	12.167
8	$ 758.89	$ 25.23	$ 6.29	$ 7.00	18.426
9	$ 965.05	$ 32.38	$ 6.29	$ 7.00	24.517
10	$ 297.14	$ 20.05	$ 6.29	$ 3.00	18.426
11	$ 402.99	$ 13.51	$ 6.29	$ 4.00	12.435
12	$ 529.38	$ 15.58	$ 6.29	$ 4.00	18.519
13	$ 604.26	$ 17.23	$ 6.29	$ 5.00	18.519
14	$ 268.43	$ 8.33	$ 6.29	$ 3.00	9.728

Besides, both scenarios with a maximum and with a minimum security inventory are considered. For this, a "buffer" is used, which allows controlling inventories in zones or levels according to the Target Inventory Level (NOI). The first scenario is the part of the inventory level in which the products needed to meet demand can be consumed and must be greater than $2/3$ of the NOI. The second scenario represents an alarm, which indicates that it must occur to fill the inventory in such a way that it is not completely consumed. This inventory is less than $1/3$ of the NOI [7]. These scenarios allow analyzing the possible variations that may occur in the SC and estimates their impacts on the optimization objectives set. For the case study, the NOI value for each model is calculated with Eq. (12), and Table 5 presents the calculated values for both scenarios.

3.3 Determination of the Number of Iterations and Parameters

Determining the number of iterations or evaluations in the use of an algorithm is crucial since it allows reducing the computational cost without neglecting the normal performance of the algorithm. From 10,000 to 100,000 iterations have been tested for this study. For the optimization using NSGA-II, and the MOPSO algorithm, the parameters used are presented in Table 6.

Table 5 Security inventory levels for the two analysis scenarios

Model	NOI	Max 2/3 of NOI	Min 1/3 of NOI
1	815	543	272
2	0	0	0
3	878	585	293
4	1518	1012	506
5	0	0	0
6	274	183	91
7	344	229	115
8	68	45	23
9	44	30	15
10	313	209	104
11	506	337	169
12	36	24	12
13	45	30	15
14	268	179	89

Table 6 NSGA-II algorithm and MOPSO algorithm parameters

NSGA-II algorithm parameters		MOPSO algorithm parameters	
Parameter	Value	Parameter	Value
Population size (N)	100	Initial population	100
Crossover probability (Pc)	0, 9	Inertia weight, W	0, 4
Mutation probability (Pm)	0, 01	Local learning coefficient, C1	1
		Global learning coefficient, C2	1

Finally, for the memetic algorithm (M-PAES), with the increase in the number of iterations, the result as a function of the benefit and the level of service improves considerably, and the size of the population is reduced when $N = 100$ which was initially indicated. We considered the parameters to implement M-PAES in Table 7.

Table 7 M-PAES algorithm parameters

Parameter	Symbol	Value
Maximum number of consecutive failures of local movements	L_fails	5
Maximum number of local movements	L_opt	10
Number of crosses	C_trials	20

Table 8 Results obtained from the three algorithms with minimum inventory

Algorithm	F OBJ. 1	F OBJ. 2	TIME (s)
NSGA-II (10 k)	$ 3,624,514.87	86.18	11.26
MOPSO (10 k)	**$ 3,728,841.21**	**88.75**	**7.84**
M-PAES (10 k)	$ 2,905,654.15	72.10	129.48
NSGA-II (100 k)	**$ 4,272,669.41**	**97.87**	**89.94**
MOPSO (100 k)	$ 3,881,112.75	90.33	55.61
M-PAES (100 k)	$ 4,185,197.22	95.26	420

Table 9 Results obtained from the three algorithms with maximum inventory

Algorithm	F OBJ. 1	F OBJ. 2	TIME (s)
NSGA-II (10 k)	$ 2,856,451.52	85.26	9.55
MOPSO (10 k)	**$ 3,074,152.51**	**87.47**	**8.19**
M-PAES (10 k)	$ 2,135,499.08	70.31	48.68
NSGA-II (100 k)	**$ 3,576,619.52**	**97.73**	**75.95**
MOPSO (100 k)	$ 3,271,055.75	91.93	61.33
M-PAES (100 k)	$ 3,475,744.91	95.49	385

4 Results

4.1 Multi-objective Optimization Results

Based on the data and objective functions described in Sect. 3, the results obtained by the three algorithms are presented with a minimum and maximum safety inventory, and 10 k and 100 k iterations (see Tables 8 and 9).

Tables 8 and 9 show as a general trend that the greater the number of iterations, the better the response level of the algorithm, and also the greater the computational processing time for all tested algorithms. Also, when the level of security inventory is the maximum, the costs associated with maintenance and conversion increase, reducing the profit of the company (see Fig. 1).

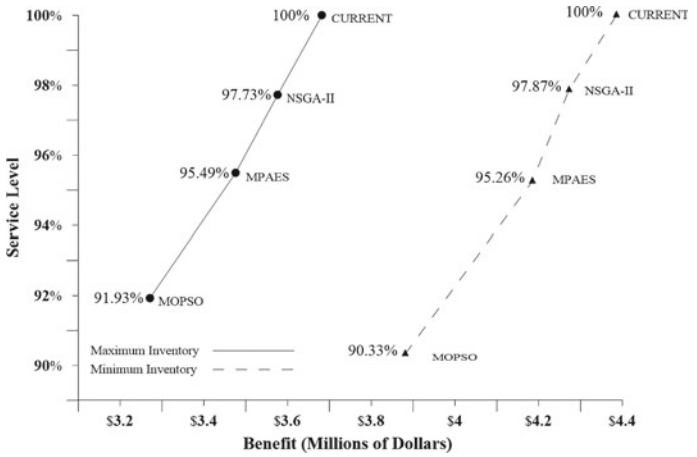

Fig. 1 Results of the tested algorithms

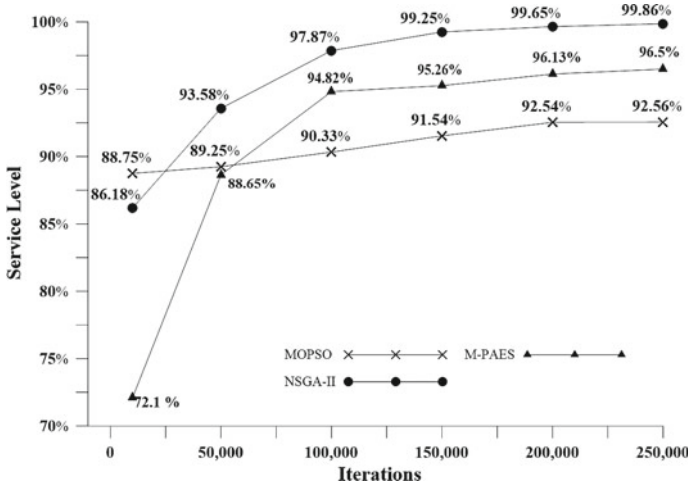

Fig. 2 Number of iterations per algorithm

The MOPSO algorithm obtains the lowest benefit, followed by M-PAES with a slight difference of an increase in its benefit, and finally, NSGA-II, which obtains the highest benefit among the three algorithms. On the other hand, with 100 k evaluations and for the two inventory levels, MOPSO presents the lowest service level among the three cases, with 90.33% and 91.93%, respectively, followed by M-PAES with 95.26% and 95.49% and finally with NSGA-II, which presents the best service level of 97.87% and 97.73%, respectively (see Fig. 2).

5 Discussion

In this research, two scenarios for optimization were tested. These two scenarios consider favorable and pessimistic options. The behavior of the service level concerning the benefit according to the different scenarios shows an improvement depending on the algorithm used (see Fig. 1). The NSGA-II performs best under the established conditions. This result coincides with the work developed in [24], where the authors mention that the NSGA-II is the most widely used algorithm for multi-objective optimization. However, these authors compared their results with only one algorithm, while in the present research it was done with three algorithms, giving a more realistic comparison.

On the other hand, the three algorithms are compared, taking into account the relationship of the number of iterations with the service level (see Fig. 2). It can be seen that the behavior of the service level curve when it is optimized with NSGA-II and M-PAES is logarithmic, so a large increase in the number of iterations is needed to obtain a minimum increase in the service level, although MOPSO, with a lower number of iterations, presents better results than the other two algorithms. While the number of iterations increases, the service level increases very slowly in the space of possible solutions, having a linear trend, so that the two other algorithms surpass it. M-PAES is known to be a complex hybrid algorithm that takes longer to present solutions, but it turned out to be better in terms of quality of results compared to MOPSO. Still, for M-PAES, these solutions improve by increasing the number of individuals in the population, differing from the other two algorithms where increasing the number of individuals affects the speed of convergence versus the number of iterations. Therefore, 100 k proposed iterations are enough to obtain favorable results and to be able to compare the three algorithms in a fair situation. Furthermore, the computational cost can be evaluated under the same conditions.

The SC optimization problem has been studied by several authors, resulting in different answers to questions posed or objectives raised. The results of this investigation are compared with others found in the bibliography, for example, with [3, 17, 18], where the authors agree that optimization by GA gives better results than PSO in bi-objective optimization of the SC. All of them agree that the MOPSO algorithm presents solutions in less time than other algorithms, just like our optimization problem. While the memetic algorithm, M-PAES, takes the longest time to present a quality answer, other SC problems as in [16, 33] and other similar studies [20, 28] have presented good results as a hybrid algorithm. In this case study, M-PAES, despite not being a widely used algorithm for optimizing the SC, presented better results than MOPSO, but worse than NSGA-II.

The SC studied gives more emphasis to assembly and distribution, which are two critical areas. While the suppliers are considered, they can provide the material necessary for the assembly line. Some works propose a SC of up to four stages with five levels (supplier, producer, distributor, wholesaler, and retailer). However, research such as [3, 14, 18, 39], to name a few, work with few products and few study periods. In the SC of the case study, the number of variables that the problem handles

increases its complexity of resolution. Thus, a total of 1,176 variables were taken into account, since it considers 12 study periods, 1 assembly plant, 14 products, and 5 distribution centers. This complexity reveals the relative efficiency of optimization algorithms, leading to finding optimal results. On the other hand, the proximity of the solution sets obtained by the NSGA-II genetic algorithm is greater than that of the sets found by the MOPSO and M-PAES algorithms, for the two study scenarios, with a minimum and a maximum security level inventory.

6 Conclusion

A multi-objective optimization problem of costs in the supply chain in an assembly company was studied. This problem was resolved by applying and comparing three evolutionary algorithms. The algorithm that had the best performance was NSGA-II. Furthermore, this research contributed to identifying the variables of the SC for assembly companies that are involved in optimization. The findings clearly indicate that the number of iterations significantly affects some algorithms, and multi-objective optimization shows that NSGA-II is more effective than MOPSO and M-PAES in searching the feasible solutions space for a set of solutions that present very close objective vectors or contained in the real set of the Pareto optimum. Thus, a value of 97.87% of service level with a benefit of $4,272,669.41 was reached by this algorithm; this value represents an increase of $391,556.66 of the worst result given by MOPSO. The minimum level of a security inventory was the best optimization scenario. One of the limitations in this investigation was assuming that the suppliers of the SC were capable of supplying all the requirements of the plant. However, in many SCs the stage of raw material supply is considered strategic and presents several challenges, since it involves different lead times depending on the type of raw material and the location of the supplier. Future work will consider this limitation. This study can be expanded to consider the level of inventory in the assembly plant, because these inventories imply high costs in some sections of the SC.

Acknowledgements This study is part of the research project "Modelo de optimización de costos en la cadena de suministro en empresas de ensamblaje" supported by the Research Department of the University of Cuenca (DIUC). The authors gratefully acknowledge the contributions and feedback provided by the IMAGINE Project team, similarly, to the management and operational staff of the television assembly company for their willingness to being analyzed as a case study.

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Construction of a Dataset for Static and Dynamic Hand Tracking Using a Non-invasive Environment

Ruben Nogales, Marco E. Benalcazar, Bryan Toalumbo, Alexis Palate, Ronnie Martinez, and Javier Vargas

Abstract The research consists of hand gesture recognition using a commercial sensor called Leap Motion Controller. For the study, we determined hand tracking carried out for 5 static and 4 dynamic gestures. For this work, the stages of the gesture recognition study were divided into data acquisition, preprocessing, feature extraction, and classification. For the data acquisition stage, we programmed an interface in MATLAB, which generates a structure of output data in images and spatial position forms. The preprocessing consists of taking the data acquired by the leap motion controller and transform them into data readable by MATLAB using the MEX compiler, these data are captured during the execution of the gesture. Besides, the proposed data acquisition interface collect demographic data, hand injuries, and the light intensity of the environment in which the data is taken. These data can be used in hand gesture recognition systems and application fields such as medicine, engineering, and robotics, among others. The development of the acquisition system is parameterized with 30 repetitions at 60 frames per second and the sampling time at 5 s. Finally, the system previews a graph of the gesture recognition test structure in specific activity time.

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M. V. García et al. (eds.), *Advances and Applications in Computer Science, Electronics and Industrial Engineering*, Advances in Intelligent Systems and Computing 1307,
https://doi.org/10.1007/978-981-33-4565-2_12

Keywords Hand gesture recognition · Acquisition system · Non-invasive monitoring

1 Introduction

A gesture is considered as a movement for the execution of a task or communication. Nowadays, gestures are formalized for the interpretation of operations of some technical movements [10]. Focusing on hand gestures is determined by the movement participants make. These movements are established by the type of gesture, whether it is a known gesture or a new one [12, 17]. Systems that recognize this type of gesture classify them into two types: static and dynamic gestures. Static gestures are movements predefined previously by some type of a guide model. On the other hand, dynamic gestures are intended to perform a movement without a guide in a free form but are correctly performed. These gestures can be determined in lapses of time for each one, for example, the opening and closing of the hand [18, 19].

A hand gesture recognition system uses both invasive and non-invasive assessment devices to observe the gesture [4, 6, 19]. Invasive devices are sensors that are placed in the participant's hands. This type of invasive sensor can hinder the participant's activity by sending incorrect data to the system. The advantage of these types of sensors is that the data can be more accurate, but the task performed cannot be the correct one. One of the most used sensors for this type of evaluation is the Myo armband sensor, which uses a bracelet that is placed on the participant's forearm. This device evaluates the electrical activity of the muscles, resulting in 5 predefined hand gestures [5].

On the other hand, non-invasive devices or sensors are currently used to determine hand gestures without the need to hinder the activity. These types of sensors can be color cameras, depth, infrared, or tracking camera [7, 16]. Therefore, a non-invasive sensor allows the evaluating of the hand gesture from a distance to the participants. The most used sensors are Leap Motion and Kinect [13]; this is due to the great demand of the market for its more commercial development. The Kinect device is configured through depth sensors, skeleton tracking, and a color camera [15]. The disadvantage of this device is that it is not used only for a specific part of the participant's body, but to evaluate all of the participant's extremities. The device that allows only evaluating the hands of a participant in the Leap Motion uses two deep vision cameras and three infrared LEDs [21]. These deep vision cameras or depth sensors allow determining the participant's distance from the device. Hand gesture recognition systems are intended to solve e-Health-oriented problems. These problems or types of activities are contextualized as solutions to facilitate the type of heavy activity performed with the participant's hands [3]. For example, an activity performed with the hands to be evaluated is the process of cutting shoes, which demands a forced use of the hand. In this context, the cutting process can be solved using a robotic arm that is previously trained with the participant's dynamic gestures [14]. In this context, the type of data and the amount of data depends on the problem

that needs to be trained. This type of training is done by obtaining a large amount of hand gesture data at certain times.

In the case of a study within non-invasive monitoring, and evaluation system is proposed to obtain hand gesture data. The system is parameterized using 5 static hand gestures included in the sensor libraries and 4 dynamic hand gestures analyzed by the activity performed [20, 22]. The static gestures are the following: Open Hand, Close Hand, Wave In, Wave Out, and Pinch Gesture. The dynamic gestures are the following: Circle Gesture, Swipe Gesture, Key Taps, and Screen Taps. The distribution between static and dynamic gestures depends on the number of repetitions that the participants make at the moment of taking the data and the time that it takes in each gesture [2]. In addition to the data obtained from the gestures, information is managed by analyzing the participant's data demographic. Each information allows having a dataset, which is formalized utilizing composite structures in the programming of the system developed in MATLAB, which is a computer software number that integrates its programming manager. On the other hand, the sensor used for evaluation is the Leap Motion Controller (LMC), because it is a specialized sensor to acquire data from the hand such as spatial positions, directions, speed and images. In addition, it is small, portable and economical. In this context, the hand gesture recognition system allows to obtain a set of data that will be treated as a training tool for hand gesture recognition models for automatic learning algorithms.

2 Methods

For this work, the study of the stages of gesture recognition is divided into data acquisition, preprocessing, feature extraction, classification, and post-processing [9]. The first stage is developed to determine the data obtained, the evaluation time, the measurement factors, the demographic information for each participant, and the computational results of the system. The development of the data acquisition stage for the dataset is structured in 4 system modules, establishing a distribution between the development module, scripts, inputs, and outputs. As a whole, it is systematized as a Non-Invasive Monitoring Environment which allows the system evaluator to obtain two types of data from depth images and spatial positions of the hand gestures.

2.1 Development Study

First, the hand gestures to be studied are established, which are specified static and dynamic gestures. The static gestures are Open Hand (a), Close Hand (b), Wave In (c), Wave Out (d), and Pinch Gesture (e), and they are determined using hand positions with the Leap sensor (see Fig. 1).

The dynamic gestures Circle Gesture (a), Swipe Gesture (b), Key Taps (c), and Screen Taps (d) are determined in free movements respecting the capture range of the

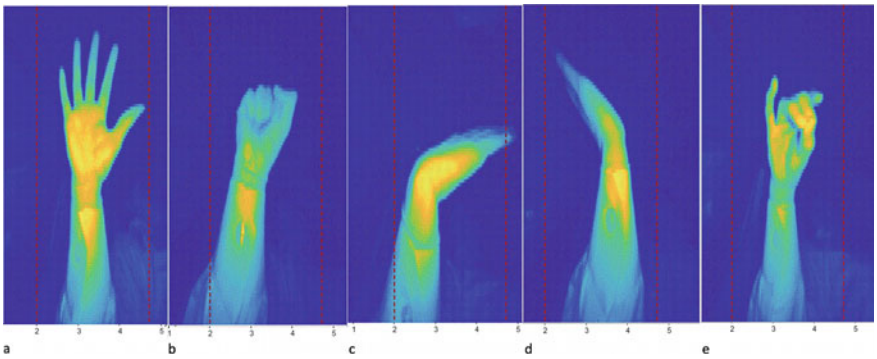

Fig. 1 Capture with the leap sensor of the static gestures

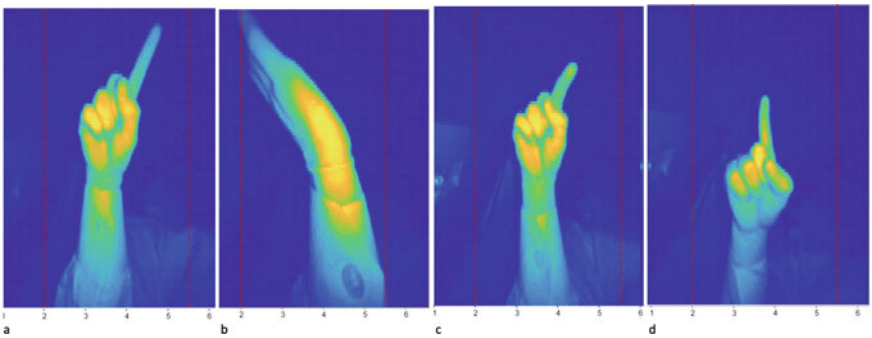

Fig. 2 Capture with the leap sensor of the dynamic gestures

Leap sensor (see Fig. 2). For each image, it shows the data of a matrix in a low-level color range. Each image is represented by a group of repetitions defined for time determination.

For static gestures, the number of repetitions per gesture are at 30 frames per second and the sampling time is at 5 s. For dynamic gestures, the number of repetitions per gesture is at 60 frames per second and the sampling time is at 6 s. The sampling frequency for the dynamic gestures is taken between seconds 2 and 5 leaving the first and last second for segmentation. On the other hand, the number of repetitions is 30 for each gesture; this allows us to have an output of each gesture for structure and image data.

The LMC sensor works in a range of 150° and 60 cm to the evaluation axes. This allows the participants to make the hand gesture naturally, which in the Non-Invasive Monitoring Environment allows decoupling from error in the data collection utilizing the depth sensors (see Fig. 3).

The parameterization of the data is established employing a sensor processing stack, which allows determining the information captured by the Leap sensor (see Fig. 4). Each process of the programming stack is managed in the LMC library [8].

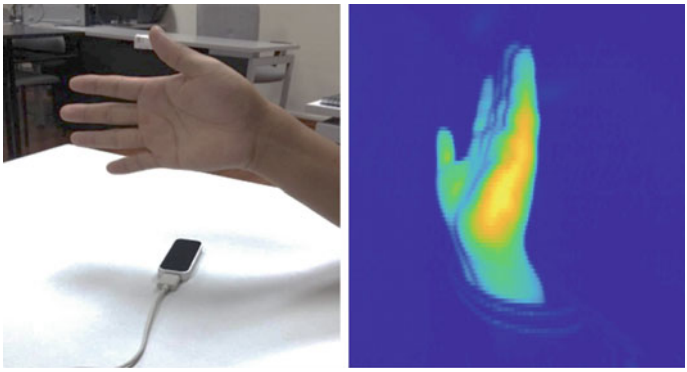

Fig. 3 Leap sensor hand position and preview image data

This type of systematization is done as calls to classes and headers of the C++ programming language type, which is processed in the compilation libraries of the C++ MEX API for MATLAB [1]. This allows us to develop a structure from each of the frames obtained and the gesture is stored in the form of a data matrix.

In addition to the structure and image data, participants are asked to provide demographic and analytical information that will help determine the participant's condition (see Fig. 5). These states allow determining whether they suffer any type of hand injury. The basic data for the investigation are name, age, gender, ethnicity, occupation, and mail. On the other hand, the study data are as follows: injury, to establish the injuries that participants have or not [11]; and lux, data that allows the evaluator to enter the level of illumination to later work with the infrared cameras of the Leap and its percentage of acceptance in the final evaluation.

A dataset with 160 users was developed for the study, with 30 repetitions at every 9 hand gestures in different types of evaluations.

2.2 System Systematization

The 4 modules of the overall system structure are linked to the data acquisition process for real-time hand gesture recognition using LMC (see Fig. 6).

The DEVELOPMENT module presents the structure or programming stack of the evaluation environment. All modules communicate with the main interface manager. As it is a non-invasive evaluation, the distances between the device and the user's hand are used. These distances are programmed at 60 cm from the capture axes of the Leap sensor. The IMAGE API BASICS is the process library that allows the system to process each frame in determining the time. Each image from the controller will determine the current frame obtained in each shot from the sensor with the tracking data from the sensor. The DEVICE process establishes the device initialization

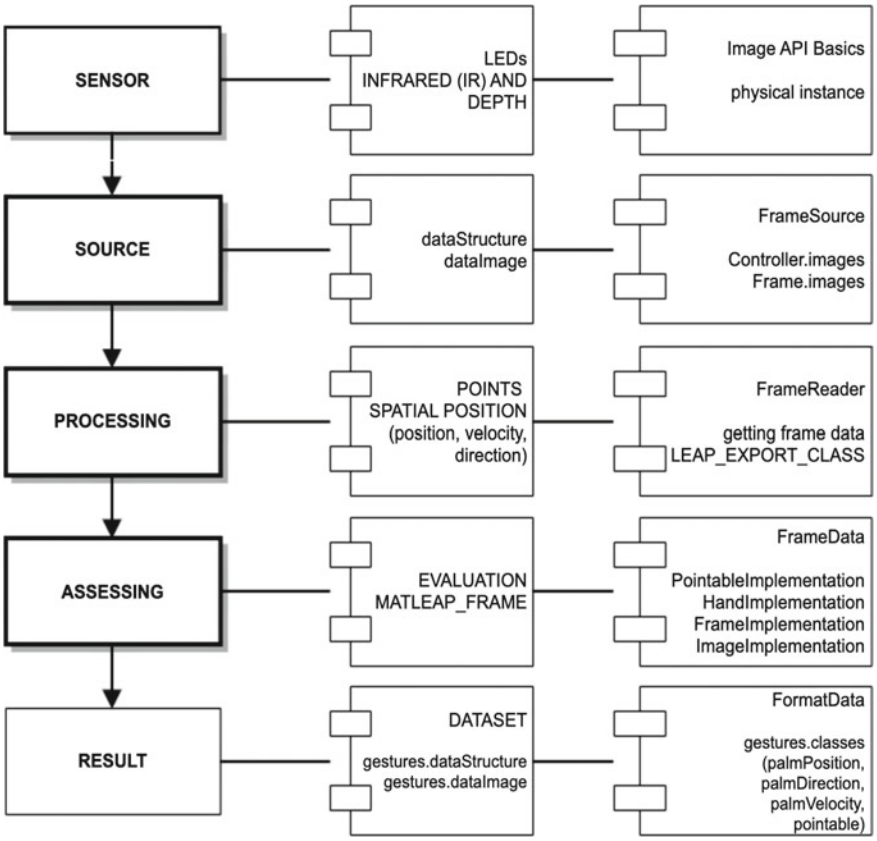

Fig. 4 Sensor processing stack, leap motion controller

1x1 struct with 10 fields

Field	Value
name	'Name Person'
age	'22'
gender	'Male'
ethnicity	'ethnicity Mzo'
occupation	'Student'
mail	'name@main'
injury_select	'no'
injury	'no injury'
lux	'45'
gestures	*1x1 struct*

newStruct.gestures

Field	Value
classes	*1x9 cell*
OpenHand	*1x1 struct*
CloseHand	*1x1 struct*
WaveIn	*1x1 struct*
WaveOut	*1x1 struct*
PinchGesture	*1x1 struct*
CircleGesture	*1x1 struct*
SwipeGesture	*1x1 struct*
KeyTaps	*1x1 struct*
ScreenTaps	*1x1 struct*

Fig. 5 Demographic data presented in MATLAB structures

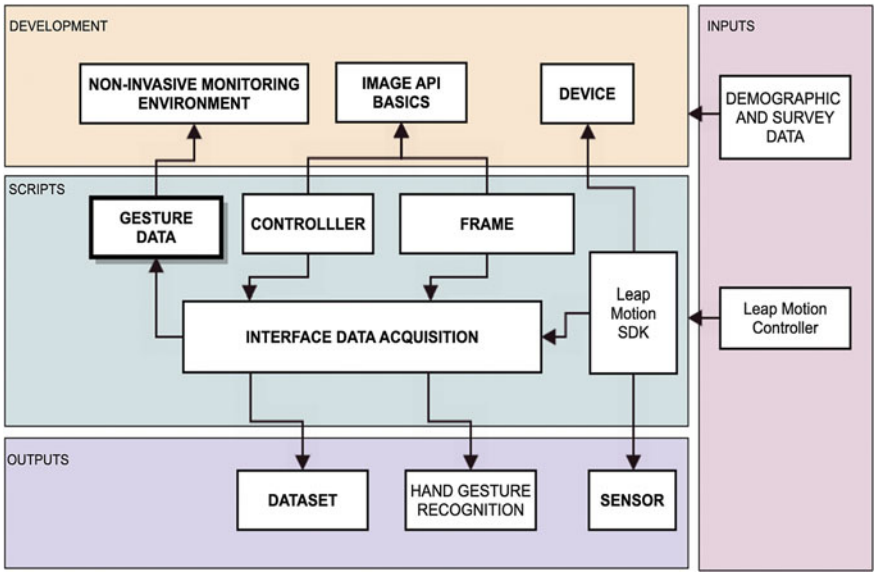

Fig. 6 Diagram of the interaction of modules with processes

parameters, and the activation of the infrared and depth camera. The SCRIPTS module integrates static and dynamic hand gestures. For this, it is established as follows:

- Open hand, a gesture of the activity where all are deployed in separation from each other in a perpendicular position to the Leap sensor.
- Close hand, the activity of the hand when closing each of the fingers in the direction of the center of the user's palm.
- Wave In, activity when the little, middle, ring, and index fingers are parallel to each other generating a turning movement to the user's internal axis of vision.
- Wave Out, activity when the fingers are parallel to each other generating a movement toward the external axis of vision of the user.
- Pinch, a gesture by which the user makes a movement where the middle and ring fingers press with the thumb.
- Circle, a movement of the index finger that makes turns on its axis thus generating a type of circle in a certain number of repetitions.
- Swipe, a movement generated by the hand when it unfolds vertically and systematically.
- Key Taps, a gesture where the movement of the index finger is in the form of an arc to the hand, thus generating a type of click as a pointer.
- Screen Taps, a gesture of touch movement by which the fingers can act on pressing objects within the space between the fingers.

On the other hand, there are the CONTROLLER and FRAME processes that allow the programming of the elements used in class extraction. These classes are

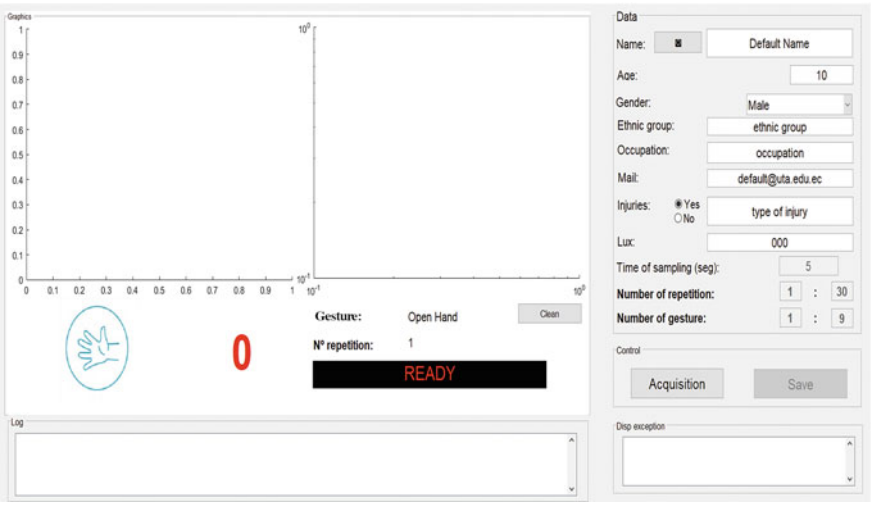

Fig. 7 Adaptive wireframe for the acquisition system

data that allow us to determine the position of the hand, the speed of the gesture, and direction concerning the Leap sensor. Each frame is taken in the internal processing development software, for a greater number of frames per second will require a high-performance computer. The Leap SDK used is the Leap Motion Orion 3.2.1 version compatible with a C program and the library of link creation with higher level languages. This is for the creation of gateways that compile between different types of languages, for example, using MEX for MATLAB. The INTERFACE DATA ACQUISITION is proposed in an adaptive wireframe for a training evaluator to take data and knowledge of each hand gesture (see Fig. 7).

The INPUTS and OUTPUTS modules first establish the Leap sensor as a data collection mechanism. To do this, each user must take into account the procedures to follow when placing the hand perpendicular to the sensor. The demographic data are extracted through direct questions from the evaluator concerning the user. These data are complemented by obtaining an App to determine the brightness levels at the physical place of evaluation.

As a final result, a dataset is obtained which will contain the data of users separated into different types of classes. This dataset is a MATLAB output structure in a .mat file format containing binary data. Later, the data of each hand gesture is formalized to generate automatic learning algorithms for hand gesture recognition.

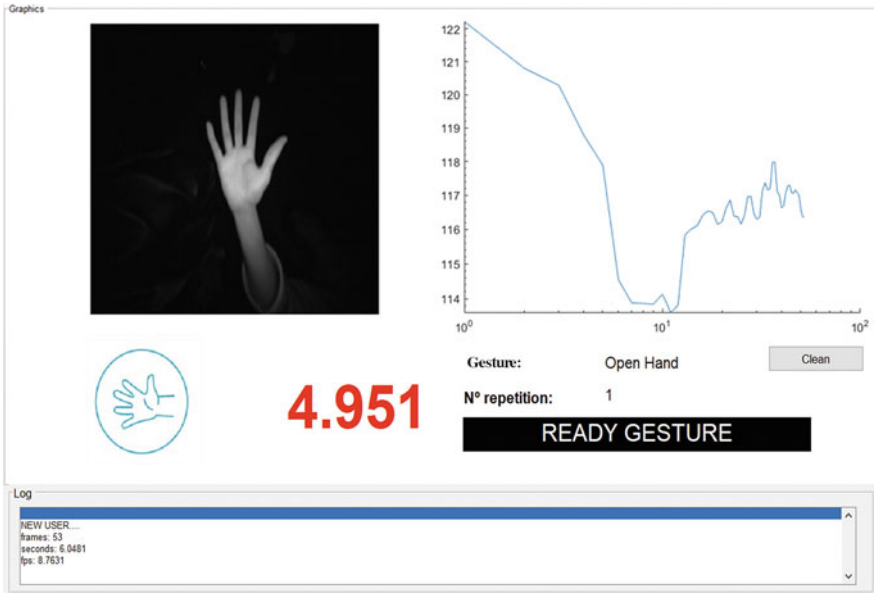

Fig. 8 Development of static gesture (real-time evaluation method)

3 Results and Discussion

The data in internal programming can be set to 5 s depending on the gesture made. In context, each hand gestures made may vary according to the conditions in the evaluation environment. If a gesture is considered wrong, this means that the sensor did not evaluate in its capture environment or it is because of a bad realization of the gesture by the user. For this reason, the evaluator and the system generate an alert which indicates the number of repetitions where the gesture had some kind of problem. Each data obtained by the system is processed in image- and structure-type data; this means that the images with matrices of numbers correspond to the executed frame. On the other hand, the structure-type data is the information of each gesture in a correlation of direction, position, and speed of the hand. For a more detailed analysis of the gesture, the data is graphed to the exact moment in time when the gesture was made. This process is called as execution time or activity time, this allows us to evaluate a window time in which the gesture is executed by the users (see Fig. 8) .

The data acquisition system has a 2-operation capture: Get the frame which obtains the number of frames while the sensor continues to track the hand. Get an image which constructs the image concerning the spatial points of the hand and capture of the infrared sensor.

The frames of the video are evaluated in the input queue, having as input constants the identification data, time-stamped, pointable, and traced hand independently if it

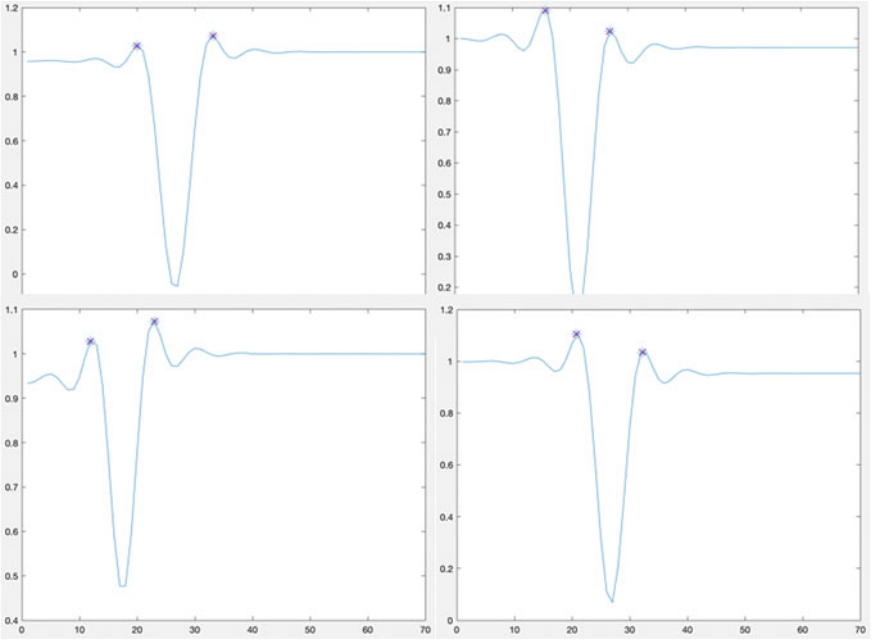

Fig. 9 Gesture test close hand action time

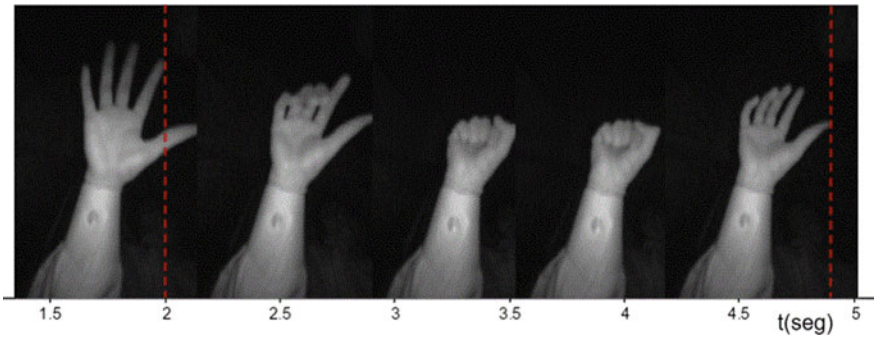

Fig. 10 Image sampling of 30 repetitions within 5 s of the gesture capture

is left or right. Each gesture is processed by the system which previews a graph of the gesture test structure (see Fig. 9).

The resulting example graphics present a gesture in the initial and final positions of the activity. The Close hand gesture is used for the example, in which at the start of the evaluation the hand is in a static state until it makes the definitive gesture in the second 2 of the video frame (see Fig. 10).

Finally, you have an output file for each gesture saved in a time of 5 s for a total of 30 repetitions for 160 users. The dataset consists of images and spatial positions

captured in the same instant of time with the LMC. The data capture was carried out on a computer with an Intel Core™ i7-4770 processor and 4GB of RAM.

To reproduce the results of the first dataset with the LMC device taken by the hand gesture recognition acquisition system, it is made available to the public on the link: https://drive.google.com/drive/folders/1MuykUhxyH6g089nweuYdf3fLeSfgQINe?usp=sharing. The dataset is currently in the preprocessing and feature extraction stages where the computational cost depends on the computational resources used to execute the code.

The preprocessing stage is composed of the translation of the coordinate axis that calculates the new values of the finger position about the new Cartesian coordinate plane. For the characteristics extraction stage, a data matrix is created for each of the fingers, a window value is defined, the same window that will go through all the signal data, and a value of a so-called step displacement is defined. For the classification stage, a neural network of the Toolbox from MATLAB is used to initially test the data. The neural network used is a forward back propagation type. These steps are related to each other for the hand gesture recognition procedure using learning algorithms.

4 Conclusions and Future Work

In continuation to the investigation in [20], an exhaustive systematic review of the literature is proposed to know the current state of the problem facing the recognition of gestures. In the case of the project, we studied the data acquisition devices, their advantages, and their disadvantages. In the same sense, in this paper, we have made available the first dataset of data acquisition for hand gesture recognition.

Besides, we successfully obtained data through a non-invasive sensor that approximates the spatial positions of the hand by obtaining hand tracking data for static and dynamic gestures. It was also possible to link different programming languages such as C++, Mex code, and MATLAB code. This is to obtain optimal processing.

Finally, it is possible to build a dataset of images and spatial positions simultaneously with the Leap Motion Controller.

Future work continues with the preprocessing, feature extraction, and classification stages. Another problem to investigate is the study of features for hand gestures and then move to the classification stage to improve recognition accuracy using context information on machine learning algorithms. In the same way, the dataset is created with the highest number of users, which allows the model to make a better approximation. Therefore, this dataset will be applied in the medicine field. As a future work we will propose a virtual rehabilitation application.

Acknowledgements The gratitude to the Escuela Politécnica Nacional and its doctoral program in computer science, for having the best human resources for the development of its students. Thanks are also due to Universidad Técnica de Ambato, for providing the facilities for continuous improvement, and to Corporación Ecuatoriana para el Desarrollo de la Investigación y la Academia (CEDIA) for the development of the research project CEPRA-2019-13-Reconocimiento de Gestos.

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Topical Part: Computer Science

Monitoring of Industrial Variables Based on LoRa Communication Protocols

Flavio Morales, Diego Mogrovejo, Edgar González, and Renato M. Toasa

Abstract Today, wireless technology continues to grow on a large scale and it provides significant benefits in areas where access to other technologies is not permitted. It meets a need for communication in communities that require it. This document shows the implementation of two wireless nodes, transmitter and receiver, which allow the measurement of water levels in the drinking water supply tanks of the Baños parish, Cuenca Canton, Azuay Province, Ecuador. For these nodes, modules with LoRa technology are used that allow communication in remote areas where there is no mobile cellular or internet coverage. This system will allow monitoring and information to be sent to the offices, thus avoiding the physical mobilization of personnel and maintaining constant control of water levels, optimizing resources, since personnel will now be mobilized to the reservoir tank when these levels need to be treated. Thus determining that the use of LoRa modules for the transmission of water-level variables, allows to obtain favorable results at long distances with a stable link, in real time and without line of sight, crossing obstacles.

Keywords LoRa module · Wireless sensors · Water level

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M. V. García et al. (eds.), *Advances and Applications in Computer Science, Electronics and Industrial Engineering*, Advances in Intelligent Systems and Computing 1307,
https://doi.org/10.1007/978-981-33-4565-2_13

1 Introduction

Industrial automation and process control systems have been an ongoing theme for researchers and developers of wireless technology over the past few years. The reduction of wiring in plant areas, mobility, and flexibility are just a few of the benefits of incorporating wireless systems into process automation [10]. Many advances have been made in recent years that have brought with them wireless sensor network technology that is of great benefit to the population [1].

Today there are networks made of intelligent wireless devices that allow system controls to be carried out, reducing costs by avoiding the use of cables for data transmission. These sensors have built-in batteries and transmit data wirelessly using base stations to cover long distances ensuring that the information reaches its destination [3]. With the advance of technology, new technological tendencies are generated that provide greater competitiveness and efficiency to companies of any type. The Internet of Things (IoT) is a technology that is being implemented and allows us to offer more complex services than those that currently exist [9].

However, in Ecuador the use of wireless sensor networks at the industrial level is limited. For the moment there is equipment that allows wireless sensor, monitoring, and control of multiple variables in industrial processes [5, 12]. The use of wireless sensor networks makes efficient use of energy as they are scalable, that is, new sensors can be incorporated without affecting performance, achieving the implementation of dynamic network topologies [15, 18]. The advantages of wireless sensors are that they can be used in places where access to establish communication is difficult. They can be integrated into a network by creating a central system from which all variables are monitored. And finally they facilitate a reduction in costs because they avoid buying expensive cables, gutters, ducts, and other accessories [16, 22].

The range of wireless sensors is limited, so it is effective to use the Internet to send data anywhere, but the problem arises when you do not have an Internet connection or access to a mobile cellular network. Then you need a device that can improve the range of the wireless signal and that provides security to prevent information theft [6, 14].

Currently, technological advances have been taking giant steps, this is due to the growing interest in the use of human intelligence [4]. For example, one advance that has revolutionized and continues to revolutionize researchers worldwide is the wireless communications boom, which in recent years has led to the growth of numerous tools that handle emerging devices and applications. Technology market analysts indicate that wireless technology will have a huge impact on the industrial market in the next five years.

This article is organized as follows: Sect. 2 is the literature review. Section 3 describes the proposal development of this work. Section 4 shows the implementation. The results of this research are detailed in Sect. 5, and finally the conclusions are shown in Sect. 6.

2 Literature Review

Below are some works with LoRa technology and their main results:

Initially, in [19] the implementation of a network of IP wan wireless sensors is shown using LoRa modules for water quality monitoring in 2 rivers. This project, carried out in 2017, consists of a prototype to transmit the variables of PH, conductivity, and the temperature of the rivers. It uses the MSP430F5529 microcontroller to perform data acquisition and to send the LoRa RN2903 microchip module with the W1063 electronic pulse antenna that transmits in the 918 MHz band, performing tests at a range of 360 m. To measure the PH, it is done with a pocket PH-meter, the temperature is measured with the DS1820 sensor and the conductivity is measured with 4 pole cells.

Also [20] shows the development of the proposed transmitter which seeks to provide a reliable, sustainable, and low-cost alternative for the transmission of output data from commercial transducers. This transmitter is used in the industry, with the use of technology LoRa, based on the use of free band long range and real time, at a frequency of 915 MHz for America. It can also be used for applications where there is no access to the Internet and constant monitoring is required as well as real-time data emitted by sensors for control and monitoring of their states in the industry.

In [8], the use of an architecture to implement a monitoring system was proposed. The system was built only to access a Local Area Network. Results showed that the smart gateway could handle the LoRa communication and the monitoring information system together. It also showed that the system average throughput is 489 bit/s with a packet loss of 26% at a 1-m distance.

Reference [24] mentions that with the emergence of LoRa technology, further improvements to applications of the Internet of Things (IoT) can be realized. By using a single receiver in the LoRa network it is able to handle many nodes at multiple locations within the area, unlike the Wi-Fi-based system which needs to have many access points to increase the coverage area. The combination of LoRa and Wi-Fi technology reduces the cost of deployment of the IoT system. In this article, the actual deployment of IoT systems uses LoRa technology with the combination of Wi-Fi technology. Besides, this article details the performance and the actual coverage area of the LoRa network in both indoor and outdoor conditions.

Reference [23] proposes a feasible solution of design and implementation, allowing the users to conveniently build a private LoRa network for various IoT applications. First, several typical application scenarios of the LoRa network are discussed. Then, the LoRa system architecture is presented with the functionality of each component. The hardware design and implementation of LoRa Gateway, is the bridge between LoRa nodes and LoRa network server. The research contributes by proposing an improved software architecture of the LoRa network server whose source codes are open on GitHub.

Reference [21] mentions that the unit is a fully autonomous wearable wireless sensor node, including a transceiver, processor, sensors, flash memory, and a low profile battery, all integrated on the feed plane of a textile antenna. The design and

characteristics of the unit are described, including radiation patterns of the fully assembled unit. Finally, an outdoor long-range performance test is performed as a proof of concept. Communication was reliable for a range of over 500 m and over 200 m with the antennas pointed toward and away from each other, respectively. In static conditions, a range of 1:44 km was observed.

Reference [7] establish signal strength measurements for the in-building and inter-building LoRa links and provide insights on factors that affect signal quality such as the spreading factor and antenna orientation. Subsequently, they provide measurement results in urban and suburban environments where the LoRa transmitter is deployed at different heights using an unmanned aerial vehicle (UAV). Our findings show that the UAV deployment height is critical for improving coverage in the suburban environment and antenna orientation affects the communication range.

Reference [11] provides a design of a LoRa mesh-networking module for IoT applications. The results show our LoRa mesh-networking module achieved an 88.49% packet delivery ratio (PDR), while the LoRa WAN in star network topology was only 58.7% under the same conditions.

Therefore, the objective of this project is to develop a prototype transmitter–receiver system to improve the range of a wireless industrial transducer using the LoRa communication protocol, offering immunity to interference, to monitor water levels in rural areas, analyzing the signal and speed with which data arrives as the transmission distance increases, displaying the values sent by the transducers in a human–machine interface (HMI).

3 Proposal

After research and data collection, it was determined that the problem in places of difficult access where there is no telephone or internet coverage is communication. In the province of Azuay, the percentage of the population with Internet access is 55.48% in urban areas and 18.09% in rural areas, within the geographical limits of the map, and 21.90% of the population is settled outside the nodes, that is, without Internet coverage [14].

In [2], there is the diagnostic evaluation developed to determine the current situation of accessibility to telecommunications infrastructure at the cantonal level and the proposal for coverage expansion in the representative cantons of the country. The dispersion of housing and the geography of rural areas complicate technological facilities in these sectors and this is why mobile phone operators do not offer their services in certain sectors of rural parishes, especially in the most remote and sparsely populated areas as their installation and operating costs would be high.

In this project, it is determined that the main problem is the water supply to Baños parish in the city of Cuenca, which must be constantly checked by the staff by hand. These records make it possible to verify if the supply is correct or not, due to the distance needed to be covered, the time and the risk that the personnel run to measure the data in this way; it is necessary to design an electronic device that allows these records

to be measured automatically and reliably, as well as optimizing human resources and time. To provide a solution to the problem found, it is required to study all the wireless components necessary to collect the information automatically, taking into account that in the area there is no access to the Internet or cell phone signal, for this we have developed a transmitter–receiver system using the communication protocol LoRa WAN (Long-Range Wide Area Network), as it is immune to interference and working in a free band channel, it does not generate costs. In addition, designing a network topology that is adapted to the environment.

3.1 Technical Proposal

The modules used in this prototype for both the receiver and the transmitter are LoRa RN2903 [13], this module was chosen because it allows work in a free band and it is friendly with the environment, besides supporting temperatures between −40 °C and +85 °C. Another important characteristic of this module is the low-power consumption because the individual voltage is from 2.1V to 3.6 v being 3.3 v the average voltage. This module is used for applications such as automated meter reading, security systems, home automation, industry control, internet of things (IoT). The antenna selected for this project is the Taoglas manufacturing FW [17].

Apart from working on a free band channel, it operates on the same frequencies as the LoRa RN 2903 module. It is very flexible and works in a 915 MHz frequency band. This antenna can be used in monitoring systems, motion sensors, and contaminant monitoring. The power consumption is low and presents an improvement of sensitivity and power in places where the signal is low. Physically, it has a height of 226 mm with a base diameter of 16 mm, and the diameter of the whip is 6.2 mm, its weight is approximately 38 g and it has an IP65 resistance to water and dust. The sensor used is the standard version LS-10, since it allows taking measurements of river and lake levels, in deposits and storage; it is a robust, reliable, and economical sensor.

Apart from the microchip, antenna, and sensor described above, other elements were also used for the assembly of the receiver and transmitter nodes, as shown in Fig. 1.

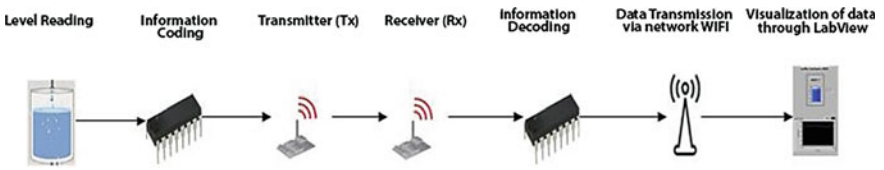

Fig. 1 General structure of the technical proposal

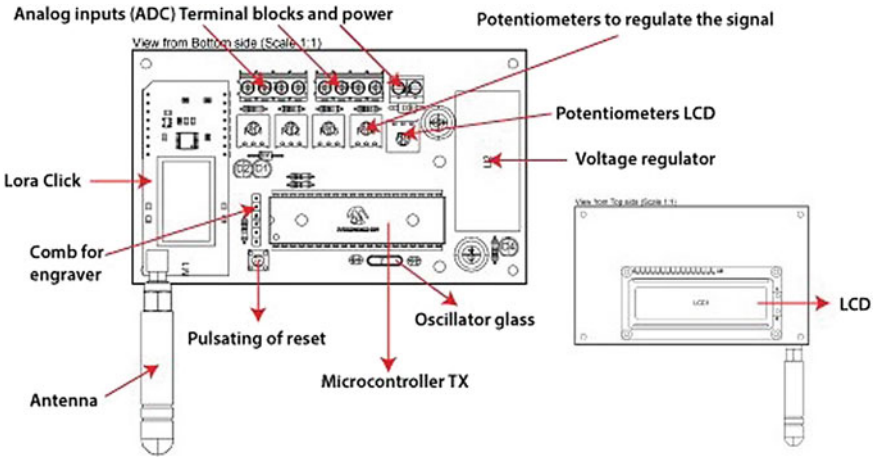

Fig. 2 Transmitter plate structure (Tx)

4 Implementation

Figure 2 shows the structure of the transmitter board (Tx).

The implementation of the transmitter (Tx) node is done in the drinking water treatment laboratory in order to share analog data, which is converted by means of the equation in LabVIEW and the receiver (Rx) microcontroller to obtain the value in meters. The tank for the supply of drinking water has a height of 6 m, when the water is at a level of 4.35 m an alarm is issued to divert the flow; however, when the water level reaches a height of 4.42 m it is because the water is leaking and involves a waste, but when the water is at a low level the outlet valve must be closed in order to fill it. It is considered as a low level when the water is between 1.30 and 1.70 m, the optimal water level considered for this project and by recommendation of the administrator is 1.71–4.34 m high.

In order to carry out better control and optimize resources, the installation of the receiving node (Rx) was carried out in the administrative offices, where a monitoring technician is in charge of checking that the level of the water emitted is among the recommended values. Figure 3 shows the structure of the receiver plate (Rx).

5 Results

Personnel from the Portable Water Administrative Board move every 2 h to the site to verify the water-level taking 19 min to move there and 19 min to return, from the administrative offices to the reservoir, using two obsolete methods for measurement. The first method was to place a tape measure from the outside of the tank and

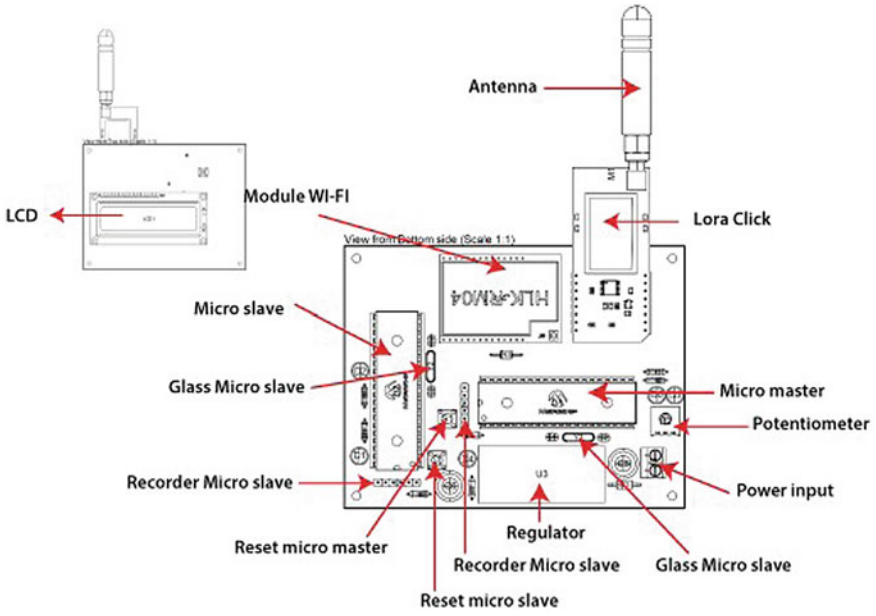

Fig. 3 Receiver plate structure (Rx)

a transparent hose taking the reference values of the tape measure and the second method was more empirical, in which to verify the level the cover of the reservoir was opened and verify the number of steps in which the water was, based on a staircase that this contains and that is occupied to descend inside the reservoir and to carry out maintenance and cleaning works when this is empty. The data on water levels was recorded manually in a notebook. This data was treated in the following way: between 1.8 m and 2.1 m, the outlet valves were closed so that the reservoir would be filled and would have the necessary pressure to supply water to the community, and another data to be treated was in the 4 levels. 1 m to 5.2 m to divert the flow, at which time the water is used to flush the purification filters, since the reservoir is fully supplied and can provide normal service to the community so its interruption is safe.

With this work, the optimization of resources is achieved, since now the personnel is mobilized to the reservoir tank when it is only at levels that need to be treated, results are validated with the next test. Figure 4 shows the distance between the treatment plant and the drinking water administration office.

The tests performed in the implementation are reading, sending, and receiving data, as shown in the following figures: Figs. 5, 6, 7, and 8.

Fig. 4 Mapping points of linkage

Fig. 5 Current tank size

Figure 5 shows the current method of measuring the tank, using a tape measure that serves as a reference for measuring the height of the tank and a transparent hose inside which there is water that raises or lowers the height according to the same level of the water content of the reservoir tank, on this occasion it is observed that it is at a height of 3.6 m.

Fig. 6 Use of the Ls-10 sensor for water-level measurement in the tank

Fig. 7 Reading on the transmitter LCD

Figure 6 shows how to introduce the Ls-10 sensor, which must reach the bottom of the reservoir tank and previously calibrated to obtain the data of the height at which the water is in the reservoir tank in real time.

Figure 7 shows the data acquired by the sensor shown on the transmitter's LCD, which is sent to the receiver and in turn displayed on the graphic interface on the computer located in the administrative offices. Figure 8 shows how it looks on the computer screen. There are two graphs, one in blue, which shows the height of the water in the reservoir in real time, and the other in black and white, which is a graph of height versus time. Figures 9 and 10 show the obtaining of radio link parameters by means of Radio Mobile simulation software.

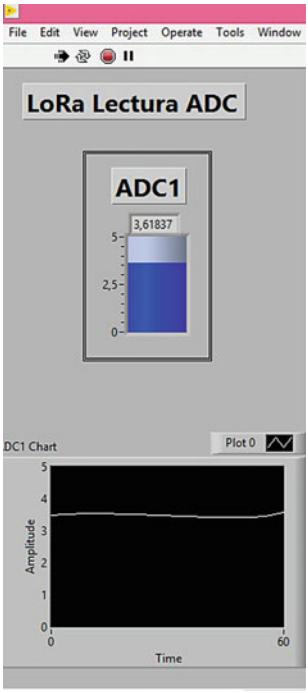

Fig. 8 Computer reading

Table 1 shows the established parameters and the resulting power parameters, obtained from the simulation with Radio Mobile. The fading margin is

$$FM(dB) = P_{rx}(dBm) - Umbral_{rx}(dBm)$$

$$FM(dB) = -86.1 - (-146) = 59.9\,dBm$$

This determines that there is at least 59.9 dB of fading margin for the link feasibility, which was simulated with the Radio Mobile software.

Figure 11 shows the final product, the transmitter (Tx) and receiver (Rx) nodes for communication via the LoRa protocol.

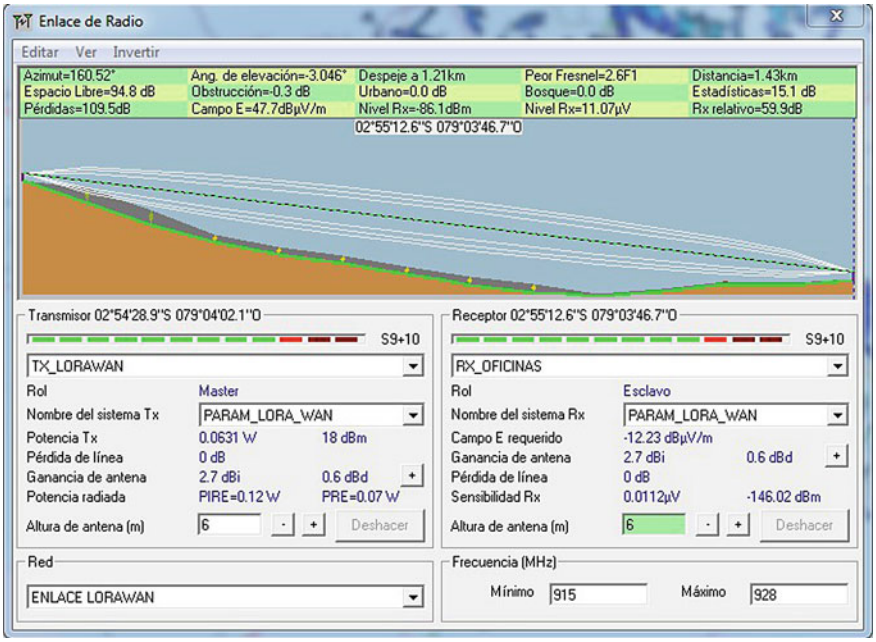

Fig. 9 Summary of parameter settings for radio link

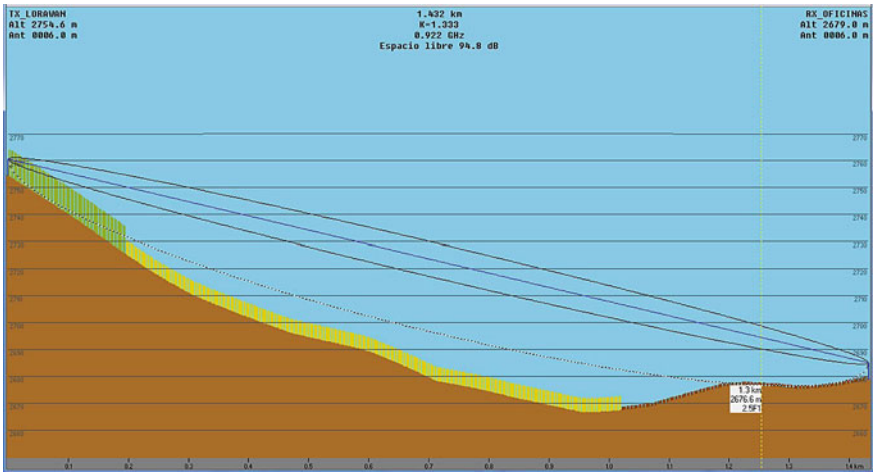

Fig. 10 Link simulation in radio mobile software

Table 1 Calculations using the propagation model: Longley–Rice model. Operating frequency: 40 MHz–100 GHz. Type of propagation model: statistical predictive

Transmission parameters	
Operating frequency	915–928 MHz
Power transmission	18 dBm
Antenna gain	2.71 dBi (0.56 dBd)
Base-antenna height	6 m
Azimut	160.5°
Angle of elevation	−3.0461°
Reception parameters	
Operating frequency	915–928 MHz
Reception sensitivity	−146 dBm
Antenna gain	2.71 dBi (0.56 dBd)
Base-antenna height	6 m
Azimut	340.50°
Angle of elevation	3.033°

Fig. 11 LoRa communication system (Tx-Rx)

6 Conclusions and Future Work

It can be determined that by using the LoRa modules to transmit water-level variables, favorable results are obtained in long-distance transmission with a stable link and real-time reception, without direct line of sight, i.e., through obstacles. With this prototype any variable of type ADC can be transmitted or for sensors that do not have this characteristic a transducer would be coupled to make the transmission of these, in such a way that it has an unlimited number of uses depending on the need of the user; that is to say, it is applicable to the whole industry. It is possible to optimize the operation of this prototype because with the data obtained with different ranges

of default values it is possible to automate equipment, such as opening or closing valves for this case.

In the future, other types of projects could be proposed, such as the following: Implementation of monitoring of industrial variables based on LoRa communication protocols for the control and automation of drinking water, Implementation of monitoring of industrial variables based on LoRa communication protocols for the reading of drinking water consumption.

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Optimization of the Mechanical Properties Responses of SBR 1502 Rubber/Amorphous Silicon Dioxide/Others by DOE-MSR Methodology

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Abstract The study of the application and mechanical behavior of new composite materials within the footwear industry for soles manufacture, allows to evaluate the mechanical behavior of a vulcanized composite material by compression. This study was carried out the optimization of the mechanical properties as abrasion, bending, and hardness of the vulcanized material manufactured under its respective elastomeric base and its reinforcing load. SBR 1502 rubber with amorphous silicon dioxide, plus other compounds (activators, accelerants, plasticizers, vulcanization agent, and anti-degradants), was used for the manufacture of vulcanization. Material configuration, vulcanization time, and vulcanization temperature were taken as input factors, the influence of these factors on responses was analyzed using Response Surface Methodology (MSR). For the optimization of experimental responses, the desirability function was used to generate the results and indicated that the optimal factors to take advantage of experimental responses or mechanical properties were the configuration of 18 Kg SBR 1502 + 7,7749 Kg amorphous silicon dioxide + 5.5 Kg other compounds, vulcanization time of 6 min, and vulcanization temperature of 165 °C, with an overall desirability value of 0.8581.

Keywords 1502 SBR ruber · Vulcanized material · Surface Response Methodology (SRM) · Desirability function

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M. V. García et al. (eds.), *Advances and Applications in Computer Science, Electronics and Industrial Engineering*, Advances in Intelligent Systems and Computing 1307,
https://doi.org/10.1007/978-981-33-4565-2_14

1 Introduction

Elastomeric materials known as rubbers have mechanical properties that make them irreplaceable for tires, footwear, pipes, drive belts, mechanical seals, etc. Until 2014, global consumption of this raw material was 28.9 million tons, increasing by 0.7% by 2015, with a vision that by 2024 consumption will increase by 3.1% annually, confirming a growing trend in the market over the past decades [6, 9].

One of the most widely used synthetic polymers within the footwear industry for the manufacture of soles is the SBR 1502, because it has excellent mechanical properties such as good resistance to bending, abrasion, traction [8, 16]. Tests based on different regulations in which they use different equipment and tools [13, 15] are currently carried out to evaluate the different mechanical properties of the SBR 1502. To evaluate abrasion resistance, the ISO 4649 drum-type abrasimeter is used in which the rubber sample passes once through an abrasive sheet simulating the 40-m route [11]. There are requirements that the tests must carry out for each mechanical property and it is a way of transmitting to the consumer that the products that are made are controlled and qualified.

Within Ecuador, Tungurahua province is the largest producer of footwear which covers more than 50% of the country's production, so companies engaged in this business know that the manufacture of a rubber compound is a very difficult task within the footwear industry because a variety of materials are needed, and therefore, the correct development of vulcanized material requires the implementation of systematic work [7, 14].

Today due to the existence of statistical tools you can know in advance the properties of a material and you can know whether or not it will be useful for the required applications [3, 5, 18]. The main objective of using Experiment Design (DOE) within the industry is to solve a problem with the use of statistical tests. For which it must be analyzed and implemented what tests should be performed and how to perform them, obtaining data that when analyzed deliver objective and concrete results [4, 10]. Within the shoe sole manufacturing industry, the use of experiments is of vital importance to correctly optimize the mechanical properties of the material obtained from the mixture of an elastomeric base with the other properly formulated ingredients. Using a statistical design for the manufacture of rubber soles allows to work in an efficient and orderly way discarding the test and error methodology. Applying DOE in complex rubber mixtures achieves savings in both time and materials and the desired material is more effectively achieved [2, 19].

This research uses an approach based on the design of experiments specifically using Response Surface Methodology (MSR). The MSR seeks to statistically analyze and with the help of the desirability function the experimental results of the given combinations (configuration, time, and vulcanization temperature) in order to propose the overall optimal combination of input factors for the mechanical properties as abrasion, bending, and hardness of the vulcanized material [1, 12, 17].

Table 1 Used materials

Material	Characteristic
SBR 1502 rubber	Synthetic rubber
Silicon Dioxide	White charge
Accelerate material	Process help
Vulcanization agent	Process help
Plasticizers	Process oil
Activators	Chemical dust/Acid
Anti-degradants	Process help

2 Methodology

2.1 Materials and Equipment

Materials. SBR 1502 Rubber (Elastomeric Base), Amorphous Silicon Dioxide (reinforced charge), anti-degradants, plasticizers, accelerate materials, vulcanization agent and activators. Table 1 summarizes the materials used in the composite elaboration.

Equipment. For the flexion laboratory essays, a machine knows as soles flex meter was used. For the abrasion essays, a soles abrasimeter was used INEN 1926 and for hardness a "Shore A" a durometer. The NTE-INEN-ISO 4649,868 and 20344 norms were used to prepare specimens for each essay.

- According to NTE-INEN-ISO, 4649 norm is necessary for 3 test tubes for each study case.
- According to NTE-INEN-ISO, 20344 norm is necessary for 3 test tubes for each study case.
- According to NTE-INEN-ISO, 868 norm is necessary for 1 test tube for each study case.
- A vulcanization press by compression localized in the company CARVIFACTORY was used to manufacture the material.

2.2 Experimental Process

The vulcanized product was obtained by the process shown in Fig. 1.

Through the compression vulcanization process were obtained test tubes with the following PHR fractions: fixed components: 100 PHR de SBR 1502 + 30 PHR of Others (5.5 Kg) and Variable Component: 22,33, 44 PHR of Amorphous Silicon Dioxide (4, 6, 8 Kg, respectively). Each of the study cases was manufactured at specific times and temperatures (See Tables 2 and 3).

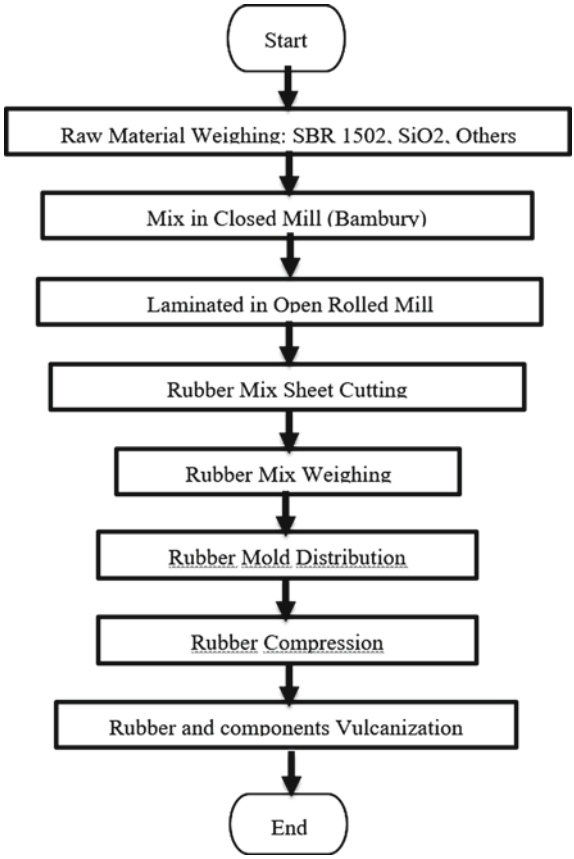

Fig. 1 Process for the obtaining of vulcanized product

Table 2 Used formulations

Rubber mixes formulations			
Configuration	1502 SBR	Amorphous SiO_2	Other
T1 = 4	100 PHR = 18 Kg	22 PHR = 4 Kg	30 PHR = 5.5 Kg
T2 = 6	100 PHR = 18 Kg	33 PHR = 6 Kg	30 PHR = 5.5 Kg
T3 = 8	100 PHR = 18 Kg	44 PHR = 8 Kg	30 PHR = 5.5 Kg

2.3 Experimental Design

The design of experiments has an objective to respond to the proposed query, compare the tested combinations (configuration, vulcanization time, and vulcanization temperature) in order to choose the best one. This study used the Response Surface Methodology (MSR), which is an experiment and analysis strategy that allows to find the optimal operating conditions of a process or material, i.e., the optimal values

Table 3 Study case

Study case	PHR fractions	Vulcanization time (min)	Vulcanization temperature (°C)
1	100 PHR SBR 1502 + 22 PHR Amorphous Silicon Dioxide + 30 PHR from Others	6	171.5
2	100 PHR SBR 1502 + 22 PHR Amorphous Silicon Dioxide + 30 PHR de Others	6.5	165
3	100 PHR SBR 1502 + 22 PHR Amorphous Silicon Dioxide + 30 PHR de Others	6.5	178
4	100 PHR SBR 1502 + 22 PHR Amorphous Silicon Dioxide + 30 PHR de Others	7	171.5
5	100 PHR SBR 1502 + 33 PHR Amorphous Silicon Dioxide + 30 PHR de Others	6	165
6	100 PHR SBR 1502 + 33 PHR Amorphous Silicon Dioxide + 30 PHR de Others	6	178
7	100 PHR SBR 1502 + 33 PHR Amorphous Silicon Dioxide + 30 PHR de Others	6.5	171.5
8	100 PHR SBR 1502 + 33 PHR Amorphous Silicon Dioxide + 30 PHR de Others	7	165
9	100 PHR SBR 1502 + 33 PHR Amorphous Silicon Dioxide + 30 PHR de Others	7	178
10	100 PHR SBR 1502 + 44 PHR Amorphous Silicon Dioxide + 30 PHR de Others	6	171.5
11	100 PHR SBR 1502 + 44 PHR Amorphous Silicon Dioxide + 30 PHR de Others	6.5	165

(continued)

Table 3 (continued)

Study case	PHR fractions	Vulcanization time (min)	Vulcanization temperature (°C)
12	100 PHR SBR 1502 + 44 PHR Amorphous Silicon Dioxide + 30 PHR de Others	6.5	178
13	100 PHR SBR 1502 + 44 PHR Amorphous Silicon Dioxide + 30 PHR de Others	7	171.5

Abrasion tests: 3 replicas for each study case and an analyzed property: Relative Volume Loss giving a total of 39 processed data. Flexion Test: 3 replicas for each study case and an analyzed property: Incision Increase giving a total of 39 processed data and Hardness Test: 3 replicas and an analyzed property: Hardness Shore A, giving a total of 39 processed data. These data are necessary for the development of the experimental designs

of one or more characteristics of the product, analyzing all the necessary statistical assumptions and subsequently analyzing the adjustment of each model to provide that the data are correct. In addition, the effect of each term on the model and the results obtained were analyzed.

3 Discussion and Results

3.1 Determining Coefficient (R^2)

To be able to say that the model adjusts correctly to the analyzed variable of the determining coefficient must overcome the 70% of adjustment, the R^2 is shown in Table 4 of each analyzed variable (Abrasion, Flexion, and Hardness).

Table 4 Determining coefficient

Mechanical property	Experimental designs SRM R
Resistance to abrasion (%)	96.24
Resistance to flexion (%)	76.10
Hardness (%)	94.12

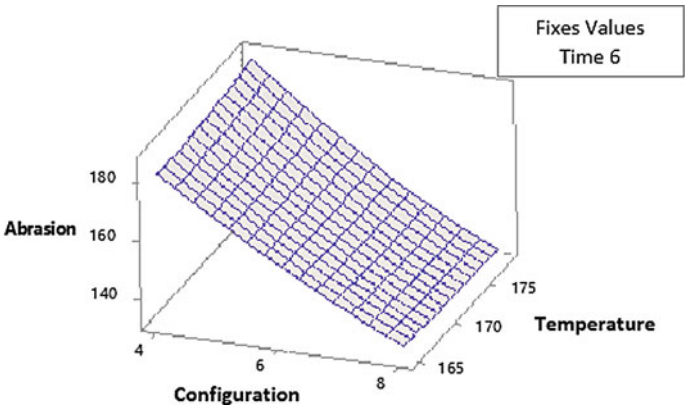

Fig. 2 Surface graph of abrasion versus configuration, temperature for 6 min time

3.2 Surface Response

Response Surface Method (MSR) is characterized by generating 3D surfaces with the input factors of the model, on these surfaces you can analyze how each response variable changes according to each factor. Under MSR you get response surfaces that help predict how the model behaves at each point, then show the main surfaces obtained for each variable.

Abrasion Data Analysis. Figure 2 provides abrasion based on configuration and time for its different levels with a fixed time value. It is also noted that to have the lowest abrasion value you need a high configuration and a low temperature for a fixed time value equal to 6 min.

Figure 3 shows that having the lowest abrasion value requires high configuration and low temperature, for a fixed time value equal to 7 min. It is also observed that as time changes the shape of the surface does not change, this is because this factor is not aesthetically significant in our model.

Figure 4 presents the abrasion response variable based on configuration and time with fixed temperature values. To have the lowest abrasion value, you need a high configuration and a low time for a fixed temperature value equal to 165 °C.

In Fig. 5, it is shown that in order to obtain the lower abrasion value it is needed a high and low time configuration, for a fixed temperature value of 178 °C. So, we can say that the higher is the PHR of SiO_2 the relative volume loss of our material is less.

In Fig. 6, it is shown that hardness in the function of configuration and temperature, for its different levels, with a fixed time value.

Hardness Data Analysis. In Fig. 6, it is shown that hardness in the function of configuration and temperature, for its different levels, with a fixed time value.

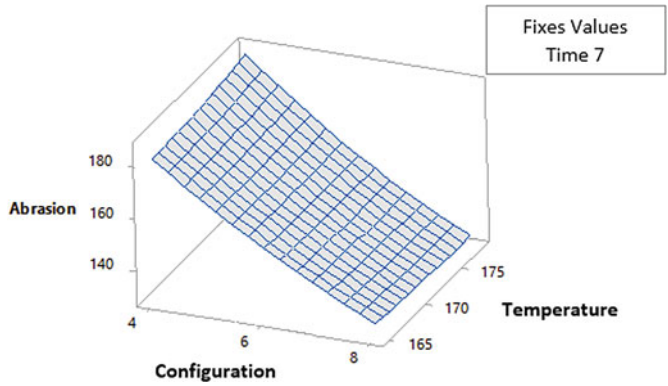

Fig. 3 Surface Graph of abrasion versus configuration, temperature for 7 min time

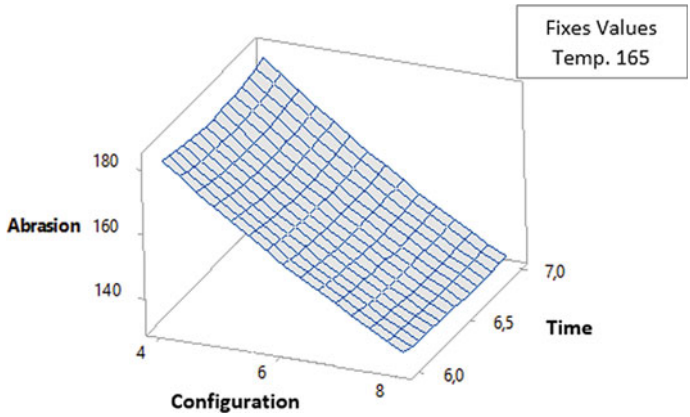

Fig. 4 Surface graph of abrasion versus configuration, time for 165 °C

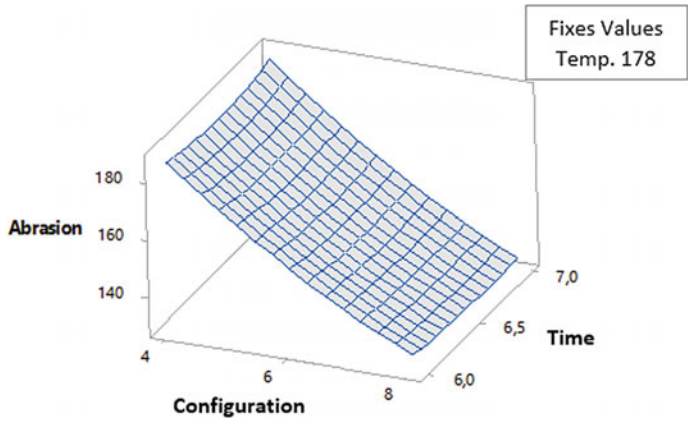

Fig. 5 Surface graph of abrasion and configuration, time for 178 °C

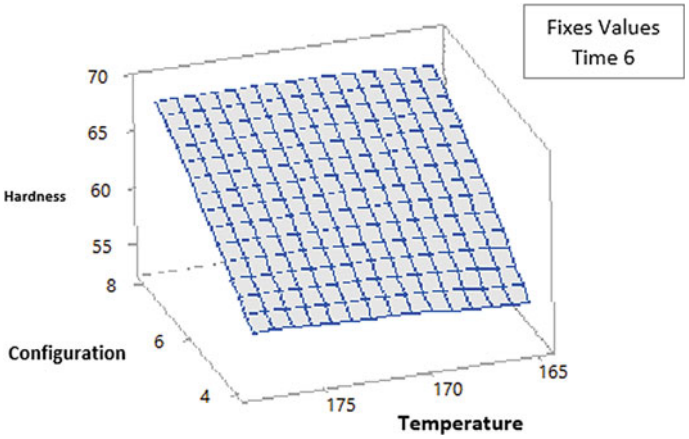

Fig. 6 Surface graph of hardness versus configuration, temperature for a 6 min time

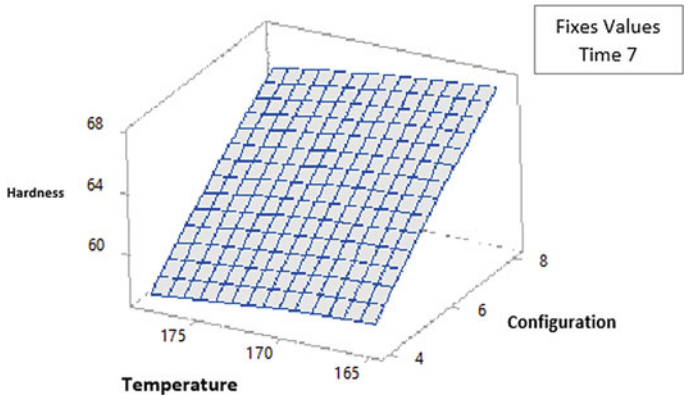

Fig. 7 Surface graph of hardness versus configuration, temperature for 7 min time

In Fig. 6, it is shown that hardness is increasing as PHR of SiO_2 increases in the configuration and as the temperature decreases, for a fixed time of 6 min.

In Fig. 7, it is shown that the hardness increases as the SiO_2 PHR increases in the configuration and as the temperature dismisses, for a fixed 7 min time. Also, it is shown that as the time changes the surface shape does not change, this is because this factor is not statistically significant in our model.

In Fig. 8, it is shown the hardness response variable in the function of the configuration and time with fixed temperature values.

In Fig. 8, it is shown that the hardness increases when the SiO_2 PHR increases in the configuration. Also, the harness increases when the vulcanization time decreases, for a fixed temperature value of 165 °C.

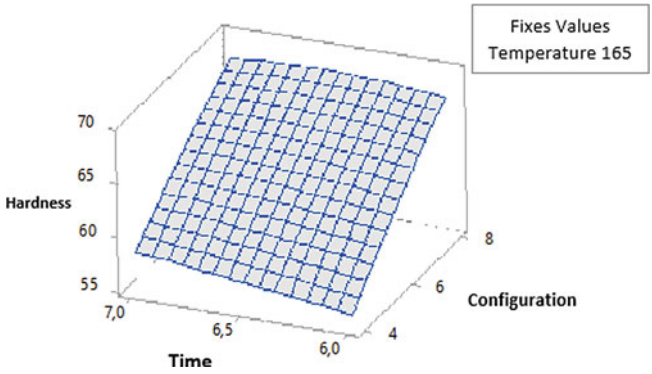

Fig. 8 The surface graph of hardness versus configuration, time for 165 °C

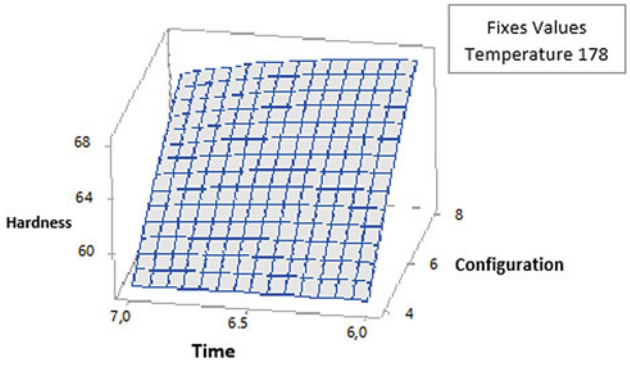

Fig. 9 Surface graph of hardness versus configuration, time for 178 °C

In Fig. 9, it is shown that the hardness increases when the SiO_2 PHR increases in the configuration. Also, the hardness increases when the vulcanization time dismisses, for a fixed temperature value of 178 °C.

So, we can say that while the SiO_2 PHR is higher, the material hardness is higher.

Flexion Data Analysis. In Fig. 10, it is shown that function flexion of the configuration and the temperature for its different levels, with a fixed time value. In Fig. 10, it is shown to obtain a minimum value of flexion of a high configuration and low temperatures for 6 min time.

In Fig. 11, it is shown that when the time changes the surface shape changes, but, the essence is the same. This surface change is because the time in this model influences somehow over the obtained responses. Also, the point where the minimum flexion is obtained is when using high- and low-temperature configuration, for 7 min time.

In Fig. 12, it is shown the flexion response variable in the function of configuration and time, with fixed temperature values. In Fig. 12, it is shown that in order to obtain

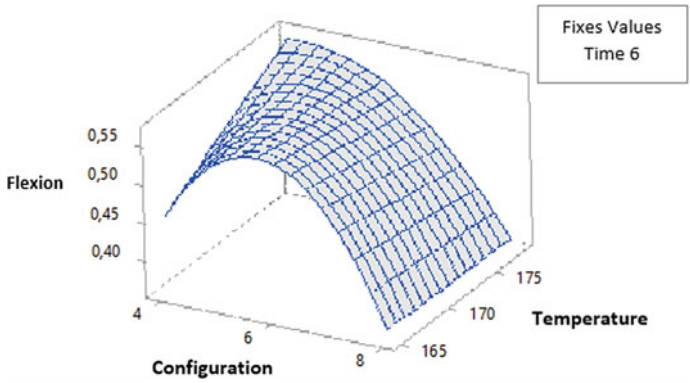

Fig. 10 Surface graph of flexion versus configuration, temperature for 6 min time

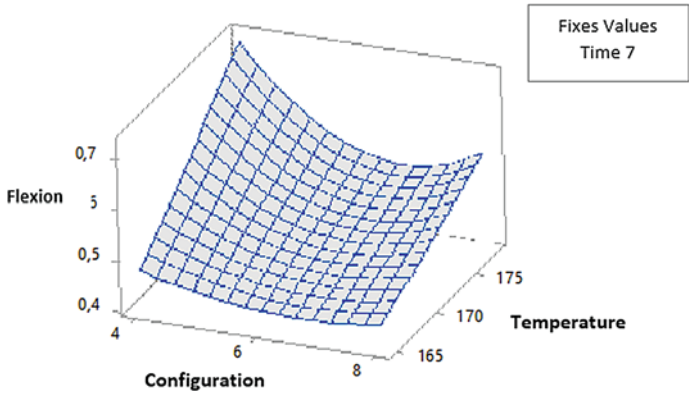

Fig. 11 Surface graph of flexion versus configuration, temperature for 7 min time

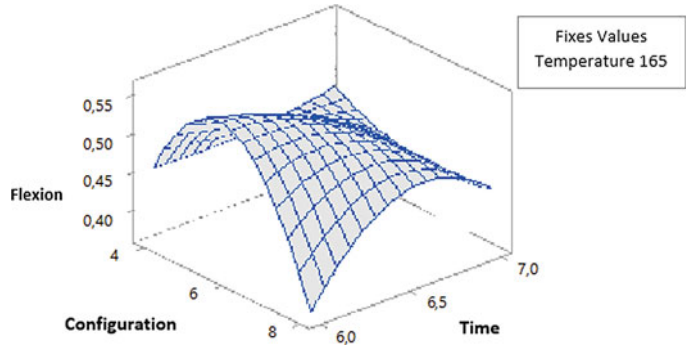

Fig. 12 Surface graph of flexion versus configuration, time for 165 °C

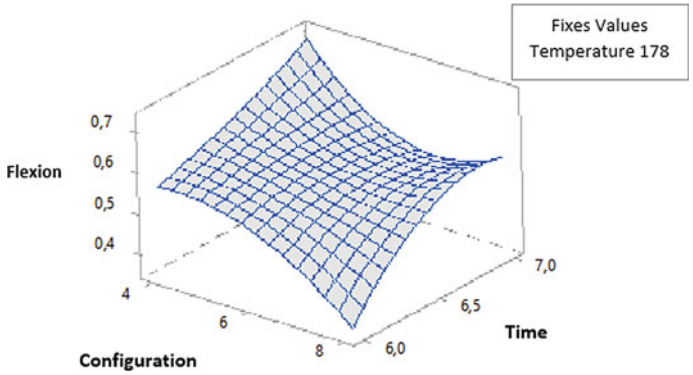

Fig. 13 Surface graph of flexion versus configuration, time for 178 °C

the point where the flexion is minimum we need to use a high configuration and a low time, for a fixed temperature value of 165 °C.

In Fig. 13, it is shown that when the temperature changes the surface shape changes, but the essence is the same. This surface change is because the time in this model influences somehow the way the responses are obtained. Also, the point where the minimum flexion is obtained when high and low configurations are obtained, for a fixed temperature value of 178 °C.

3.3 Individual Optimization

When a response variable optimization is required, there are 3 alternatives: minimize, maximize, and objective. In this study, the following information was considered:

Abrasion Resistance: Minimize. The method used to find the optimal value is the desirability function, in which parameters are specified to the measured abrasion data. In this case, the objective is to minimize as much as possible according to the NTE-INEN-ISO 20345 standard for which an abrasion value less than or equal to 170 mm^3 is required. In Fig. 14, the optimal values for the three factors are observed: configuration, time, and temperature. The optimal value of the response variable is also observed in this case, abrasion resistance.

Hardness: (60-70 SHORE A) Range. The method used to find the optimal value is the desirability function, in which parameters are specified to the measured abrasion data. The goal of maintaining a hardness within a range is (65± 5) SOHRE A. This is reflected in the NTE-INEN-ISO-20346 norm. Figure 15 shows the optimal values for all three factors: configuration, time, and temperature. In addition, the optimal value of the response variable is observed in this case, hardness.

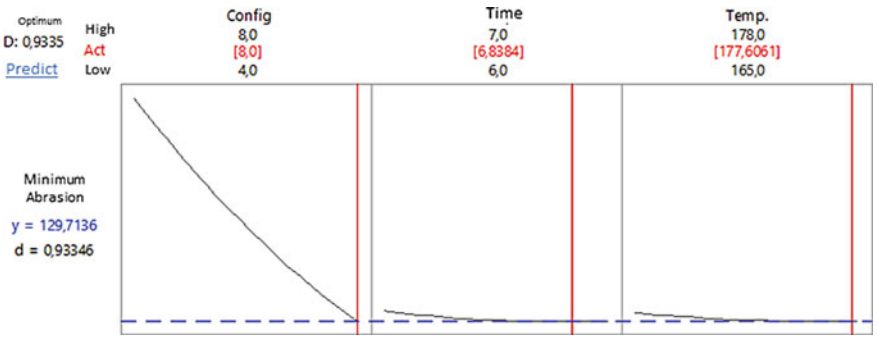

Fig. 14 Graph for abrasion optimization

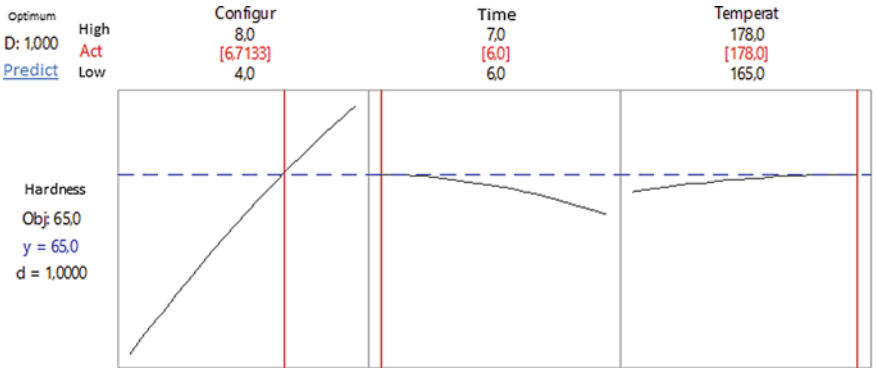

Fig. 15 Graph for hardness optimization

Resistance to Flexion: Minimize. The method used to find the optimal value is the desirability function, in which parameters are specified to the measured abrasion data. In this case, the objective is to minimize bending according to the NTE-INEN-ISO 20347 standard. Figure 16 shows the optimal values for the three factors: config-

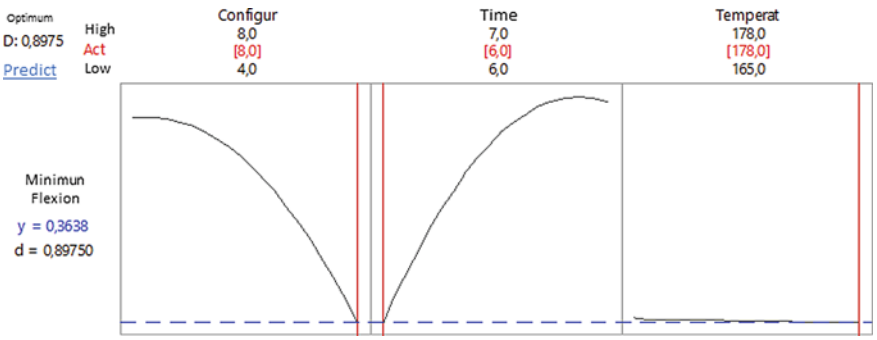

Fig. 16 Graph for flexion optimization

Table 5 Individual optimization of abrasion, hardness, and flexion

Properties	Factors		Response variable	
Abrasion	Configuration	8 = M3	Relative Volume Loss (mm3)	0.3543
	Time (min)	6.8384		
	Temperature (°C)	177.6061		
Hardness	Configuration (SiO2 PHR)	6.7133	Hardness (SHORE A)	65
	Time (min)	6.0		
	Temperature (°C)	178.0		
Flexion	Configuration	8 = M3	Growth Incision (mm)	0.3638
	Time (min)	6.0		
	Temperature (°C)	178.0		

uration, time, and temperature, the optimal value of the response variable is also observed in this case, Flexion.

Therefore, the obtained results for individual optimization for each variable using SRM are shown in Table 5.

3.4 3.4 Global Optimization (Simultaneous)

The objective of applying the Surface Response Methodology is to obtain a global optimum point, either inside the experimental zone or inside the operation zone, in Fig. 17 it is shown the global optimization of three response variables with their respective entry factors.

The levels for each factor that is optimized, for each response variable according to the criteria that were given are detailed in Table 6. Emphasizing again that the optimal points are predicted by the model.

4 Conclusions

The present experimental study used the desirability function based on a response surface design determined in the optimal global point of the entry factors for the abrasion, flexion, and hardness of vulcanized material mechanical properties. Starting from the investigation results, the following conclusions can be drawn: The configuration of the composite vulcanized material is the most significant factor for all the response variables or considered mechanical properties.

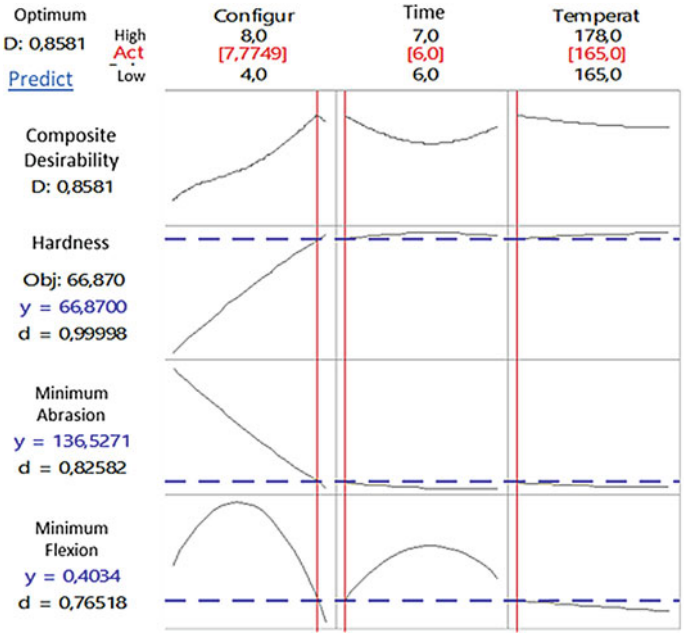

Fig. 17 Graph for Flexion Optimization

Table 6 Global optimization

	Factors	Response variable	
Configuration	18 Kg SBR 1502 + 7.7749 Kg SiO2 + 5.5 Kg de Others	Relative volume loss (mm3)	136.5271
Time (min)	6	Hardness (Shore A)	66.87
Temperature (°C)	165	Incision growth (mm)	0.4034

The determination coefficients interpret a great variability for each variable, getting to values until 96.24%, being 70% the minimum required. Another interesting point is that the desirability function altogether with the SRM turns the subjective analysis of the mechanical properties, into an objective analysis through a comparable value in each combination, which makes the analysis practical at the moment to optimize factors. Final, the Optimal Global Point in which the mechanical properties reach the required values occurs when used: 18 Kg SBR 1502 + 7.7749 Kg SiO2 + 5.5 Kg of Others, with 6 min time and a 165 °C temperature, obtaining an abrasion resistance of 136.5171 mm^3, an incision growth of 0.4034 mm and hardness of 66.87 SHORE.

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Interactive Application for Learning Electric Motors Using Leap Motion Controller

Xavier Cobos, William Oñate, and Gustavo Caiza

Abstract Technology provides a great variety of opportunities in different educational fields from virtual libraries to the use of state-of-the-art equipment and sensors such as the Leap Motion Controller, which highlights due to its precision when detecting gestures made with hands and fingers. In this study, this sensor was utilized together with Unity to develop an application called VISDOM motor, which enables consolidating the learning of electric motors in an entertaining and dynamic manner, operating a fluent and easy to use interface, with gestures that are natural and adaptable to both right-handed and left-handed people. Functionality and satisfaction tests were carried out to validate the application, which exhibited good results with an average score of 94% in the functionality of the application.

Keywords Education · 3D environment · Leap motion controller · Electric motor

1 Introduction

At present, the use of new technologies has allowed enhancing teaching and learning methods through motivation, and this is the reason why it is important to apply them to improve cognitive processes. According to the Cognitive Load Theory articles [16], the attention and memory capabilities are a consequence of the learning environment,

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M. V. García et al. (eds.), *Advances and Applications in Computer Science, Electronics and Industrial Engineering*, Advances in Intelligent Systems and Computing 1307,
https://doi.org/10.1007/978-981-33-4565-2_15

and based on this a new linkage is created toward new interaction methodologies such as gamification, virtual reality, augmented reality, among others, which may be utilized as vehicles to enhance the access to information and knowledge.

According to articles [4], in many technical institutions, the courses about electric motors are purely theoretical, and this is the reason why professionals being trained do not have enough skills to repair, recognize, or replace the different electrical and mechanical components of a motor. With this research, it is intended to overcome this shortcoming by making the knowledge to be acquired more interactive, visual, and closer to reality, achieving a deeper notion about the different elements of an electric motor. For this purpose, articles [14] considers that the use of 3D environments within a teaching–learning process, combined with multimedia and hypermedia components, helps trainees to utilize different cognitive styles that enable extending the theoretical understanding captured in traditional texts.

The 3D environment applied in the present paper will help the student to visualize in a better way the different components that constitute an electric motor. The Leap Motion Controller (LMC) sensor eases the connection with diverse 3D environments in Unity since it enables an easy coupling between the peripheral, the PC, and the application due to its hardware and software. It is explained in articles [2] how the software analyzes the images captured by the hardware, and sends the information acquired to the application under execution through the scripts of the plugin. In article [19], this device is utilized together with unity for learning about the human skeleton by means of creating an interface where the user may recognize the main bones of the human body, achieving satisfactory learning results and pleasure in using the application. This paper develops an executable application on a computer with Windows operating system whose name is VISDOM motor (Visdom means wisdom in Danish and motor emphasizes on the electric machine, giving importance to the name of the application, wisdom about motors) to ease and motivate students interested in learning about electric motors and their parts, seeking to cover the gap in the literature by explaining the operation of each of these elements in a recreational and enjoyable way during learning, enabling improving the academic and professional competences of the users that utilize the application.

The methodology utilized in this research work is experimental, for which the application was tested with users interested in expanding their knowledge about the components of an electric motor, monitoring the versatility of the application in an environment with several users. At last, the results obtained while testing the operation of the application were analyzed through evaluative research.

At last, the structure of this paper consists of describing methods and materials including the tools utilized for developing the application. Then, the analysis of the data and the results obtained in the implementation of the application are presented. Finally, it is included in the section which concludes that this research is replicable in educational environments of great magnitude with conditions similar to the ones considered in this study.

2 Methods and Materials

The development of the VISDOM motor (wisdom about motors) for recognizing the main parts of an electric motor using the LMC was developed as a hybrid. This is due to the fact that its operating and usage interface, on one side, enables the use of gestures with the hands for learning the different parts of the electric motor. On the other hand, the use of a traditional mouse to navigate fluently in the application, with the purpose of avoiding in a better manner mental and physical fatigue, which according to article [17] is due to a mainly intellectual work which is usually directly linked with physical demands of postural sedentariness, and in addition demands for information treatment and application of cognitive functions such as comprehension, reasoning, and memorization.

The application consists of two important parts to acquire a deep and solid learning. The theoretical part, where the user may find the most important information related to electric motors, and the interactive part (practical), where it is fundamental to the use of the LMC for recognizing the parts of the motor with their corresponding names, together with the assessment section that enables deepening the knowledge, and this was implemented because many research studies state that this is the best way to learn, and it is expressed in article [15] that it is important to bridge the gap between theoretical and practical activities existing in educational plans, to achieve a comprehensive formation of the engineering students.

When the LMC is used within the application, it captures the presence and position of the hands and fingers on the sensor as the input to the system, which is processed in the application thanks to the SDK of Leap Motion for Unity, giving way to the visualization of the disassembled motor and the corresponding legends in each part on which any of the two hands is placed, enabling the interaction with the motor piece of interest. In the assessment section, the user has three discard tests which enable reinforcing the knowledge acquired, indicating a congratulatory message since articles [11] states that positive messages stimulate people with low self-effectiveness to increase their competence, (see Fig. 1).

2.1 3D Model of the Electric Motor

The user's experience is essential in VISDOM motor, and therefore a 3D model was developed based on the model and characteristics of a real electric motor, (see Fig. 2) as close as possible to a real machine, with the greater detail in each of its pieces; the motor specifically utilized for the application is a squirrel cage motor modeled in Autodesk Maya and imported into Unity. The color of the materials that make up the modeling was actually created within Unity to avoid complications when importing the 3D model. This type of motor was specifically chosen for the application since, according to article [3], three-phase induction motors are the most widely used in industry and in power electronics, due to their design, construction, and affordable price.

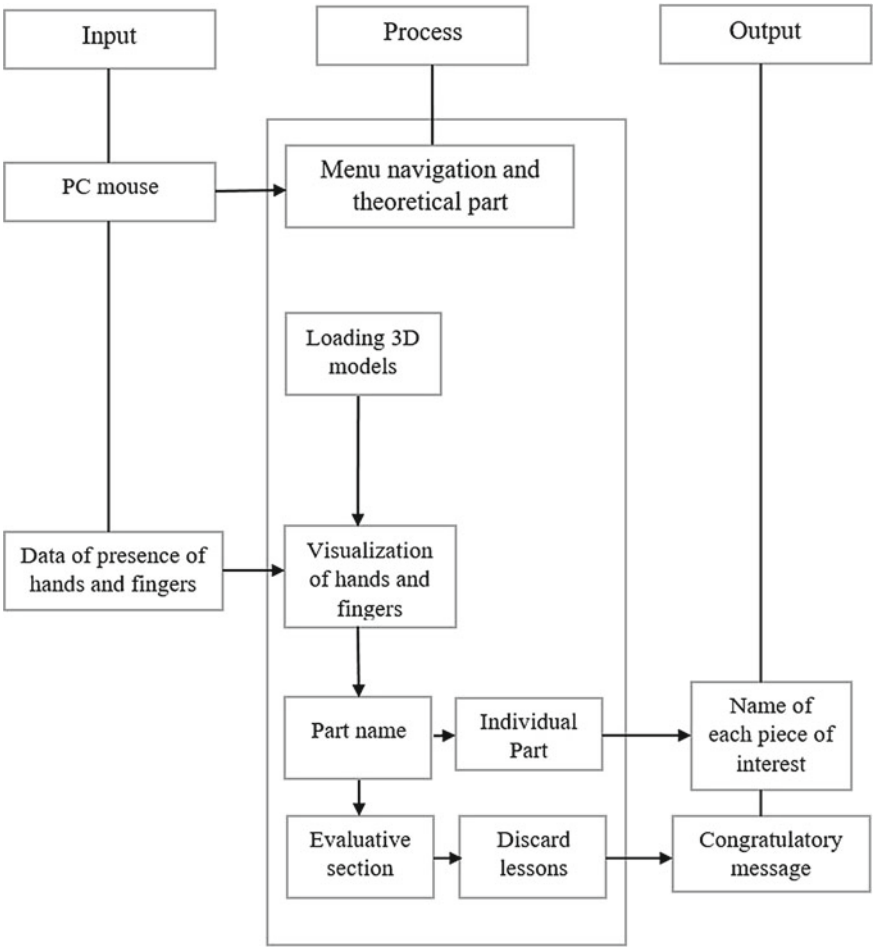

Fig. 1 Application structure

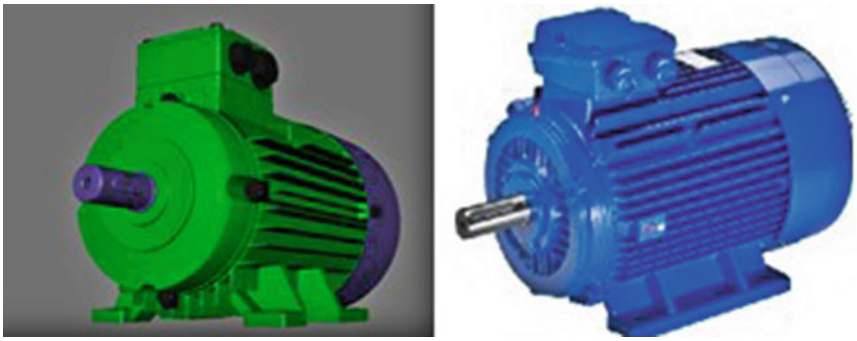

Fig. 2 3D model of electric motor in Autodesk Maya

2.2 Leap Motion Controller (LMC)

It is a device with a USB connection to the computer. It is used in different engineering, medicine, rehabilitation and education article [19], article [8], article [20], article [1], article [12] applications, among others. It has compact dimensions, namely $3.05 \times 8.13 \times 1.27$ cm, with two IR monochrome cameras and three infrared LEDs, with a capturing area of approximately 1 m, on which the hands may be placed and execute various applications specifically developed for use with LMC, and even controlling the computer. It has a different approach compared to its competitors, such as the Microsoft Kinect, since it enables personal interactivity and specific movements articles [3, 6], achieving a free interaction and without any type of accessories on the body.

Within the VISDOM engine, the advantage of the LMC over the Kinect is that the size of the LMC is much smaller than the second, which is essential because this sensor must be mounted as one more peripheral of the PC. In addition, the Leap Motion Controller sensor is a device specifically designed to capture the movement of hands and fingers with great precision, a feature that Microsoft's device does not present directly and in this application, this advantage makes LMC the most optimal in the development of VISDOM motor.

2.3 Data Collection

The system detects the position of the hands placed on the LMC as one of the inputs (Fig. 1). The device is responsible for collecting the data and for guiding the hands located on the upper part of the sensor, within the application. This sensor may capture hands, fingers, and bones without needing to touch them; this plus provides comfort and effectiveness to the users. With the purpose of capturing the position of the hands, it has a coordinate system using the right-hand rule, whose origin is the center of the upper part of the sensor, the x-axis is in the horizontal plane and runs parallel to the long edge of the device, and the y-axis is in the vertical plane, with positive values increasing upwards. The z-axis is in the horizontal plane and has positive values increasing toward the user articles [5, 12, 18].

A total of 100 data were acquired (20 in the theoretical part, 20 in the section of the disassembled motor, and 20 in each of the assessments); among these acquired data, 75 were taken from external participants as a test of operation, and 20 from the developer as training. Besides this acquisition, an extra collection was carried out having an average of 40 additional data which represent the handling and interaction with the individual parts of greater interest.

2.4 Interaction Engine

The scopes of the LMC are increasing daily, and therefore the development of modules offers a world of possibilities for developers. The Interaction Engine is part of this continuous advancement process, enabling the interaction with virtual objects within the application, either a baseball, a 3D cube, an electric motor and its parts, a button or an interface panel, a hologram with more complex possibilities articles [10]. The implementation of the Interaction Engine complemented by various Scripts programmed in C, some included in the module and others created, enable that VISDOM motor has an interaction both fluent and according to the requirements of the application.

The configuration of this module for the disassembled motor consists of disabling the grasp and touch of the hands with the 3D objects, to enable the visualization of the names with any of the two hands placed on the desired part. On the other hand, there are the individual pieces and the assessment section which is configured such that the grasp of the 3D objects is active, and enables the movement of the objects grasped to perform the visualization and the discard of the corresponding motor parts.

2.5 Legend in the Electric Motor

The names indicated when passing the hand above the part of greater interest of the disassembled motor were based and simplified from the technical paper "Three-phase electric motors: applications, components and operation" in the components sections articles [23]. This section is indicated in Fig. 3.

In article [23], each part is named as follows: 1. Housing, 2. Stator, 3. Rotor, 4. Shaft, 5. Keyway, 6. Fan, 7. Fan Cover, 8. Motor Covers, 9. Bearings, 10. Base, 11. Lifting Eyebolt, 12. Connection box, 13. Features Plate, 14. Rings. This guide helped in the development of the application since a squirrel cage motor is used in VISDOM motor, with the difference that the names used were more general in the disassembling (Fig. 4) so that the information is simpler to assimilate.

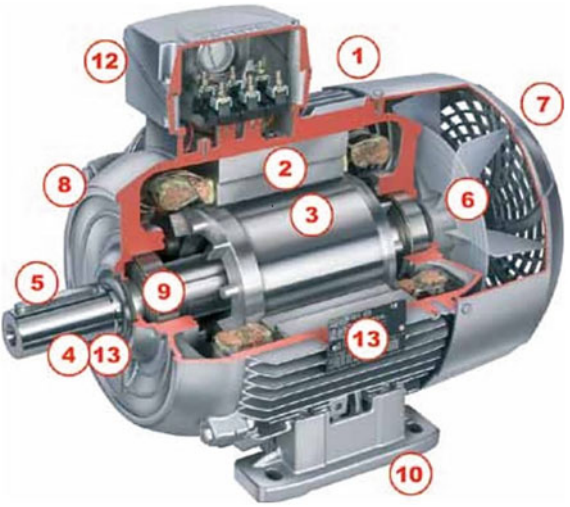

Fig. 3 Numbering of each part of electric motor

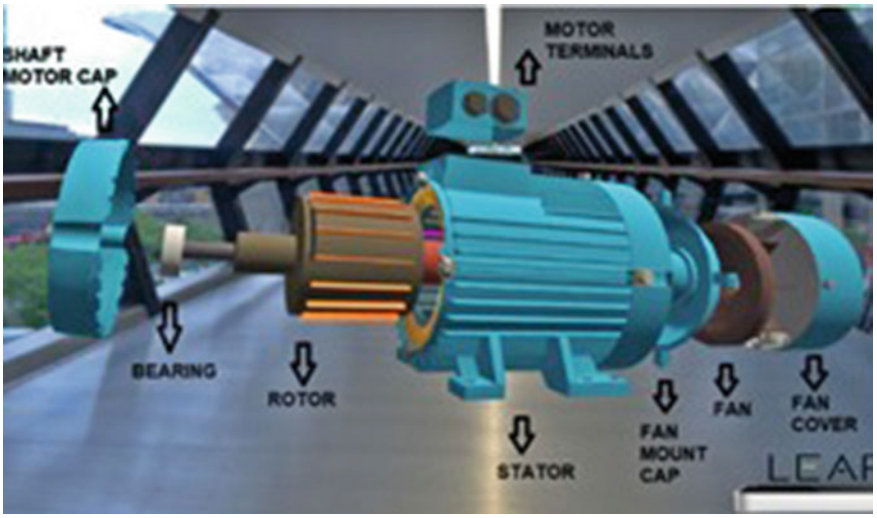

Fig. 4 Labels of each part of electric motor

Table 1 Test parameters

Parts to be tested	Items
Theoretical	Navigation through the Main Menu
	Navigation through the Theory of Electric Motors
	Theoretical information
Interactive	Precision when placing the hand on each part of the motor
	Visualization of the name of each part of the motor
	Manipulation of each individual part of the motor
	Assessment 1
	Assessment 2
	Assessment 3

2.6 Test System

The functionality of the VISDOM motor is important for the educational purpose for which it was developed. In order to validate if the application may be used in an educational environment, a test system based on the black-box method was conducted; it is mentioned in the study with LMC presented in article [19] that this method enables validating the operation of their application. The test parameters can be seen in Table 1.

2.7 User Satisfaction Evaluation

The users of VISDOM motor should feel comfortable when using the application. For this purpose, a survey was carried out with 10 questions related to the use and navigation within the application; 15 people participated in the survey, ranging from 15 to 60 years of age. The users that participated are not people with knowledge about electric machines, because the application presents basic concepts that are introductory to the learning about electric motors. The academic background of the participants is very diverse, and includes PhDs, teachers, engineers, students, among others.

The population selected was distributed as follows: 53.333% with great interest in learning about electric motors and the remaining 46.667% who wish to use the application for curiosity and for using the LMC. This filter provided a more realistic result of the surveys, because not all participants feel comfortable with the application topic, but regarding the navigation, their comfort should be opposed to the interest in the main topic.

3 Analysis and Results

3.1 Menu and Theory About Electric Motor

3.1.1 Menu

When the application is executed for the first time the user is received by the main menu, which is controlled by the PC mouse (Fig. 1) to access any of the options. The name of the application VISDOM motor is indicated here, whose main focus is education, and this is the reason why the first symphony of Amadeus Mozart, composed in 1764, is listened to in the background, with the purpose that users can relax and concentrate better when navigating through the theoretical section; it is remarked in article [22] that the Mozart effect enables developing better intellectual skills, despite an existing controversy regarding this point, the compositions of this interpreter may be referred to as music that enables relaxing the body due to its low frequencies.

3.1.2 Theory of Electric Motor

The users find the most relevant information about electric motors in short texts and hyperlinks (buttons) that enable navigating through the application sections of more interest, where basic information about the chosen sub-topic will be found. Despite this, it is recommended to follow the complete theoretical guide of VISDOM motor in the order indicated which goes from the definition of electric motor and of the group to which it belongs to the use of these equipment in industries and real applications.

The applications intend to be intuitive with short texts and the smallest possible number of clicks to avoid boring the user. The theoretical part is a presentation targeted to people who want to learn about electric motors, and for this purpose each theoretical section was made as an introduction to each topic; it is stated in article [9] that a presentation with visual aid should not last less than thirty seconds, nor more than three minutes to avoid distractions and loss of interest.

3.2 Interaction with the 3D Electric Motor and Its Parts

The use of the LMC is a requirement to utilize the sections that indicate the leap motion symbol in the bottom right part, because the gestures performed with the hands enable the interaction level sought in the application.

The motor was mounted on a Skybox that represents a total envelope of a specific scene of the application, and shows how the world would be seen beyond its geometry article [7], the design chosen was as clean as possible and representative of an environment on which an electric motor can be mounted; at the beginning, it

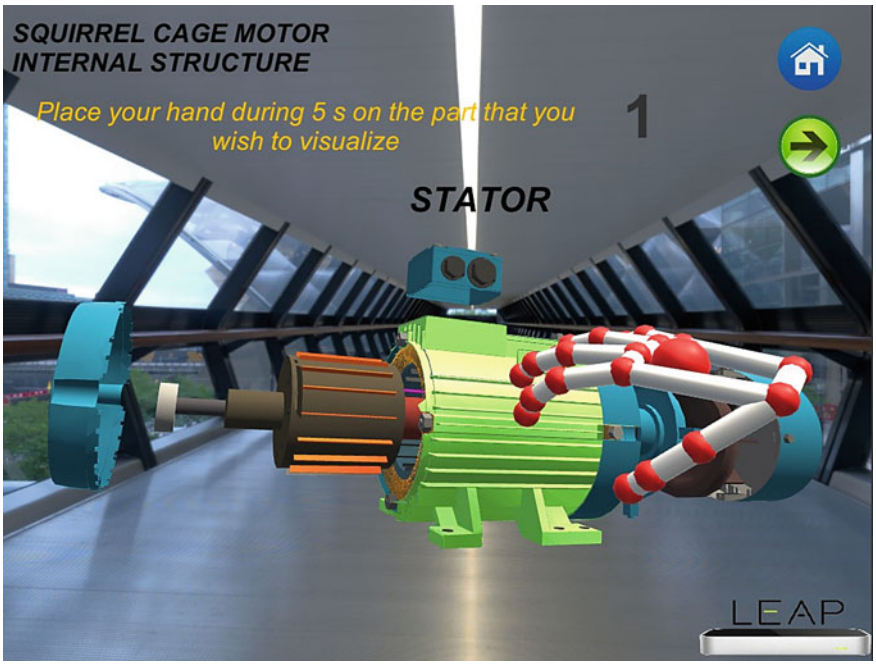

Fig. 5 Labels of each part of electric motor

was desired to do it in a Skybox with an industrial setting, but the motor, which is the key object of the research, did not have the necessary relevance, and therefore something with more natural light and somewhat futuristic was chosen (Fig. 5).

The Leap Motion sensor was chosen for this study taking into account features such as versatility, to detect hands and fingers, using Orion V4.0.0+52173, the Leap Motion Core Assets 4.4.0 package, and the Interaction Engine module. The price, adaptability with Unity, and its great community of developers were fundamental pillars in the implementation of this research, since it is possible to access specific and necessary information for the development of applications that utilize LMC, (see Fig. 6).

In the section where it is presented the motor disassembled, when the user places one of the two hands on any of the parts indicated using the LMC, a previously programmed 5 s descending timer starts counting to change the scene and present the motor part of greatest interest for a specific user, with the purpose that the person may have a greater approach with each part of the motor, enabling to rotate, move, take, and tap the piece, in brief, interact with it. It was avoided to rotate, move closer, or away the parts of the motor when it is disassembled since it results in uncomfortable observing the pieces all together.

In order to reinforce knowledge, three consecutive assessments were posed consisting of discard games, i.e., it should be discarded the correct or incorrect option

Fig. 6 Positioning of hands on Leap Motion

as applicable. The purpose of this strategy lies in the importance that games have for adults, children, or teenagers, as games take part in the life of all human beings regardless of the age since this action enables recreation, fun, distressing, learning, among other articles [13].

The assessments of VISDOM motor were considered as the gamification within the application due to its dynamic elements, mechanics, and components, which provide dynamism and illustration; it is stated in articles [21] that gamification is a tool that may convert learning into an immersive activity.

3.2.1 Assessment 1

Recognition of parts (Fig. 7). In this assessment, the participant should read the question and select the answers that enable advancing to the next assessment (Fig. 8) (Each part shows up randomly).

Fig. 7 Participant conducting assessment 1

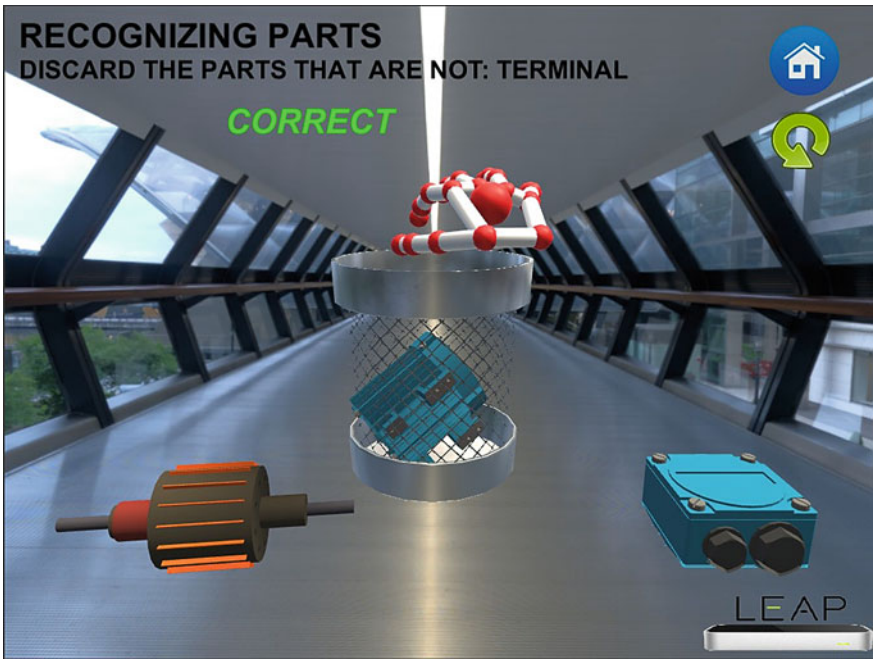

Fig. 8 Assessment 1

According to the black-box method, it used to prove if the application is suitable to be used in an educational environment, positive results are visualized regarding the level of acceptance of the users to implement the application. In the different sections that constitute VISDOM motor it can be observed that the application passes (Table 2).

The users who tested the application present results where it is approved that the navigation through the menu interface as in the theory and in the interactive section presents the necessary elements to handle VISDOM motor intuitively. Because the participants were people with little or no knowledge regarding electric motors, they affirmed that the information found is very complete to take a step into the electrical machines learning.

Regarding the interactive section, the precision of the engine is high and allows the user to navigate very smoothly when using the LMC to be able to visualize and manipulate each of the parts of greatest interest. In the same way, in the evaluative section, the 3 lessons present satisfactory results, allowing participants to reinforce their knowledge about electric motors.

Table 2 Table captions should be placed above the tables

Parts to be tested	Items	Result of test
Theoretical	Navigation through the main menu	Pass
	Navigation through the theory of electric motors	Pass
	Theoretical information	Pass
Interactive	Precision when placing the hand on each part of the motor	Pass
	Visualization of the name of each part of the motor	Pass
	Manipulation of each individual part of the motor	Pass
	Assessment 1	Pass
	Assessment 2	Pass
	Assessment 3	Pass

3.3 Results of the Evaluation Satisfaction

The results of the satisfaction tests conducted are promising for VISDOM motor and Fig. 9 shows the results obtained from the 15 users that tested the application in different environments and under different conditions.

The values indicated in Fig. 8 are an average percentage of 15 samples acquired for each parameter indicated. Each user utilized the application and assigned a score from 1 (unsatisfactory) to 5 (very satisfactory) in each item, according to the experience using the application. The item Navigation through the interface of VISDOM motor

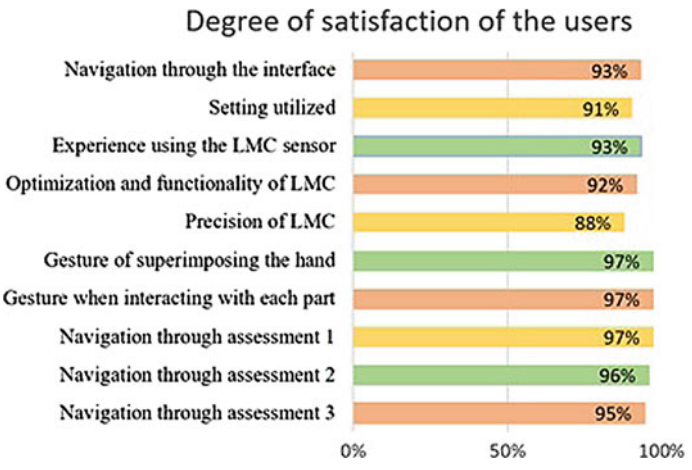

Fig. 9 Satisfaction test

shows a degree of satisfaction of 93%, indicating that the user felt comfortable when navigating through the different menus and scenes. The setting with a value of 91% is shown because each user has different design perspectives, but with high attraction to the general interface. The use of the LMC resulted satisfactory with 93% together with its functionality with 92%, when using the sensor in the required sections. Despite this, the lowest score is obtained for the precision of the sensor with 88%, which occurs because the application was tested in different environments in which the light has influence when reading, and besides the LMC is a technology that should continue improving to provide better experiences.

When using the sensor in the item of superimposing the hand and interacting with the parts of the motor, the users showed great interest and comfort, with a value of 97% in both items; in addition, the assessments are an important point in the research since they enable consolidating knowledge and dominating the use of the sensor to be able to complete the proposed lessons, and for this the user should feel comfortable, concentrated and inspired in order to move forward. Assessments 1, 2, and 3 showed values of 97%, 96%, and 95%, respectively, in degree of satisfaction.

Comparing the results obtained in research works conducted in different areas using LMC, such as article [19], article [20], VISDOM motor exhibits a more comprehensive interface and very promising results when using the Leap Motion sensor. However, these works show satisfactory results in the use, interaction, and gestures for learning the anatomy of the human body. This is different from VISDOM motor, which is oriented to other fields, the technology field, with a similar principle focused on education.

4 Conclusions

The use of different modules such as Interaction Engine and scripts created by the developers of LMC to configure the sensor within Unity, enable the development of more advanced and much more fluent applications with Leap Motion Controller which may be applied in any desired field, from games for entertainment, virtual reality or augmented reality applications for rehabilitation, up to educational applications as it is the case of this research. When utilizing the application, the users showed high expectations regarding their comfort, design, structure, and functionality with an average degree of satisfaction of 94%, which may be considered as the starting point that provides a different strategy so that new devices together with new technologies enable the first level and much more solid education.

In future research, it is planned to develop a second version of VISDOM motor where the user has different types of electric motors that can be mounted on different 3D environments, besides an extra assessment section, where the user may assemble a motor using LMC to improve the learning and the dynamism in the application.

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Low-Cost Assistive System for Deaf People Based on Artificial Vision

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Abstract Hearing-impaired people have trouble communicating with the rest of society because they do not have an effective and inexpensive means of communication. People who learn sign language find it difficult to locate qualified interpreters who can get their message across. This article proposes the development of a software application, using artificial vision and digital image processing to translate the Ecuadorian Sign Language (ESL) into the written language of the Latin alphabet. The objective of this research is to create an economic support system for people with hearing disabilities to improve their autonomy and reduce the cost of medical care. For the creation of the system, digital image processing was performed through four stages: acquisition, preprocessing, the extraction of characteristics, and recognition-translation into the Latin alphabet language. Within the controlled tests conducted in this research, an average processing time of 905.88 ms was obtained, i.e., less than one second for each letter. Regarding the precision in the translation of the system, the efficiency of 97% was obtained.

Keywords Digital image processing · Sign language · Artificial vision · Hearing impairment

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M. V. García et al. (eds.), *Advances and Applications in Computer Science, Electronics and Industrial Engineering*, Advances in Intelligent Systems and Computing 1307,
https://doi.org/10.1007/978-981-33-4565-2_16

1 Introduction

Hearing loss refers to the total or partial inability to hear well. It is considered a disability if there is a decrease of 40 dB in the perception of the human ear. According to the World Health Organization (WHO), more than 5% of the world population suffers from hearing loss. From this number, 432 million are adults and approximately 34 million are children. WHO describes that the majority of people with this disability come from low- and middle-income countries [15, 17]. In the last summary of the world report on disabilities, it is mentioned that apart from the medical difficulties experienced, negative side effects such as lack of citizen participation, low quality of health, school, and economic performance are suffered [5, 14].

Hearing-impaired people often have trouble accessing services due to the lack of a means of communication. Some people decide to learn sign language, which allows them to transmit signs as visual gestures using forms created with the hands, arms or body, facial expressions, and lips to convey word meanings instead of acoustic sound [16]. However, the difficulty in finding an interpreter to communicate with hearing people is high. A survey conducted in 93 countries revealed that 30 countries had 20 or fewer qualified interpreters [11].

In Ecuador, according to numbers from Consejo Nacional para la Igualdad de Discapacidades (CONADIS) of the total of people with disabilities, 14.0% corresponds to hearing impairment. Specifically, in the province of Tungurahua, there are 3,542 people with this health problem [3, 5]. In this country, the Ecuadorian Sign Language (ESL) is used, which is described in the Ecuadorian Sign Language Dictionary "Gabriel Román" that has 9 groups of sign configurations with 82 variants, each represented by a specific hand posture. The LSE language is similar to other languages used in the region with slight variations in some characters [19]. However, it is only used within the deaf community. Outside it is difficult to find people who understand this kind of language, reflecting the communication barrier that still exists in the world [4, 16].

The continuous process of care for people with disabilities includes access to auxiliary technologies that improve autonomy, encourage participation and can reduce the costs of assistance and support [5]. These technologies can be improved by manufacturing, assembling, or creating products or services locally, reducing import taxes, and adapting to the reality of the environment of people with disabilities. In this field, several studies have been carried out that propose technological solutions to help people with hearing disabilities to integrate effectively through communication. Below is a list of relevant works carried out in the area of digital signal processing aimed at sign language translation.

Yeasin et al. [25] describe the use of sensor gloves and a mobile app that translates Lebanese sign gestures into spoken words. The project is developed through the use of artificial neural networks and the MLP's backpropagation algorithm, programmed in MATLAB and Python libraries. The precision of this system obtained results with an efficiency of 98%. Guzman et al. [9] have developed an electronic glove composed of an artificial voice module with wireless connection and a screen that allows real-

time interpretation of sign language. It serves to train both hearing-impaired people and the normal hearing society in the use of sign language. As a translation result, 90% hits were obtained when translating manual gestures, which demonstrate high system precision.

A translator glove for the Turkish language with flexible sensors to detect movement of the middle, thumb, and index fingers with a gyroscope to detect movement of the hand has been designed by Yalçın et al. [24]. For this purpose, they used the MPU6050 sensor, and the MATLAB program to process the signal. As a result, the detection of 18 symbols of the Turkish alphabet was obtained. They determined that improvements are necessary through the use of printed circuit boards, in addition to expanding the data ranges to distinguish the letters because some confuse their detection.

Abhishek et al. [1] have developed an electronic glove with capacitive sensors and an embedded device for processing and translating sign language into sounds. The prototype recognizes numbers from 0 to 9 and 26 characters of the English alphabet from A to Z, based on 1080 tests. Effectiveness of 92% was determined. Finally, Guerrero et al. [8] created a system with artificial vision techniques for the recognition of static signs of the Colombian Sign Language (CSL). This system performs digital signal processing on an Altera FP2 EP70C70F896C6 Cyclone II device. As a result, the system has a recognition rate of 98.15%.

Based on the above, the objective of this work is to develop a software application using artificial vision and digital image processing with a menu of two options. The first translates ESL into written Latin alphabet language. The second option is a trainer, which allows users to learn this language. The use of other types of devices is not necessary so that it reduces implementation costs and therefore creates an economic and effective system that is available to people with hearing disabilities.

This article is divided into four sections including the introduction, section two presents the methods used to develop the proposed system, section three shows the experimental results, and finally, in section four, the conclusions and future work are developed.

2 Materials and Methods

The system performs automatic recognition and translation into the text of the letters from A to Z and the numbers from 1 to 9 interpreted in ESL (see Fig. 1). It includes a spellchecker, in case of misinterpretation of symbols.

The system is made up of two processes. The first is called Translator, it allows users to translate the ESL language into Latin alphabet text. The second makes it possible to learn the ESL language through practice. It is called Trainer. To comply with the two proposed processes, it is necessary to perform an image comparison. To achieve this task, the images of the hand are captured in a controlled environment. Based on [7] to process an image, various phases can be applied that group different algorithms and processes, so for the development of this project the following steps

Fig. 1 Processed sign language

are used (i) image acquisition (ii) preprocessing, which includes the image segmentation processes, and mathematical morphology, (iii) image processing where the extraction of characteristics is performed, here the LabVIEW software through the Vision Assitant libraries is used, (iv) corrections are made to the text in case of errors and finally, (v) the information is displayed to the user (see Fig. 2).

2.1 Image Acquisition

The image acquisition is carried out through a transducer, which using light manipulation obtains the digital representation of any object [22]. For this research, a 6 LED digital camera was used. It has a resolution of 640 x 480 pixels and a USB port. Its cost is economical and it has high availability in the market [6]. To reduce the complexity of digital image processing, the acquisition phase is carried out in a contrast-controlled environment, i.e., the light parameters are artificially established with the use of lights and color contrast [21]. In Fig. 3, the diagram of the environment for testing and image acquisition is observed. **A** shows the location of the camera while **B** represents the primary lamp located behind the camera. **C** indicates the sec-

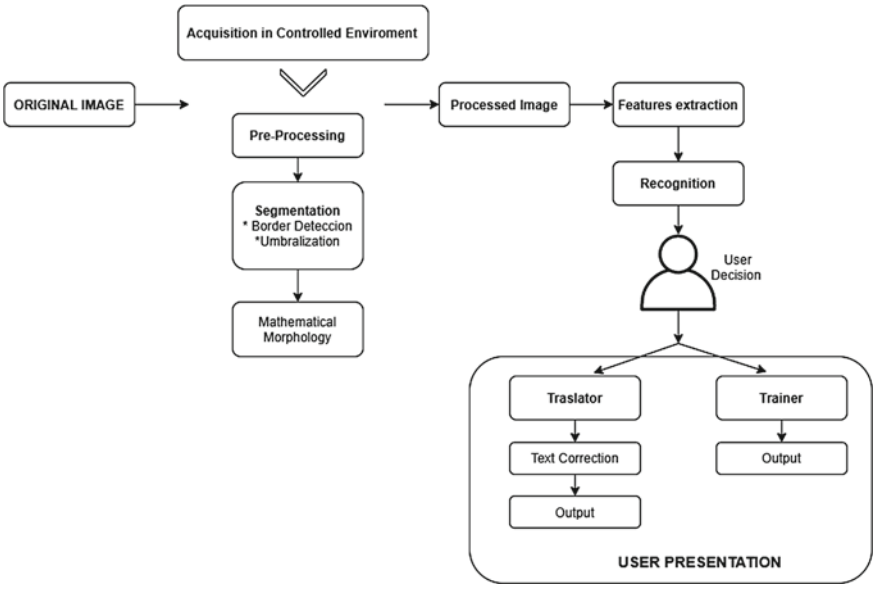


Fig. 2 System block diagram

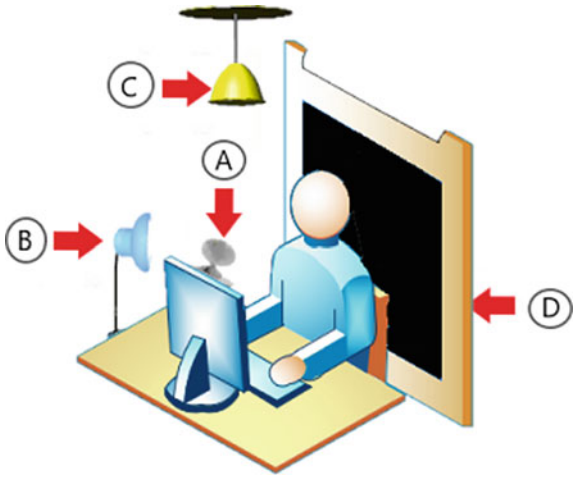


Fig. 3 Controlled environment for image acquisition

ondary lamp located on the ceiling and finally, **D** indicates the black background that allows contrast with the light emitted by the lamps. It is located behind the user.

2.2 Preprocessing

In a controlled environment, the image of the signal is acquired. This color image is made up of three layers. The image is converted to grayscale to characterize it without losing its properties and facilitate its processing [13]. Due to the Gaussian noise that is added because of the effect of the camera and the lighting, a stage of filtering, improvement of brightness and contrast that is carried out in Vision Assistant with the function Color Plane Extraction should be considered [10].

2.2.1 Image Segmentation

Once the grayscale image has been obtained and filtered, the segmentation process is carried out. Image segmentation consists of the method of extraction and division into regions with similar properties [20]. There are several techniques to perform segmentation, in this case, thresholding and edge detection are used, which are the most common techniques for this process [2]. The thresholding allows to group the pixels of the different objects present in the image. The original image is defined by the function f(x, y), after the thresholding process g(x, y), a threshold is set between 0 and 255 [18]. This operation is defined by Eq. 1.

$$g(x, y) = \begin{cases} 255\ , & f(x, y) > Threshold \\ 0\ \ \ , & f(x, y) \leq Threshold \end{cases} \tag{1}$$

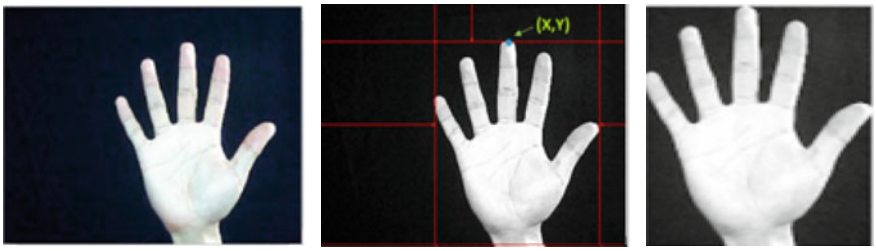
The segmentation is based on the choice of one or more thresholds that allow the pixels to be grouped into regions with similar characteristics depending on their gray levels. It is determined by Eq. 2 [2].

$$T = T[x, y, p(x, y), f(x, y)] \tag{2}$$

where T represents the threshold of an image, f(x, y) is the gray level of the point (x, y), and p(x, y) represents the measurement in a neighborhood environment of this point. The equation that defines the image obtained is represented in 3. This process is known as binarization, the pixels represented by 1 belong to the desired object and 0 to the background pixels [2]. The function "ExtractSingleColorPlane.VI" is used inside the Vision Assitant to carry out this process.

$$g(x, y) = \begin{cases} 1\ , & f(x, y) > T \\ 0\ , & f(x, y) \leq T \end{cases} \tag{3}$$

Edge detection lets you see significant discontinuities at the gray level, that is, it splits an image based on sudden changes in two adjacent regions that indicate the



(a) Acquire image (b) Grayscale conversion (c) Cropped process

Fig. 4 Image segmentation

existence of an edge. Discontinuities are detected with first-order derivatives using the gradient operator. The derivative estimators used are Sobel and Prewitt. These allow finding the points of the image where the intensity changes radically based on a specific threshold and the detection of the edges of the image [12].

After edge detection, the image is cropped in right–left and top–bottom orientation to find rising and falling edges through the most noticeable points of the image. In Fig. 4a, the original image is observed. In Fig. 4b the image converted to grayscale after the segmentation process is presented, in red lines the edge detection points are indicated. Finally in Fig. 4c, the cropped image focused on the object of interest is shown.

2.2.2 Mathematical Morphology

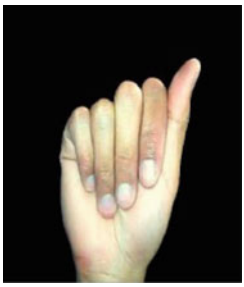
The mathematical morphology allows to post process the result of segmentation to eliminate residues and smooth the contours of the image, in this way the extraction of characteristics obtains more precise results [7].

For this, the morphological gradient is used, which is the difference between the dilation and erosion algorithms. Dilation tries to enlarge an image while erosion decreases it. Therefore, the difference will be similar to the edges of an image [22]. In Fig. 5 the image resulting from the preprocessing process can be seen.

2.2.3 Characteristics Extraction

The Machine Vision function of Vision Assistant is used with which it is possible to extract a characteristic vector from the image that contains the most relevant information represented in one dimension. The structural matching shape numbers method is used to find the characteristic vector; the comparison of the limits of regions with a degree of similarity represented by the letter k is formulated. These two forms have a degree of similarity k if they satisfy Eq. 4.

Fig. 5 Preprocessing



(a) Acquired image (b) Image resulting from pre-processing

$$s_j(a) = \begin{cases} s_j(b) \quad , \quad for j = 4, 6, 8.....K \\ \\ \neq s_j(b) \ , \ for j = k+2, k+4, ... \end{cases} \tag{4}$$

where s indicates the shape number and the subscript shows the order. The distance between two shapes is defined as the inverse of their degree of similarity [22], as shown in Eq. 5.

$$D(a, b) = 1/k \tag{5}$$

The distance satisfies the following properties described in Eqs. 6, 7 and 8.

$$D(a, b) \geq 0 \tag{6}$$

$$D(a, b) = 0 \tag{7}$$

$$D(a, b) \leq max[D(a, b), D(b, c)] \tag{8}$$

D or k can be used to compare 2 shapes. If the degree of similarity is longer than k, it is the most similar form [22]. After this mathematical process, the characteristics are obtained in a single vector that will be used for comparison in the next phase with the Eq. 9.

$$D(a, b) = 1/k \tag{9}$$

After this mathematical process, the characteristics are obtained in a single vector that will serve for comparison in the next phase.

2.3 Recognition

To achieve the identification of the signal in the ESL language and translate it into the language written in the Latin alphabet, the K-Nearest Neighbor algorithm is used, which is based on the Bayes algorithm and tries a direct estimate of the probability density [23]. It has as input data the characteristic vector obtained in the previous stage, and k takes the value of 4 classes to increase the percentage of correct answers. To improve the recognition process, the user must have previous training.

2.3.1 Learning Phase

This phase uses a database with samples of each image in the sign alphabet. To obtain greater accuracy when performing sign translation to text, it is necessary to take several samples distributed in classes with different hand sizes.

In the Edit Classifier program option, an example of a signal stored in the database, the samples, and their respective classes can be seen. Furthermore, the sample can be deleted or changed to different classes with the Relabel and Delete options.

For classification, there is the classify option to train the database, i.e., to detect and classify each of the signs and then assign them the corresponding character.

2.3.2 Detection Phase

When acquiring the image in the controlled environment, real-time processing is performed through the algorithms previously described. Subsequently, the user must choose the process they want to use, that is, the translation process or the training process.

2.4 User Options

As described in this research, the system has a menu with two options for the user. The first as a Translator and the second as a Trainer. Next, we describe each one of them.

2.4.1 Translator

The translator function is used to convert the ESL language to text in the Latin alphabet. If the Translator option is selected by the user, an intuitive graphical interface is displayed where the steps to follow for its operation are indicated. These are listed below:

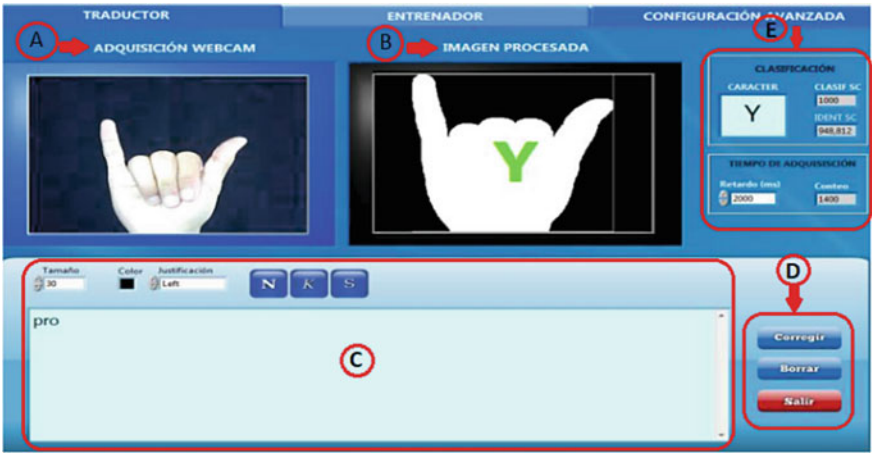


Fig. 6 Translation interface

1. Position the user's hands correctly on the camera to proceed to capture the image.
2. The system displays the letter corresponding to the detected image.
3. A preamble for writing characters in Spanish is presented.
4. When ending the word, the user can apply the spellchecker, so that the final word or phrase is displayed correctly.

In Fig. 6, the translation interface is shown. **A** shows the acquisition of the image through the webcam, **B** represents the processed image in real time, **C** depicts the translation panel, **D** shows the options to correct, delete, or cancel the process. Finally, **E** indicates the character, acquisition time, and processing task.

The spellchecker option is based on programming blocks called "Dictionary" created to search for words similar to those that appear in the original text using the Spanish dictionary. If spellchecker is activated, the programming block searches for a similar word and reassembles the text. In the case of not finding a similar word, the system chooses the non-corrected word. In Fig. 7, **A** presents the text that was initially detected and **B** shows the amended words.

2.4.2 Trainer

This option is a process of passing information through meaningful messages between interacting sources and recipients. This section was made to allow the user to know the correct way to perform the ESL sign language. In the trainer tab, the image is acquired and processed with the same programming used for the translator. For the user to correctly use this stage, he must follow the next steps.

1. Type the wanted character in the box "Character to display", the accepted characters are A–Z and 1–9.

Fig. 7 Spellchecker option

2. If a blank space is required, the "Blank space" button must be pressed.
3. Click on the Display button to generate the sample corresponding to the selected character.
4. The user must imitate the generated image.

Once the process is completed and if the sign made by the user is correct, the processed image is shown in a green box and a "Character Detected" message appears. Otherwise, the process must be repeated.

Figure 8 shows the graphical interface of the trainer. **A** shows the pattern corresponding to the character that the user types. In **B**, the image obtained and processed in real time is displayed.**C** shows the instructions that the user must follow. In **D**, the character inserted by the user and the options of Delete, Display, and Exit are displayed. In this case, the sign made by the user is correct and the green box is displayed in the real-time acquisition.

2.4.3 Advanced Settings

In the last tab of the user interface, some settings can be made before using the translation or training processes. Since the amount of light used in image acquisition is known to influence its processing, the system allows the user to distinguish whether it is day or night and adjust the brightness and contrast values. Additionally, the type of camera used and the interface through which the information is being transferred are indicated. This data may be required for the user to make modifications.

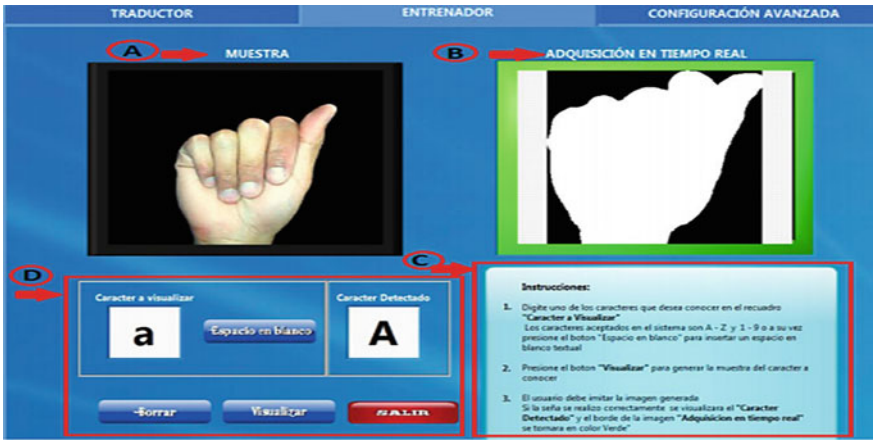


Fig. 8 Trainer interface

3 Results

The operation of each of the program processes proposed in the investigation was verified. The translator was checked by taking samples consisting of words and short sentences to determine the average recognition time of each alphabet symbol and numbers. The tests were carried out in a controlled environment and with different people to capture data. As shown in Fig. 9.

According to the data displayed in Table 1, the result of the average processing time is 950.88 ms, that is, less than one second for each character. The letters that cause the greatest inconvenience in detection are m, n, r, and p due to the time it takes for the user to perform the signal, which is greater than the image acquisition time.

Fig. 9 Controlled tests

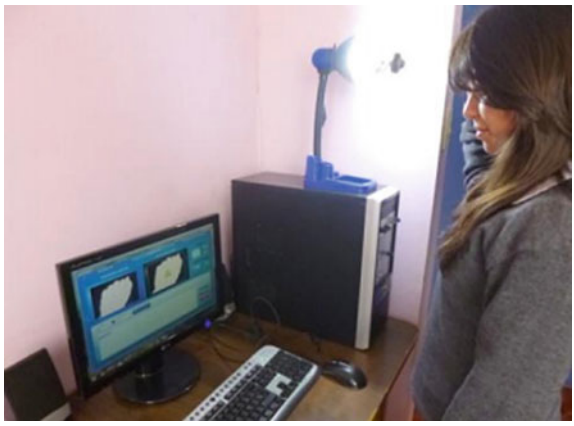


Table 1 Processing time

Character	Processing time (ms)	Character	Processing time (ms)
A	948.51	S	945.82
B	952.38	T	952.58
C	941.32	U	938.49
D	965.42	V	957.82
E	966.42	W	960.41
F	955.24	X	958.23
G	942.31	Y	956.48
H	964.25	Z	959.62
I	941.23	1	932.12
J	948.75	2	952.32
K	966.85	3	942.51
L	938.67	4	936.28
M	971.36	5	932.62
N	973.68	6	942.8
O	964.81	7	931.56
P	931.79	8	939.57
Q	948.63	9	954.58
R	965.36		
Average = 950.88 ms			

Also, translation tests were carried out on 100 words used in short sentences. The system hit rate was 80% without the use of the spellchecker. It was determined that the main drawback in the translation of words is the duplication of letters due to the speed with which the system acquires the signals, which is 2000 ms, while the time it takes for the user to change symbols is approximately 2200 ms. The second drawback is the wrong letters on detection.

These problems are solved with the use of the spellchecker. The system efficiency was of the 97%, the errors were observed in the last character, so the word can be easily understood. This shows that the system is of high precision and reliability as depicted in Fig. 10.

The effectiveness of this project compared with the FPGA-based translation system from Colombian sign language to text and Glove-based hand gesture recognition sign language translator using the capacitive touch sensor is shown in Fig. 11.

The first two systems use external elements such as FPGA cards and electronic gloves that, although they allow the acquisition of data and translation of signals, increase the cost of the equipment. The FPGA-based translation system has a 98% success rate in the translation, thanks to the processing capacity of the card and the use of an MLP neural network structure. In the second case, the Gloved base hand gesture recognition has 92% of efficiency using a Raspberry PI card and capacitive

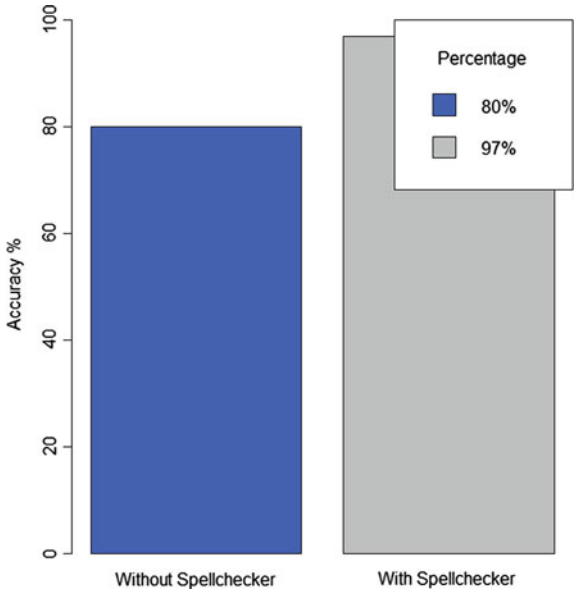


Fig. 10 System accuracy

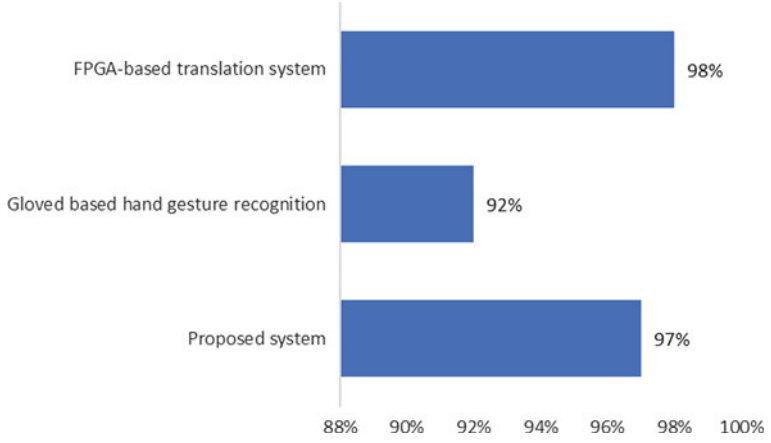


Fig. 11 Translation systems comparison

type sensors. While the proposed system has a 97% success rate using only the computer as hardware and the software developed. It can be placed on any computer even in school environments, where learning this language will be significant.

4 Conclusions and Future Work

This paper described the development of an assistance program for people with hearing disabilities without the use of external elements to reduce the cost of implementation.

The LSE is used for the translation tests because it is the language used in the country, which is very similar compared to the languages of the region, differing only in characters such as a, f, g, q, s. The program describes two modes of operation, the first is a translator from LSE sign language to Latin alphabet text and the second is a trainer. Both processes are based on the recognition of images which was carried out in these stages: acquisition of the image in a controlled environment, preprocessing, extraction of characteristics, recognition, and final presentation to the user.

As future work, it is proposed to use the combination of recognition algorithms to improve the time and effectiveness of image processing in the translator system. In addition to considering variables such as hand rotation, two-handed language, and the time intervals that exist in the change between each of the characters.

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Selection of Classifiers for Hand Gesture Recognition Using Analytic Hierarchy Process: A Systematic Literature Review

Ruben Nogales, Freddy Benalcazar, Jaime Guilcapi, and Javier Vargas

Abstract This article presents a systematic study for the selection of classifiers for hand gesture recognition by electromyography signals. The selection of a classifier can be determined using an arbitrary search criterion or employing an Analytic Hierarchy Process (AHP). The classifiers are determined as alternatives, which for the study are K-Nearest Neighbors (KNN), Naïve Bayes (NB), Support Vector Machines (SVM), and Linear Discriminant Analysis (LDA). Each of these alternatives is selected through search criteria, which are average training accuracy, average testing accuracy, sampling fee, average acceptance rating, and scrap rating average. These criteria and alternatives allow through a systematic study and the AHP model to select each search factor of the analysis of the systematic mapping (SMS) quantitatively. The results determine the KNN and SVM classifiers as the most used for research projects in electromyography signal recognition (EMG).

Keywords Systematic review · Analytic hierarchy process · EMG · Hand gesture recognition

1 Introduction

An electromyographic signal or set of signals can be described as the study of muscle function at the time of contraction, which generates an electrical signal [19].

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M. V. García et al. (eds.), *Advances and Applications in Computer Science, Electronics and Industrial Engineering*, Advances in Intelligent Systems and Computing 1307,
https://doi.org/10.1007/978-981-33-4565-2_17

Each electrical activity is measured by some kind of surface or skin electrode [25]. Some studies use surface electrode data collection to determine large-scale statistical values. The obtained values are generated by the motor units, which offer the possibility to calculate directly or indirectly their discharge frequency. On the other hand, it is necessary to determine whether a muscular activity is present or not, and each detected movement is linked to an action of the arm [13, 21]. In summary, what is determined in each study is an electromyographic signal or electromyogram (EMG), where an electrical potential is generated in the muscle fibers when the muscles are contracted [24]. They provide information on the state of the muscles to determine the gesture made according to their characteristics.

However, a classification procedure of the original signal is necessary. The EMG readings obtained by the device are subdivided for each channel by each electrode. To be able to classify a signal, it is necessary to have a classification criterion that allows a choice between each signal or wave data, the movements or contractions generated by the person [12, 29, 30]. After obtaining the discriminant packages, it can apply several classification methods such as the K-Nearest Neighbors (KNN), Naïve Bayes (NB), Support Vector Machines (SVM), and Linear Discriminant Analysis (LDA) [4, 17, 30]. These classification methods or learning algorithms are considered as Non-Parametric methods [18], which are used to match each event to the physiological class it belongs to.

For the systematic literature review on some research, where they determine the classification of an EMG signal with its respective interpretations, they use the concept of the perspective of systematic mapping review (SMR) [5, 15]. The objective of this analysis is to help researchers to obtain a comprehensible picture of which could be a good classifier according to specific criteria or indicators obtained from each research study as a whole. The evaluation criteria that could be determined for a classifier are average training accuracy, average testing accuracy, cost of sampling, average acceptance, and rejection classification. This indicators' selection applies through an analytic hierarchy process model (AHP) [27].

An AHP model is a technique used for decision-making. Its hierarchical processing allows a visualization of each of the chosen decision impacts according to the alternatives presented with each of the most common criteria.

The classification in the AHP model is divided into three stages, the objective, the criterion, and the alternative. Each of these stages is a selection preprocessing that can be subjected to hierarchical subdivisions for decision-making [20].

2 Context and State of the Art

For the systematization of the classifiers, a previous compilation of the most referenced studies of a great impact on the research on EMG signals is made.

Table 1 Sorting methods—alternatives

	Description	Objective
KNN	Nearest neighbors is a non-parametric parameter, used to classify according to the nearest training examples in the space feature [23]	KNN calculates the distance from the new data to the existing neighboring k
LDA	In linear discriminant analysis, linear characteristics simultaneously reduce the dimensionality and the separability of case classes [11]	Reduces the size of the character space by preserving most of the information discriminating between classes
NB	Classifier that makes the simplistic assumption that attributes are independent given the class, so that probability can be obtained by the product of the individual conditional probabilities of each attribute given the class [7]	They predict the likelihood of possible outcomes, assuming the presence or absence of a characteristic
SVM	SVM with Linear Kernel is used for unsupervised anomaly detection. It models the underlying distribution of normal data by being insensitive to noise or recording formation anomalies [2]	It is based on identifying the position of each element in an input vector in n-dimensional space with a number of characteristics

2.1 Alternatives

In a selection process of the alternatives to be evaluated, it is necessary to have a study criterion on the models or classification methods. Therefore, each method selected depends on the focus of research on the most commonly used gesture recognition models in Table 1.

In [10], the authors made the comparison of the quadratic discrimination analysis of the k-nearest neighbor, and the QDA and LDA algorithms for the classification of wrist movement directions with up, down, right, left, and resting-state movements. EMG signals were collected from the forearm for the above movements using a two-channel electromyography (EMG) system. From the statistical analysis performed, they used the difference of the absolute mean value (AMV) to build a feature map, and the LDA, QDA, and k-NN algorithms were used to classify the signal directions.

In [23], the work consisted of performing a six-gesture pattern recognition, mainly of the thumb and index finger, of the electromyographic (EMG) signals acquired employing a single myo bracelet, although the bracelet placement required special care. The analysis was performed on the time domain to establish the classification performance based on machine learning techniques, k nearest neighbors (KNN), and SVM. They analyzed the data into three sets, maintaining the same parameters.

In [9], the authors explained automatically identifying hand movements: opening, closing, bending, extension, pronation, and supination, including the rest con-

dition. Characteristic extraction was implemented using three approaches: time domain, frequency domain, and frequency-time domain, obtaining the characteristics Mean Absolute Value (MAV), Root Mean Square (RMS), Wavelength (WL), Self-Regressive Coefficients (AR), and Discrete Wavelet Transformation (DWT) [26].

In [6], the authors evaluate the off-line performance of the LDA classifier and other types of LDA, using the signals acquired with the Myo bracelet. They indicate that the average off-line accuracy for the motion classification of these two classifiers can be over 90%, but LDA is more stable than other types of classifiers.

In [14], the aim was to investigate the impacts of varying detector positions on the arm for EMG pattern recognition and motion classification on amputated upper limbs and solutions to reduce these impacts. The results showed average in-position and out-of-position classification errors in the five-arm positions and five subjects of the order of 7.3 and 29.9% of the amputated arms, respectively, being approximately 1.0 and 10% lower compared to those with intact arms. When EMG data from all five arm positions were involved in the training set, the average classification error reached a value of about 10.8% for amputated arms.

In [8], the authors worked with five types of classifiers: Nearest Neighbors KNN, Linear Discriminant Analysis (LDA), Machine Support Vectors (SVM) with radial base function kernels (MSS-RBF), and Machine Support Vectors with linear kernels (MSS-L), and Decision Trees (DT). Of these proposed gesture selection methods, an experimental test was carried out to compare reference performance by ordering and grouping similar types of motions. As part of the results found, all the proposed selection methods gave a higher classification accuracy than the baseline method, except for the LDA classifier.

In [16], the authors propose to improve the benefits of the Myo armband device for the detection of EMG signals using the automatic learning technique (machine learning), because although this wireless device currently allows interacting with the computer using electromyography (EMG) sensors, certain postures are not detected or are detected incorrectly. Therefore, to increase the accuracy of the device, EMG data were tested in 8 learning algorithms (Naïve Bayes, Neural Networks, RBF network, KNN, J48, Decision Tree, Decision Table, and Random Forest) on gesture recognition problems. The results show that the RBF network, Naïve Bayes, and Random Forest present the best behaviors with all the available data.

Reference [1] consisted of a comparative analysis between different classifier methods, such as Direct Feed Neural Networks (FFN), Machine Support Vectors (SVM), Naïve Bayes Classifier (NBC), and Linear Discriminant Analysis (LDA). The authors applied pattern recognition to electromyographic (EMG) signals of forearm muscles to identify the five movements of the hand: closed hand, open hand, inwardly bent hand, bent hand, and relaxed position. The data were obtained using the "Myo Armband" device. Using the algorithms above mentioned and cross-validation, they calculated the training accuracy of the classifiers for $K = 10$, obtaining: for FFN 78%, for SVM 99. 6%, for BNC 87%, and for LDA 96.4%.

In [28], the researchers proposed to develop an algorithm to classify different hand gestures using electromyographic accurate (EMG) signals that are independent

of the subject from whom the data are acquired. They worked with five automatic learning algorithms: Nearest Neighbor (KNN), Discriminant Analysis (DA), Naïve Bayes (NB), Decision Tree (DT), and Support Vector Machine (SVM). Besides, all classifiers are close to the mean values when using standardized EMGs. Also, the classification accuracy differences between the original and standardized EMGs were in the range of 0.48 to 1.17% for the different classifiers used.

In [3], the authors evaluated the feasibility of using Machine Support Vectors in the analysis of myoelectric signals acquired using a Myo armband device when performing hand grasp gestures. The data used for both classification and training were taken from the same group of individuals considered for the study. Different Kernel functions were studied (Linear, Polynomial, and Radial Base Functions) and with the same amount of training data and electrode combinations. They determined different lengths of training values versus different lengths of sorting samples. On the other hand, in [22], the authors worked with 6 kernels (linear, quadratic, cubic, fine Gaussian, medium Gaussian, and thick Gaussian), where the linear kernel presents the penultimate precision in the classification. The linear kernel is presented as a significant alternative for users because it is faster and has a simple mathematical function than other types of kernels.

2.2 Criteria

For each article, there is a different match which, taken by the analysis of the SMS, is based on the following type of query (TITLE-ABS-KEY): TITLE, ABS for the abstract, and KEY for the keywords that fit in the plus section. Besides, it is necessary to take into account the hierarchical subdivisions that this query may have between AND and OR. The rating is represented on a scale of 1 to 5 in Table 2:

- value of 1 for a single reference (mentioned in the study); this means that the study presents a confusing presentation of results or little information relevant to the study.
- value of 2 for cross-reference (likely study alternative); partially appears in the study. The terms are managed correctly in the search.
- value of 3 for adapted reference (coupled within the development of the study); a correct presentation of the results are oriented to the research proposal.
- value of 4 for applied reference (presented as part of the study process); the investigation if it is substantiated and established correctly in the search parameters.
- value of 5 for a valid reference (feasible for the study); there is an acceptable evaluation criterion concerning the search parameters and the present investigation of the reviewer.

Within the systematic study of the mapping of the articles for the selection of a suitable classifier to determine the behavior of the electromyographic signals, the results of the empirical tests that exist in each of them are presented. The table below subdivides the studies according to their corresponding analysis.

Table 2 Sorting methods—criteria

Criterion	Alternative				SMS	Reference no.
	KNN	LDA	NB	SVM		
Average training accuracy	5	3	3	5	Valid (4)	KNN: [8, 17, 23, 30] LDA: [10, 11, 14, 30] NB: [7] SVM: [1, 2, 8, 23]
Average testing accuracy	3	2	1	4	Cross (2, 5)	KNN: [16, 17, 23, 30] LDA: [9, 14] NB: [7, 16] SVM: [1, 3, 17, 28]
Sampling fee	5	2	1	5	Adapted (3, 25)	KNN: [8, 10, 23] LDA: [6, 11, 14] NB: [1, 16, 28] SVM: [3, 8, 22, 23]
Average acceptance rating	4	2	1	5	Adapted (3)	KNN: [10, 16, 28, 30] LDA: [14] NB: [7, 28] SVM: [1, 3, 28]
Scrap rating average	2	4	4	1	Cross (2, 75)	KNN: [16, 28] LDA: [10, 11] NB: [1, 7] SVM: [2, 17, 23]

For the AHP model, non-representative values are not taken into account, as they do not comply with the hierarchical order of selection of the inclusion criteria.

In a systematic or mapping literature review of the same, for the mapping of must take into account which analysis factors that allow reviewing the document. These factors are from the perspective of the analyzer or the person who is in the process of investigation. These factors or criteria can be taken arbitrarily by the reviewer. When one of the review criteria is presented in the referenced document, it can be treated as a possible solution to the research problem. Each document presents its analysis of results, as well as different factors that allow determining whether the proposed method of classification is ideal or not for the research. These data are sometimes presented arbitrarily as they are short studies or presentations of results from some larger research. It should be noted that the literature reviewer determines these evaluation criteria for the project, which allows for the establishment of average training accuracy, average testing accuracy, sampling fee, average acceptance rating, and scrap rating average.

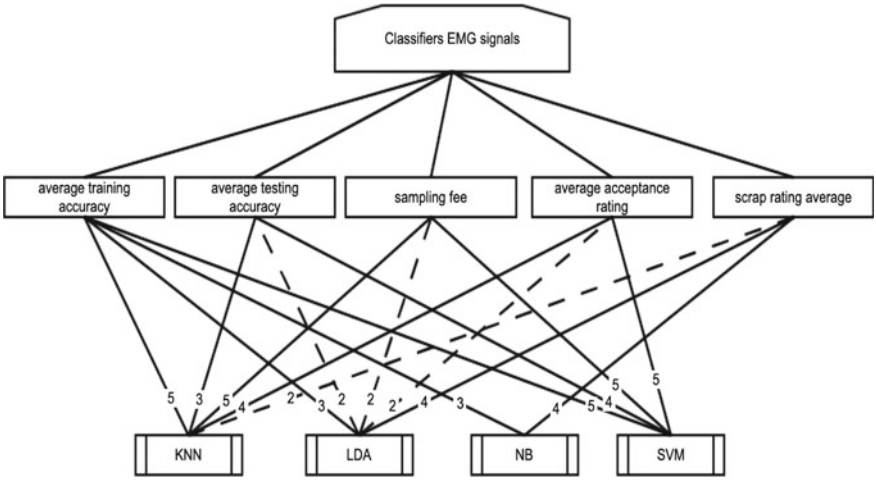

Fig. 1 AHP model for the selection of classifiers for EMG signals

3 AHP Model

To represent the AHP model, the results obtained in Table 2 are selected hierarchically to meet the objective of a suitable classifier applied to determine the behavior of EMG signals. Figure 1 shows the continuous line segment representing a high value (5–4), a dashed line for a medium value (3–2), while for the low value (1) the rating is not taken into account.

For the analysis of the systematic mapping study, the indicators state that for the average training accuracy, the percentage training result should be established using a considerable number of samples. For average testing accuracy, it is necessary to determine whether or not the sample was tested in the study. It should be emphasized that these are data from each previous research according to the characteristics taken into account. For the cost of sampling, it is determined whether, in the investigation, there is a certain mechanism for using tools for processing the information; in this case, the computational cost intervenes. While the average of the acceptance and rejection classification is influenced by the comparative characteristics that some authors present on the analysis of each of the classifiers, this average value is usually presented as a percentage.

Once the AHP model is determined graphically, it can be established that among the most referenced classifiers within the analyzed investigations are KNN, LDA, and SVM. Selecting an alternative with the highest weight can be established by a data matrix where the values go on a numerical scale from lower to higher. This type of evaluation is done quantitatively since a search weight is established for each of the elements. For example, in the first analysis, it is established that KNN is one of the most used as a classifier, even though it is not established as a value in the search parameter of the scrap rating average shown in Fig. 2.

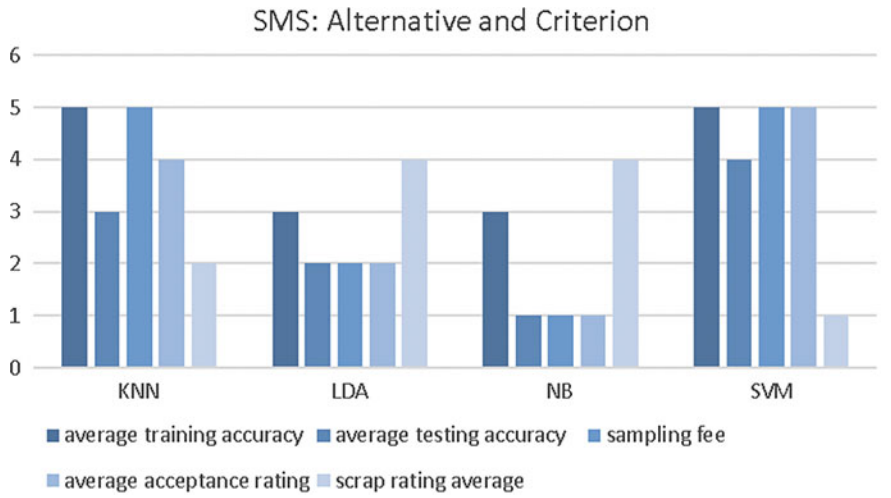

Fig. 2 Systematic mapping based on the alternatives and criteria

4 Results, Analysis, and Comparisons

For the interpretation of the results, the studies that within a research project allow facilitating three stages to determine the behavior of the EMG signals are analyzed. These stages are Feature Extraction, Classification, and Post-processing.

The values of the scale are simple algebraic sums, giving an interpretation that KNN has five coincidences with values of $5 + 3 + 5 + 4 + 2$, which gives us a result of 19. For LDA, it also has four coincidences with values of $3 + 2 + 2 + 4$, which gives a result of 11. For NB, counts two matches $3 + 4$, which gives a result of 7. Finally, the obtained SVM with four matches with values of $5 + 4 + 5 + 5$, which gives a result of 19.

4.1 KNN

It includes five selection criteria (in Table 1) with a sum value of 19, performed by SMS. This value is represented in an early analysis of the systematic review, which tells that the KNN ranking method is one of the most used in different studies. It should be emphasized that being one of the references in different articles does not mean that it is one that has a higher percentage of acceptance of obtaining and processing the EMG signal (Fig. 3).

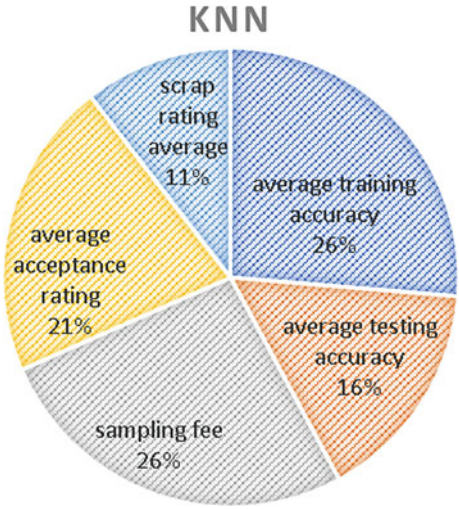

Fig. 3 KNN performed by SMS and AHP for multi-criteria decision-making

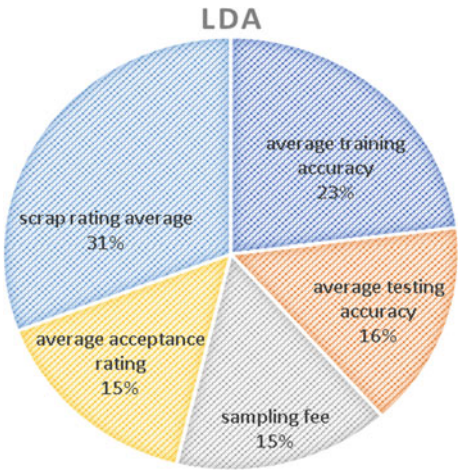

Fig. 4 LDA performed by SMS and AHP

4.2 LDA

For this classifier, its estimated value adds up to 11, interpreted by SMS. Each diagram is represented in a pie shape to help the researcher understand its usability within a wide range of EMG signal samples. The most referenced criteria or those with the highest number of coincidences are analyzed in more detail in the investigations of Table 2 with the reference number to which they belong (Fig. 4).

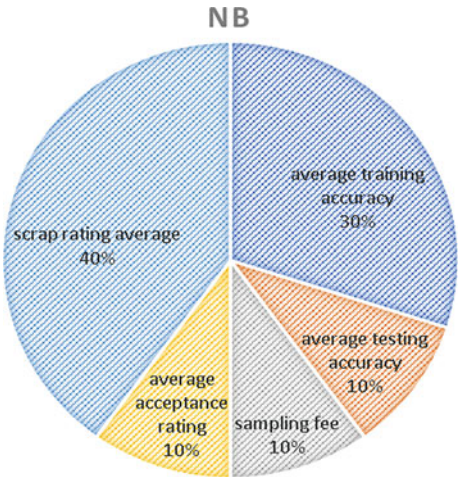

Fig. 5 NB performed by SMS and AHP

4.3 NB

For the NB classifier, there are only 2 coincidences that add up to 7. However, this means that it is not a bad classifier, only that, due to its simplicity or complexity, as analyzed depends more on the authors who use this classifier. For example, it has a 40% scrap rating average, which tells that there is a disadvantage when using it in comparison with other classifiers, but it has a great acceptance average (Fig. 5).

4.4 SVM

This classifier shares results with KNN by giving its sum of 19, but it must be taken into account that they are two different classifiers taken from different samples. If we analyze the two classifiers, it is determined that they are of great acceptance in research projects. For example, with SVM the percentage of rejection is small compared to others. Determining which is the better classifier will depend on the number of interactions and acceptance results found in the studies (Fig. 6).

In an environment of certainty of the selection process of a suitable classifier for the classification stage of EMG signals, it was determined to associate a quantitative reference value in the SMS literature search. This process of attaching the criteria and alternatives in a hierarchical process allows through a no diffuse process, so the associated values of this method represent the relative importance. Therefore, the selection process using the AHP model seeks the objective based on the analysis of each criterion concerning the present alternatives. Each thread among the alternatives has a weighted weight that is established in the Criteria Sect. 2.2 and represented in Fig. 1; this allows having a scale so that the lines or threads can reach the objective

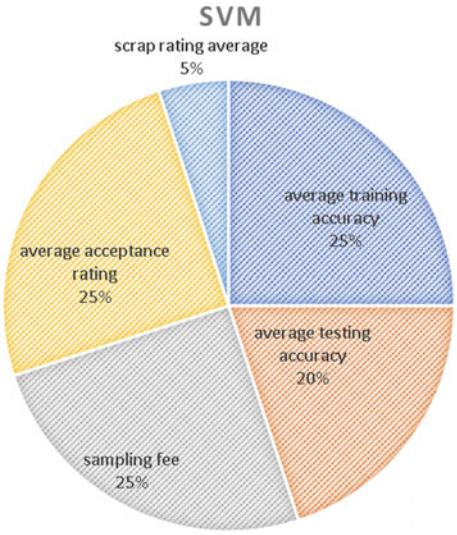

Fig. 6 SVM performed by SMS and AHP

Table 3 Parallelisms of the distribution of AHP model

Alternative	Criterion (%)					Reference (match)
	Average training accuracy	Average testing accuracy	Sampling fee	Average acceptance rating	Scrap rating average	
KNN	26	16	26	21	11	Applied reference
LDA	23	16	15	15	31	Adapted reference
NB	30	10	10	10	40	Cross-reference
SVM	25	20	25	25	5	Applied reference

in research projects. Each selection process does not seek to rank from best to worst, which is intended to adjust for specific types of research that should be the correct rank to implement in the project. For the final analysis of AHP, the structure presents a systematic order of selection, in addition to the number of references present in the research (in Table 3).

For example, the matching shows a general mapping in Fig. 1 (NB), where NB is not feasible due to its very low percentages for study acceptance averages. On the other hand, SVM meets the selection criteria, including a score of 1 for a single reference. These data are either your own selection criteria or a convenience criterion, which does not show a hierarchical order of selection (Fig. 7).

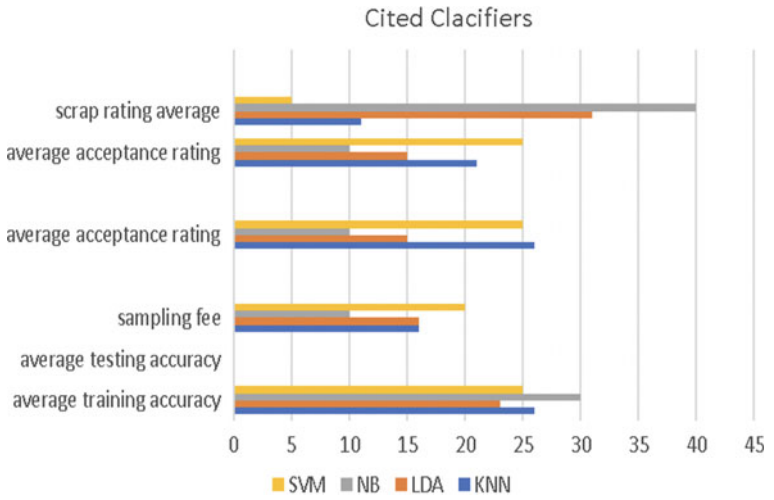

Fig. 7 Classifiers according to criterion and alternative

5 Conclusions

The current study used a systematic mapping reviewing factors such as detailed explanation summarized from the anisette articles, how it is used to classify multi-channel time series (EMG signals), how it is used to classify non-stationary data, computational cost training, and computational cost testing. These factors were derived from the evaluation criteria more adjusted to the research project.

For the hierarchical analytical process, it was established that the values are presented employing a search based on the criteria and the alternatives. Each one of these values is represented quantitatively, which allowed determining that the KNN and SVM classifiers are more adjusted to the study of EMG signals. On the other hand, the other classifiers allow determining the average rating in each of the interactions that the EMG signal can have. These indicate the performance of the EMG pattern recognition method based on the rating.

Criteria-based decision-making allows the reader to establish search parameters that facilitate the training of the classifiers. It allows in EMG signal recognition for hand gestures. This study is based on a determination of the stages of Data Acquisition and Preprocessing. Therefore, the Classification stage will allow reviewers to interpret gesture recognition accuracy within previous studies.

Acknowledgements The Corporación Ecuatoriana para el Desarrollo de la Investigación y la Academia (CEDIA) for the development of the research project CEPRA-2019-13-Reconocimiento de Gestos.

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Toward a Sustainability Balanced Scorecard for Managing Corporate Social Responsibility: A Conceptual Model

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Abstract The Sustainability Balanced Scorecard (SBSC) allows companies to track organizational operations and measure their impact on company objectives. To monitor the impact of Corporate Social Responsibility (CSR) activities and ensure its alignment with the company's strategy, CSR elements need to be integrated into the organization's dashboards. The main goals of this study are threefold: (1) identify the

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M. V. García et al. (eds.), *Advances and Applications in Computer Science, Electronics and Industrial Engineering*, Advances in Intelligent Systems and Computing 1307,
https://doi.org/10.1007/978-981-33-4565-2_18

main CSR elements and the proposal of an analysis scheme for CSR's strategies; (2) assess local and regional CSR implementations using the previously identified elements, and (3) incorporate the identified CSR metrics into a management dashboard based on the findings of the previous steps. Both a systematic literature review and in-depth analysis of case studies were used in this study. The results show that four elements: principles, dimensions, stakeholders, and means can be applied to analyze CSR strategies consistently. In addition, a structure for a management dashboard that incorporates subcategories and indicators for the assessment of sustainable CSR strategies aligned with the company goals is proposed.

Keywords CSR · CSR elements · Sustainability balanced scorecard · CSR management dashboard

1 Introduction

Corporate Social Responsibility (CSR) was conceived as a response to emerging social concerns regarding organizational behavior. From its origins, this concept has gradually evolved to address different economic, social, political, and environmental contexts, which has led to the absence of a single definition.

Initially, CSR definitions focused mainly on social issues [44]. Subsequently, in the 1970s, the evolution of the CSR concept was influenced by different types of events, such as population growth, pollution, resource depletion, and social movements related to human and labor rights, and environmental responsibility [27]. At about the same time, the concept of "sustainability" appeared, emerging from ecological movements with an emphasis on environmental issues and has evolved to include three dimensions: economic, social, and environmental.

In 1994, John Elkington steered CSR approaches toward economic prosperity, environmental quality, and social equity, linking business and CSR with the triple bottom line of sustainability [5, 25]. Since then, many companies have included sustainable aspects of CSR practices [24, 28]. However, the main barriers for CSR implementation and reporting remain to be the lack of agreement on its definition and its core underpinning [37].

A large number of sustainability assessment (SA) initiatives and methodologies have been developed to cope with the complexity of the implementation of the sustainability paradigm [32, 36]. In this sense, the Society for Environmental Toxicology and Chemistry (SETAC) and the United Nations Environment Program (UNEP) created the Life Cycle Initiative (LCI) [26] to promote "life cycle thinking" (LCT) in the mindset of decision-makers.

Thus, LCI contributes to the achievement of the Sustainable Development Goals (SDG). LCT is defined as a holistic approach that considers sustainability factors throughout the entire life of a product or process, from conception to use and disposal [13, 14, 31, 36, 46]. Its primary goals are to reduce environmental impacts, improve

the socioeconomic performance throughout the life cycle of a service/product, and avoid transferring harmful effects to other phases in its life cycle [29].

A series of life-cycle-based methodologies have been developed to achieve the LCT objectives, such as Life Cycle Costing (LCC), Social Life Cycle Assessment (SLCA), and Environmental Life Cycle Assessment (E-LCA). These methodologies were designed to support decision-making at all levels of the value chain, offering the possibility to examine a wide range of key impact categories and indicators. Life cycle-based methodologies are recognized worldwide as one of the best ways to assess sustainability. LCT helps companies to look beyond their economic interest, to transfer environmental awareness along supply chains, to create incentives for environmental, economic, and social improvements, and consequently play a significant role in CSR implementations [40].

Management dashboards are essential to companies to promote, measure, and profit from implementing sustainable development strategies. They allow decision-makers to link business information to business objectives, thus supporting the design and implementation of business strategies [6]. One of the most popular management dashboards is the Balanced Scorecard (BSC) [12]. BSC is divided into four main dimensions: finance, customers, internal processes, and organizational learning [33]. These dimensions allow controlling the effects of actions, improving the vision of the company's performance, and anticipating its future performance [7].

When BSC incorporates economic, social, and environmental aspects in implementing business strategies, it is called Sustainability Balanced Scorecard (SBSC). This integration can be achieved either by adding CSR metrics in each BSC dimension restructuring the existing strategy maps and indicators or creating a specific fifth CSR dimension [30].

Although many studies related to CSR can be found in the literature, its implementation continues to be a challenge for companies that are overwhelmed by the lack of agreement on the CSR elements that should be considered to embrace sustainable practices. Furthermore, to monitor the impact of CSR activities and ensure alignment with the business strategy, CSR metrics need to be designed and integrated into the organizations' dashboards, allowing companies to monitor their activities and impacts.

The aim of this study is threefold. Firstly, to identify the main CSR elements to organize and understand their fundamental basis under the lenses of the sustainability paradigm. Secondly, to use the specified components to analyze CSR implementations through five case studies in Ecuador and Latin America. Lastly, to propose the structure and indicators of a management dashboard that includes the sustainable CSR elements identified.

The remainder of the article is structured as follows. Section 2 describes the applied methodology divided into three stages: the CSR literature review, the analysis of local and regional CSR implementations, and the incorporation of sustainable CSR elements into a management dashboard. Section 3 describes the results obtained, organized in the same three stages presented in the methodology. Finally, Sect. 4 presents the discussion and conclusions drawn from the study and opportunities for further research.

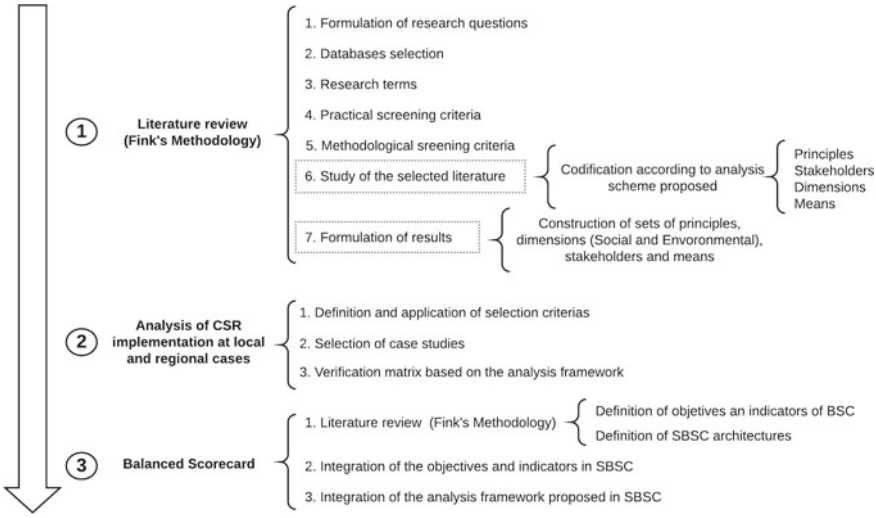

Fig. 1 Methodological scheme for the study

2 Methodology

This study was developed in three stages, as shown in Fig. 1. First, a systematic literature review on the CSR concept was carried out, and an analysis scheme was proposed. Second, local and regional CSR implementations were analyzed with the proposed scheme. Finally, based on this scheme, a structure of a management dashboard incorporating sustainable CSR elements is developed.

2.1 CSR Literature Review

A systematic literature review was developed based on Fink's methodology to explore the CSR concept. This methodology considers seven steps: (1) Formulation of the research questions; (2) Selection of source databases; (3) Selection of research terms; (4) Application of practical screening criteria; (5) Use of methodological selection criteria; (6) Review of documents; and, (7) Summary of the results. For the initial step, the approach and scope of the investigation were established.

The following research questions were formulated: (1) What are the elements of the CSR concept? (2) What methodologies or tools are used to implement CSR in companies? (3) How are the impacts of CSR strategies evaluated? And, (4) How is sustainability considered in CSR strategies? The second step corresponds to the database selection. This study was focused on digital resources in the following databases: ProQuest, Science Direct, SciELO, Springer Link, and Google Scholar. As a third step, research terms were determined: "CSR definition", "CSR elements",

"CSR evolution", and "CSR context". The fourth step was applying the practical screening criteria as a publishing period from 2009 to 2020, and the language as only the articles published in Spanish and English.

The fifth step was the application of the methodological screening criteria. This step required using a "Findings Matrix", which contains information such as the publication year, author's name, document title, content information, and the abstract. These elements were used to perform a content analysis to determine if the articles contain relevant information for the research. After applying the practical and methodological screening criteria, an initial sample containing 47 articles was established (Appendix A). Moreover, life-cycle-based methodologies' guidelines documents and a CSR guideline were also included to incorporate the sustainable approach (e.g., Life Cycle Assessment—LCA, Organizational LCA—OLCA, Social LCA—SLCA, Social Organizational LCA—SOLCA, Ethos). The final sample of 47 articles and 5 guidelines for the literature analysis was determined.

The sixth step corresponded to the study of the selected literature. Each article was read, and its elements were identified and coded using an analysis scheme. This scheme was divided into four codes, i.e., Principles, Dimensions, Stakeholders, and Means, which were defined based on the results of the findings matrix of the previous stage. The Principles refer to the fundamental basis for decision-making or for determining behavior [22]. The Dimensions correspond to complex variables that can be individually analyzed using elements that indicate their response, i.e., through indicators [4]. Stakeholders refer to individuals or groups interested in any decision or activity of the organization [22]. Finally, the Means correspond to the method or manner of doing something [15].

Finally, the last step formulates the results. For this, quotes within each code were analyzed. Thus, a set of principles and stakeholders for the analytical scheme was obtained. Special treatment was given to the "Dimensions" code because this element included subcategories and indicators. In this context, the three sustainability dimensions, Economic, Social, and Environmental, were first considered a reference because they have a broader approach and provide methodologies for evaluation. However, after discussions with the research team, the Economic dimension was not considered. This decision was made because CSR practices are mostly related to financial performance, which does not require CSR practices for its development. Likewise, many economic aspects are included in the Social dimension. The analysis of the Economic dimension in CSR is open to further debate in future research. The study was performed with particular emphasis on strategies described in the Ethos guidelines to identify Means, Ethos is a widely used management tool that supports sustainability and CSR implementations [11].

This tool is structured in five organizational levels: 4 dimensions (strategic vision, governance, and management, social and environmental); 8 topics; 18 subtopics; 48 indicators, and 741 sub-indicators. Due to a large number of specific Means found, they were classified into macro activities to facilitate the presentation of results.

The LCA and OLCA guidelines were coded to identify subcategories and indicators of the environmental dimension. The results were then contrasted with impact categories and quantitative indicators subcategories of Ethos using a comparative

matrix. Thus, a set of environmental subcategories and indicators was obtained. LCA is a methodology that assesses environmental performance throughout the life cycle of a product or service considering its potential contribution to the categories of environmental impact, such as climate change, human and eco-toxicity, ionizing radiation, and resource depletion [39].

The benefits of this approach can be expanded to the organizational assessment. OLCA evaluates the inputs, outputs, and potential environmental impacts of an organization [42]. A broadly used environmental assessment method within LCA is ReCiPe, a method that transforms the long list of life cycle inventory results into a limited number of indicators. These indicators show the relative severity of an environmental impact category [34]. It determines indicators at two levels: 18 midpoint indicators that focus on individual environmental impacts, such as climate change or acidification, and 3 endpoint indicators that show environmental effects at three higher levels of aggregation: human health, biodiversity, and resource scarcity [20].

Ethos, SLCA, and SOLCA guidelines were used to identify the subcategories and indicators of social dimensions. SLCA is defined as a methodology to assess the positive and negative social and socioeconomic impacts of products and services throughout its life cycle, focusing on people [40]. SLCA has links to the SDGs and is considered the best tool in social sustainability. SLCA assesses the social impact by classifying stakeholder groups as workers, consumers, local communities, children, society, and value chain actors [41]. These stakeholders are linked to 36 subcategories, which are measured by 205 social indicators. SOLCA has been recently developed as a complement to SLCA with a perspective beyond the product, i.e., the organization as a whole [43].

This methodology assesses the social performance of the organization, considering a life cycle perspective. While SOLCA is organized based on the subcategories, indicators, and stakeholders used in SLCA, Ethos is organized into dimensions, sub-dimensions, indicators, and sub-indicators. The strategic vision, governance, and social dimensions of Ethos (37 indicators) and SLCA (36 subcategories) were selected as inputs for the social dimension. Three types of relationships were identified between the SOLCA subcategories and the Ethos indicators. That is fully matched, partially matched, and entirely new subcategories. A set of subcategories was obtained to consider these relationships and to measure the social CSR dimension.

2.2 Analysis of CSR Implementations of Local and Regional Cases

The second stage of the study consisted of analyzing CSR implementations in local and regional case studies. To do this, five case studies were selected, three local (Ecuador) and two regional (Latin America), considering service and production enterprises. The selection criterion for the local case studies was the position (best,

Table 1 Local and regional CSR reports analyzed

Country	Local cases			Regional cases	
	Ecuador			Chile	Mexico
Company	Pronaca	Adelca	CNT	BCI	Grupo Bimbo
Product/Service	Food	Steel	Telecommunications	Financial	Food
Year of creation	1979	1963	2008	1937	1945
Number of employees	7905	1573	8941	11209	133824
Year of report	2018	2017	2017	2019	2019

average, and worst) held by Ecuadorian enterprises in the "Ranking of Corporate Reputation in 2019" [30].

For regional cases, the position (best and worst) occupied by the Latin American countries in the "Sustainability Goal Development Index and dashboard 2019 report" was used. Then, from these countries, an enterprise was selected according to its "Ranking of Corporate Reputation in 2019". For local cases, the enterprises Pronaca (ranking two), Adelca (ranking 51), and the National Telecommunications Corporation-CNT EP (ranking 83) were selected. For regional cases, Chile and Mexico were selected as the best- and worst-performing countries. Consequently, the companies Chile's Credit and Investment Bank (BCI) and Grupo Bimbo from Mexico were chosen. Table 1 shows general information on comparative analysis [2, 9, 16, 18, 35]. Then a verification matrix was built from the sustainability reports of the case studies and the analysis scheme established in the first phase.

2.3 Balanced Scorecard

Finally, the third stage of this study consisted of integrating the elements identified in the analysis scheme in a management dashboard. To this end, the following steps were performed. Firstly, a literature review similar to that described in Sect. 2.1 on BSC and SBSC was conducted, focusing on their architectures, generic objectives, and indicator categories. Four research questions were formulated: (1) What are the general objectives of a BSC? (2) What are the metrics used in a BSC? (3) What are the architectures behind an SBSC? (4) How can a CSR perspective be integrated into a BSC? To answer these questions, the following databases, Science Direct, Springer Link, and Google Scholar, were used. Likewise, the subsequent search terms were utilized: "SBSC architecture", "BSC indicators", and "BSC objectives". Additionally, the same practical and methodological screening criteria described in Sect. 2.1 were used to obtain a final sample of 12 articles (Appendix B).

Each selected article was reviewed and analyzed. Two summary matrices were developed. The first matrix contains the main SBSC architectures and their characteristics, while the second matrix includes generic BSC objectives and indicators.

Secondly, elements for the social and environmental evaluation of CSR were incorporated into the generic goals and indicators categories found in the literature of four traditional BSC perspectives, i.e., Financial, Customer, Internal Process, and Learning and growth. For the perspectives of Social and Environmental sustainability, the subcategories of indicators were taken from the element called "Dimensions" identified in the proposed analysis scheme. Their generic objectives were presented according to these indicators. Finally, based on the definitions and characteristics of the other CSR elements identified, and the discussions with the research team, the principles, means, and stakeholders were also incorporated into the proposed SBSC structure. It is essential to mention that the interactions among indicators, objectives, and perspectives were not yet considered in the SBSC.

3 Results

The results are presented in three parts. First, the outcomes of the literature review and the proposed analysis scheme are presented. Secondly, five case studies of CSR implementations in Ecuador and Latin America are analyzed. Finally, based on the findings in the literature review, the CSR elements are incorporated into an SBSC structure.

3.1 CSR Literature Review

The resulting literature review of CSR showed that although a large number of studies focused on CSR were found, most of them offer different conclusions about its definitions and core underpinning. However, it is possible to identify a group of four elements with similar characteristics. The identified factors are Principles, Dimensions, Stakeholders, and Means, which can be employed to analyze CSR implementations. In addition, it was found that the Means are the link between Principles, Dimensions, and Stakeholders. They describe the actions that enterprises take to achieve CSR goals. Many enterprises implement CSR strategies by using tools such as Ethos or the Global Reporting Initiative (GRI), which provide metrics for evaluating CSR strategies and incorporate some aspects considered in the sustainability assessment. Finally, an analysis scheme was proposed to organize and analyze the CSR information found. In this context, 18 principles, 11 stakeholders, and 18 subcategories of the social dimension were identified. Regarding the environmental dimension, 7 subcategories and 24 means were identified for the analysis scheme. Figure 2 presents the CSR elements organized into three groups: principles, stakeholders, and dimensions (subcategories and indicators). In turn, each element is divided into three categories: only present in CSR, only present in Sustainability approaches, and present in both. Figure 3 presents the macro activities identified as commonly carried out for CSR implementations.

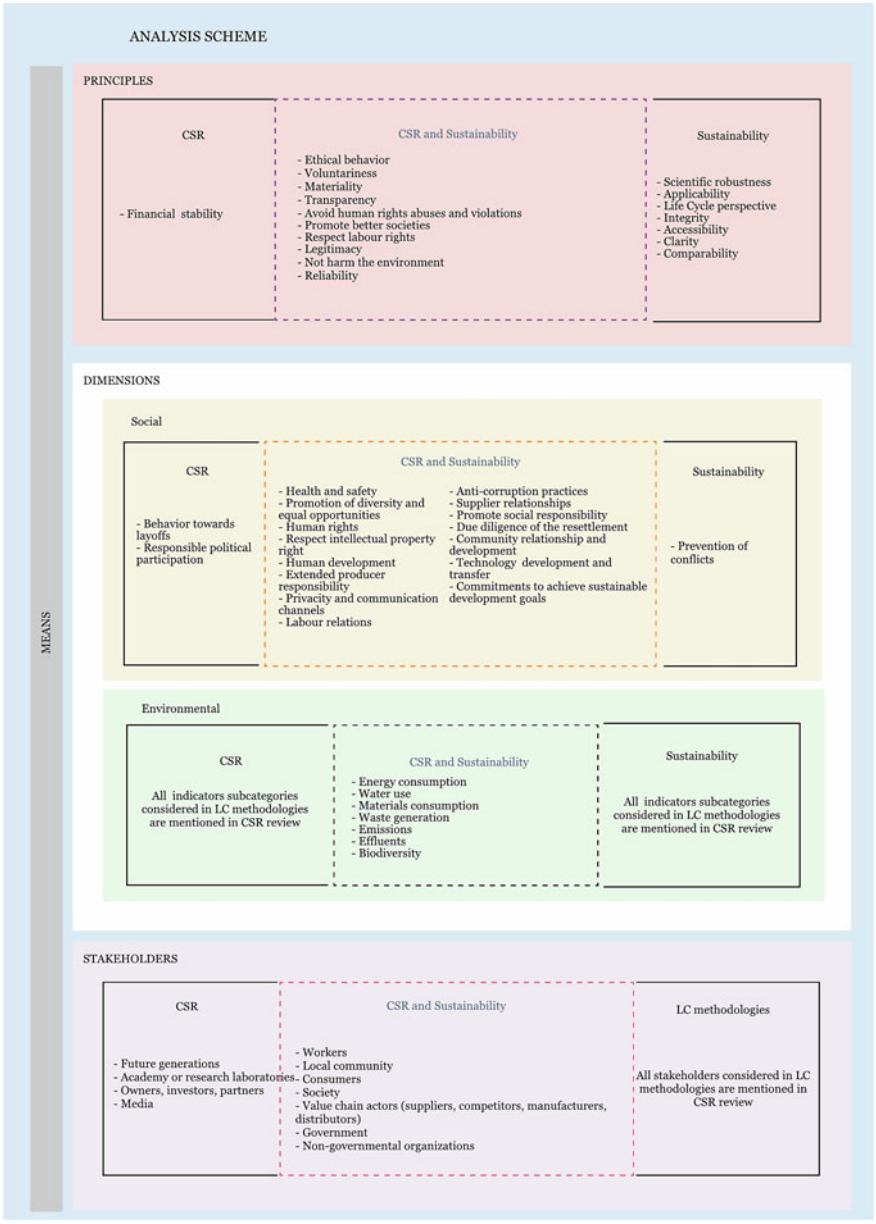

Fig. 2 The resulting CSR analysis schema

Fig. 3 Commonly suggested means

3.2 Analysis of CSR Implementations of Local and Regional Cases

The review of the local and regional case studies showed that most of the elements of the analysis scheme were identified in the CSR implementations. Additionally, the principles, stakeholders, and social and environmental subcategories and indicators can be classified into two levels, explicit and implicit. "Explicit" when they were easily identifiable in the reports and considered priority in the actions of the company. "Implicit" when they were found only in some specific practices described in the reports. Figure 4 shows the principles identified in the case studies, distinguishing both implicit and explicit. Findings indicate that 15 out of the 18 principles identified in the analysis schema were mentioned at least once in the business reports, and companies consider, on average, five principles. In addition, the principles of Legitimacy, Scientific robustness, and Applicability were not identified in the case studies.

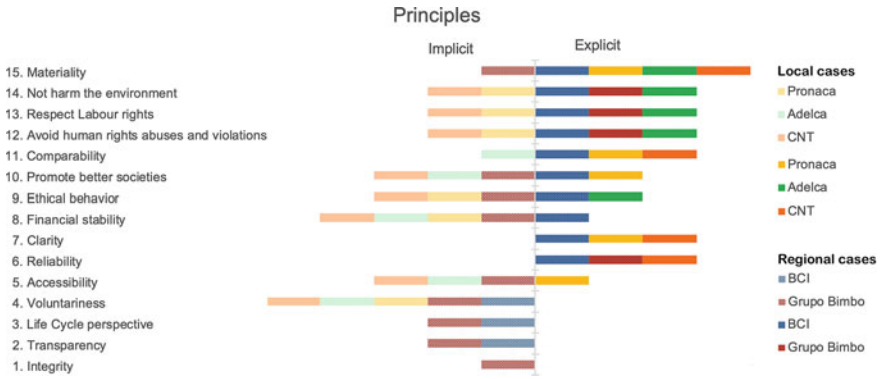

Fig. 4 Principles identified in the case studies

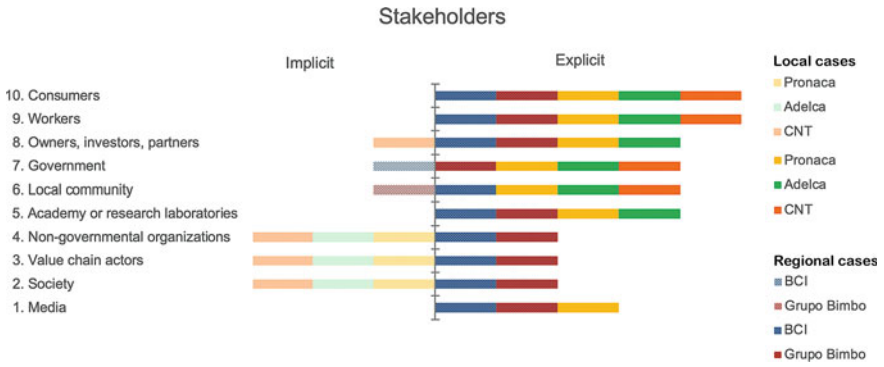

Fig. 5 Stakeholders identified in the case studies

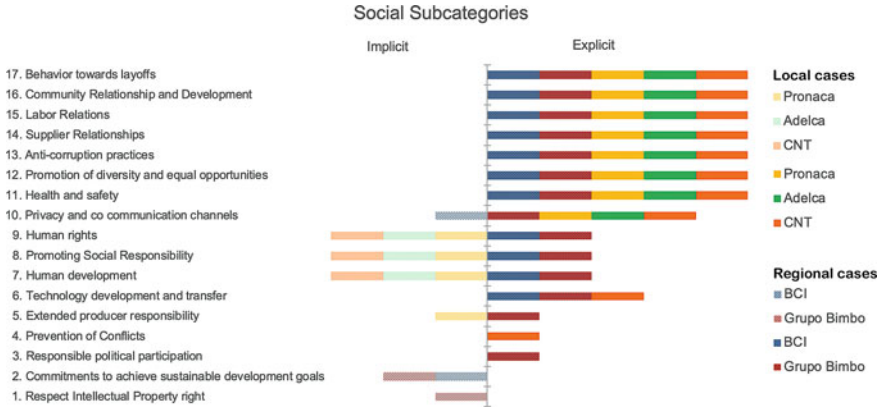

Fig. 6 Social subcategories identified in the case studies

Figure 5 shows the stakeholders identified in the case studies. Results indicate that 10 out of the 11 stakeholders proposed in the analysis scheme were found in the case studies. Consumers and Workers were identified as explicit in all enterprises; while, Future generation was not detected in any case. Other stakeholders, such as local community, government, owners, investors, and partners, were explicitly identified in four enterprises, and implicitly in one. Important to notice is that stakeholders Society, Value chain actors, and Non-governmental organizations were explicitly identified in regional enterprises, i.e., BCI and Grupo Bimbo. On the contrary, they were implicitly in local enterprises (i.e., Pronaca, Adelca, and CNT). Finally, stakeholders academy or research laboratories, and media were explicitly identified in four enterprises.

For the social dimension, 17 out of the 18 subcategories were found in the business reports, as shown in Fig. 6. Health and safety, Promotion of diversity and equal opportunities, Anti-corruption practices, Supplier relationships, Labor relations, Community relationships and development, and Behavior toward layoffs were identified

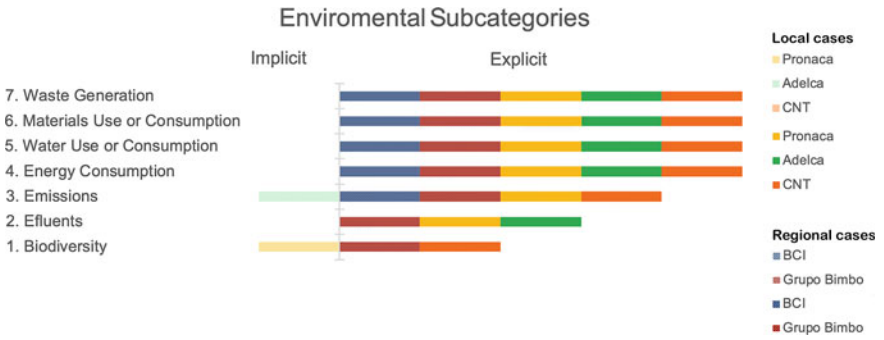

Fig. 7 Environmental subcategories identified in the case studies

as the most common social subcategories explicitly measured. Less common subcategories include Respecting intellectual property rights, Commitments to achieve SDGs, Responsible political participation, Conflict prevention, and Extended Producer Responsibility. Interestingly, Human development, Promoting social responsibility, and Human rights were explicitly identified in regional enterprises and implicitly in locals. Technological development and transfer and Privacy and communication channels were identified as explicit in three and four enterprises, respectively. The subcategory Due diligence of the resettlement was not detected in any enterprise analyzed.

Finally, for the environmental dimension, all seven subcategories proposed in the analysis scheme were identified in the five case studies, as shown in Fig. 7. The consumption of Energy, Water, and Materials, and Waste generation were determined as explicit environmental subcategories in all enterprises. Emissions, Effluents, and Biodiversity were explicitly identified in four, three, and two enterprises, respectively. Furthermore, Emissions and Biodiversity were also identified as implicit in Adelca, and Pronaca, respectively.

3.3 Sustainable Balanced Scorecard

In the BSC and SBSC literature review, 12 general architectures were identified, describing different manners on how the social and environmental perspectives can be integrated. Nevertheless, the "A0 architecture" was considered as the most suitable option to incorporate the identified elements of CSR in an SBSC. The reasoning behind this is that the A0 architecture maintains the traditional BSC perspectives and includes two independent sustainability perspectives, social and environmental. This allows maintaining its objectives and indicators, letting interactions with different new perspectives to be omitted in the first instance. Therefore, it was decided to use the A0 architecture, since this study did not analyze the formulation of strategies and interactions between the different BSC perspectives. Within the analysis, 45

Table 2 Generic objectives and indicator's categories of traditional BSC

Financial perspective	Customer perspective	Process perspective	Learning and growth perspective
Generic objectives			
Improve profits Reduce operational cost Gain financial budget Environmental cost savings Costs related to social impact Labor cost savings Increased revenue	Increasing the market share Improve customers' loyalty Improve the quality of services offered Link enterprise to Sustainability Expand the market niche Improve the customer's perception of product Customer attraction and retention Improve response time Provide new products Achieve customer satisfaction Improve the image of the enterprise Improve client management	Improve the quality of services and products Reduce the time of a process Develop new products Increase investment in new products Modernize the administrative structure Improve safer warehousing and transportation Provide an efficient process Improve human resources management Increase productivity Improve delivery system Improve product design process Promote continuous improvement Develop the support system	Improve the skills of employees Improve security Improve infrastructure Ensure employees well-being Efficient resource planning Obtained certifications Develop the support system Improve employees' retention Improve employee productivity Strengthen IT Culture Improve competencies Improve worker motivation Improve teamwork
Generic indicators categories			
Revenue grows Productivity grows Asset utilization Return on Investment Annual cash flow increase Sales growth Payback period Cost of fines Energy costs Operating expenditures Cost of employee benefits Costs legal actions Total tax paid Total sales	Market share Customer acquisition Customer retention Customer satisfaction Customer profitability Percentage of sales to new customers Customer referrals New product offers to customers Product attributes Customer relationship Average annual number of customer complaints Customer involvement in decision making	Innovation process Operations process Post Sale service process Cost indicators Quality indicators Time indicators Time to process the customer order Annual number of stock-outs for an order Percentage of all deliveries Time of launch new products to market	Employee retention Employee productivity Employee satisfaction Employee potentials Technical infrastructure Climate for action Employee turnover Research & development Employee knowledge sharing Labor force skills Effectiveness of training

generic objectives and 38 categories of generic indicators of the traditional BSC were identified and reported in Table 2.

The literature indicates that the Financial perspective focuses on improving profits. The Customer's perspective is focused on achieving customer satisfaction, improving

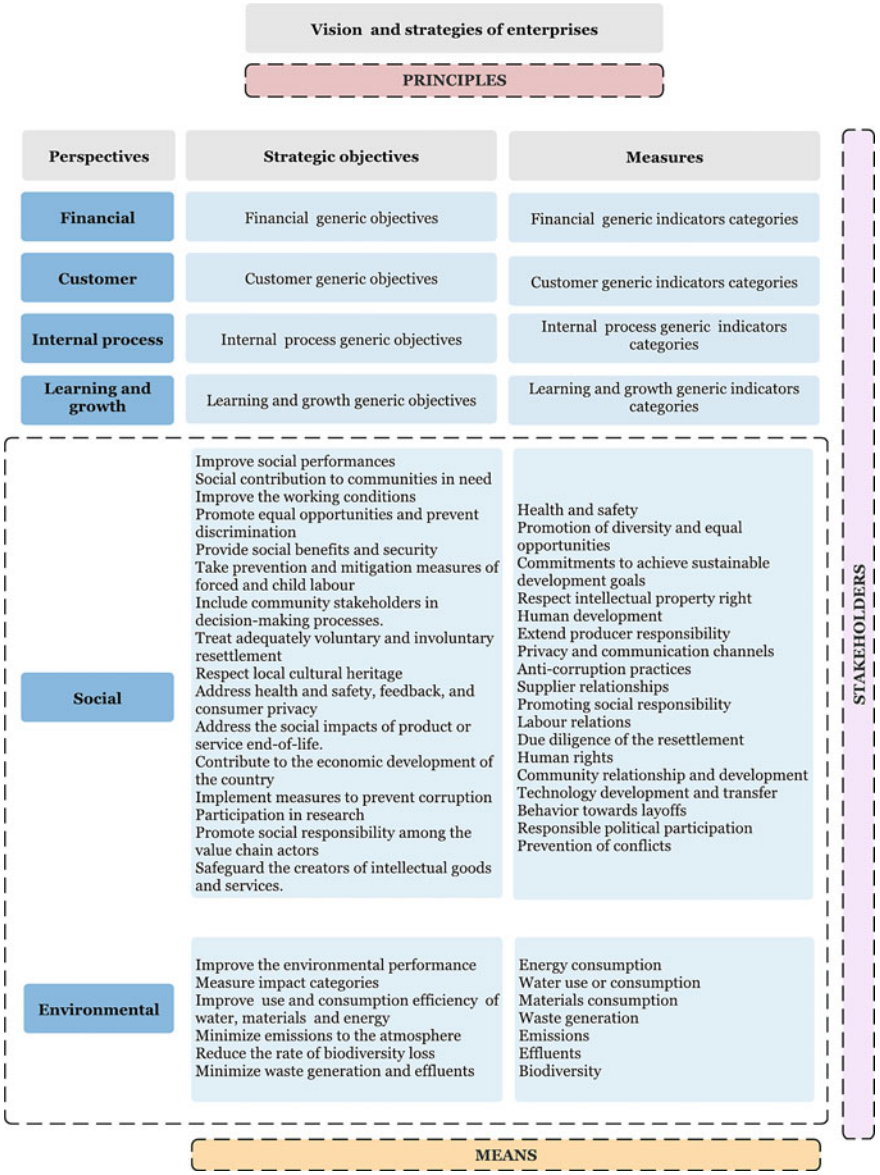

Fig. 8 Proposed SBSC framework

the quality of the services offered, and increasing market share. The Internal process perspective focuses on providing efficient processes.

And the Learning and growth perspective focuses on improving workers' knowledge, skills, and competencies. For the social and environmental aspects, 16 and 6 objectives were proposed, respectively, according to the subcategories and indicators identified in the CSR elements. In general terms, the Social perspective focuses on the well-being of stakeholders, and the Environmental perspective on improving business environmental performance. Principles were incorporated as a baseline of the enterprise vision and strategies since they are considered as the fundamental basis for decision-making.

Stakeholders were included across the six SBSC perspectives because they are deemed to be interested in any decision or activity of the organization. Eventually, the Means were incorporated at the end of the SBSC structure as it is considered a manner to operationalize and achieve business objectives. The resulting SBSC framework is illustrated in Fig. 8.

4 Discussion and Conclusions

The literature review on CSR showed no clear definition of CSR and its core underpinning [17]. However, the CSR elements identified in the proposed analysis scheme significantly facilitated the analysis of CSR approaches. In this sense, the analysis scheme corresponds to a first proposal to support CSR understanding and homogenization that needs to be further developed in future studies. Further investigation should be performed to create an analysis framework that facilitates the evaluation of CSR practices and strategies through the lenses of sustainability. The literature reviewed also showed that more and more businesses use sustainability dimensions to develop and report CSR practices [1]. Sustainable dimensions, i.e., Social, Environmental, and Economic, establish links between resources and the impacts associated with the use of these resources by particular sectors or production locations along the supply chain to the final consumer [45].

However, the role of the economic dimension is not exact in the CSR approach, as it is mainly related to financial indicators. The economic dimension refers to achieving business efficiency by providing goods or services without violating social or environmental values. On the contrary, financial performance refers to improving the company's profits [10], which are achieved with or without CSR practices. Some sustainable elements are already considered in current CSR approaches; however, they have a different application level. LC methodologies incorporate indicators to assess and report the social and environmental performance of products and services [41].

CSR approaches present indicators focused on improving their performance in enterprises through specific practices related to their interests but not with the measurement of impact categories and long-term practices [3, 21].

Additionally, several conventional implemented means are based on legal and philanthropic compliance, whereas many CSR means only translate into basic legal requirements and charitable activities. Moreover, it was found that the six stakeholder groups are considered in both the sustainability and CSR approaches. However, similarly, as with principles, dimensions, and means, each approach contemplates them differently; i.e., CSR considers stakeholders in specific practices, while the sustainable approach measures the impact associated with each stakeholder category.

Second, the analysis of five case studies at the national and regional level showed that several CSR elements identified are already implemented by enterprises and, therefore, evidence that these case studies also incorporate sustainability aspects. However, the CSR practices implemented in enterprises are focused on achieving an excellent performance of the specific indicators. They do not take into account the integrated impact in the social and environmental dimensions. As a result, these actions have a low impact level. Both local and regional enterprises considered different principles, stakeholders, indicators, and means that showed the CSR implementation according to their specific context.

This implies that some CSR elements can be disregarded or considered following the enterprises' interests that commonly focus on promoting the corporate image. As a result, the application level of CSR in local and regional enterprises remains unclear. Moreover, CSR reports are commonly used in large enterprises, which have the resources to incorporate programs, projects, and other actions related to CSR. However, this does not represent the reality of other companies of different sizes. Future research is needed to identify the main differences in the CSR application among regions and diverse corporate sizes.

Finally, the SBSC is considered an essential tool to design and achieve the key objectives of corporate sustainability management and represents a suitable tool to incorporate CSR strategies. From both the social and environmental dimensions, the subcategories and indicators identified in the analysis scheme facilitated the proposal of the strategic objective and the inclusion of the sustainability approach.

The operationalization, visualization, and monitoring of indicators are crucial for corporate information with added value and transparency and for establishing strategic objectives that help companies implement an efficient sustainability strategy. However, it is necessary to consider the interactions between all perspectives of an SBSC [21]. According to Goldratt, the A0 structure leads the corporate strategy to improve profits now and in the future and includes two new Social and Environmental perspectives that establish sustainability criteria. In this manner, the A0 architecture maintains the traditional BSC hierarchy, as described in several studies, such as [8, 21, 38]. It also supports decisions that require trade-offs, considering a suitable design to integrate other perspectives, without changing the strategic maps of the companies [23]. Nevertheless, some authors believe that an adequate manner of implementing the sustainability approach corresponds to less traditional architectures that include this perspective transversely in all BSCs [19].

Thus, to determine a suitable option, it is necessary to analyze the specific objectives of each enterprise and their interactions with the indicators. Given that this study theoretically links CSR with sustainability indicators to structure an SBSC that man-

ages CSR, the selected architecture was adequate for this first version; however, more specific analyses should be carried out in future research.

In conclusion, in this study, the main CSR elements were identified, and the first version of an analysis scheme with a sustainability approach was proposed. It was found that the four CSR elements identified: Principles, Dimensions, Stakeholders, and Means help to analyze sustainability aspects in regional and local case studies. This finding shows that there are sustainability aspects embedded in the analyzed CRS implementations. However, CSR practices are specific to each enterprise and typically have limited impact. Additionally, the identified CSR elements were incorporated into a management dashboard structure. The results showed that the subcategories of social and environmental indicators contribute to the strategic objectives of the business formulation. The other elements identified are well adapted to fit the general structure of the SBSC.

Appendix A—Full list of references read in the literature review for the CSR analysis scheme The list of sources used in the literature review for the CSR analysis schema can be found online at https://imagineresearch.org/wp-content/uploads/2020/07/CSR-Appendix-A.pdf

Appendix B—Full list of references read in the literature review for the SBSC scheme The list of sources used in the literature review for the CSR analysis schema can be found online at https://imagineresearch.org/wp-content/uploads/2020/07/CSR-Appendix-A.pdf.

Acknowledgements This research was carried out under the projects "Enhancing the Social Value of the Circular Economy in Latin-American" and "Incorporating Sustainability concepts to management models of textile Micro, Small and Medium Enterprises (SUMA)" funded by the Flemish Interuniversity Council (VLIR) and the Research Direction of the University of Cuenca (DIUC).

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M. V. García et al. (eds.), *Advances and Applications in Computer Science, Electronics and Industrial Engineering*, Advances in Intelligent Systems and Computing 1307,
https://doi.org/10.1007/978-981-33-4565-2