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Presentation of the Content

In the first article we present, *Architectural Design of a Cyber-Physical System (CPS) for Irrigation Automation in Ornamental Horticulture* by SALTOS-PINEDA, Luis Manuel, FIGUEROA-MILLÁN, Patricia Elizabeth*, AMEZCUA-VALDOVINOS, Ismael and CHÁVEZ-VALDEZ, Ramona Evelia, with adscription in the Tecnológico Nacional de México / I.T. Colima, as next article we present, *Prediction model of the terminal efficiency of Computer Engineering at the Autonomous University of Tlaxcala applying Data Mining* by SÁNCHEZ-SÁNCHEZ Norma, MORA-LUMBRERAS, Marva Angélica, SÁNCHEZ-PÉREZ, Carolina Rocío and DÁVILA-GUTIÉRREZ, Blanca Leticia, with adscription in the Universidad Autónoma de Tlaxcala, as next article we present, *Prototype of a mobile application for monitoring childhood immunizations* by SALAZAR-CASANOVA, Hermes, MENDOZA-SAN JUAN, Luis Alberto, MENESES-FLORES, Arturo Elfego and JUÁREZ-CASTILLO, Efrén, with adscription in the Universidad Tecnológica de la Huasteca Hidalguense, as last article we present, *Geolocation mobile application for delivery of agrochemical packages* by OCHOA-ORNELAS, Raquel, ALTAMIRANO-GODINEZ, Naylea and RODRÍGUEZ-SANDOVAL, Ever Essaú, with adscription in the Tecnológico Nacional de México/Instituto Tecnológico de Ciudad Guzmán.

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Architectural Design of a Cyber-Physical System (CPS) for Irrigation Automation in Ornamental Horticulture

Diseño Arquitectural de un Sistema Ciber Físico (CPS) para Automatización de Riego en Horticultura Ornamental

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Abstract

The Internet of Things (IoT) in agriculture has contributed to the efficient and effective automation of agricultural production processes. However, automating irrigation is a complex task due to the technological adoption challenges faced by producers using unsustainable, inefficient, and ineffective conventional methods, as well as the actions it entails in the environment based on sensed data. Therefore, as a proposed solution, the design of a Cyber-Physical System (CPS) for automating irrigation in ornamental horticultural production is presented. This system follows a spiral methodology, allowing the efficient construction of the prototype due to its iterative and sequential capabilities. The result is the modeling of the irrigation system based on a CPS, which will enhance water usage efficiency, reduce labor efforts and production costs, providing a mechanism for preventing and controlling mite-type pests in ornamental horticultural production.

Irrigation Automation, Cyber-Physical System, Pest Control

Resumen

El Internet de las Cosas (IoT) en la agricultura ha contribuido a la automatización eficiente y eficaz de procesos de producción agrícola. Sin embargo, la automatización del riego es una tarea compleja tanto por la dificultad de adopción tecnológica por parte de los productores que emplean procesos convencionales insostenibles, ineficientes e ineficaces como por la actuación que implica en el entorno con base en los datos sensados. Por lo tanto, como propuesta de solución se presenta el diseño de un Sistema Ciber Físico (CPS) para la automatización de riego en la producción hortícola ornamental. Éste sigue una metodología en espiral, ya que, gracias a su capacidad de iteración y secuencialidad permitirá construir de manera eficiente el prototipo de dicho sistema. Como resultado se obtiene el modelado del sistema de riego basado en un CPS el cual contribuirá a la eficiencia del uso del agua, reducción del esfuerzo laboral y costos de producción, proporcionando un mecanismo para la prevención y control de plagas tipo ácaro en la producción hortícola ornamental.

Automatización de Riego, CPS, Control de Plagas

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Introduction

Horticulture is a key field related to vegetable crops and the embellishment of physical spaces, which, when integrated with different areas, contributes to the creation of employment, educational, industrial, and technological opportunities (Morales Lugo et al., 2020). In this field, as in the production of any agricultural product, pest control, inefficient water use, and the automation of agricultural tasks are significant in everyday challenges. It is for this reason that agricultural automation is capable of increasing sector productivity. The application of IoT is viewed as the paradigm that could achieve a 70% increase in global food production by 2050, meeting the demand needs of an estimated population of 9.5 billion (Tovar Soto et al., 2019).

Implementing technologies derived from IoT improves the efficiency of traditional agricultural activities, with the use of around 30,000 million IoT devices in 2020. This implies the consideration of their integration with artificial intelligence, 5G technology, Edge Computing, among others, to offer innovative solutions (López & Contreras, 2020). Consequently, irrigation systems in the agricultural sector have been significantly influenced by IoT, allowing for improved water management and achieving efficient and precise use of this resource (Karpagam et al., 2020).

Moreover, the implementation of IoT-based innovative solutions to resolve a specific agricultural problem determines the technologies needed for its successful implementation. Among these technologies, CPS are used, combining physical and digital components to interact with the real world through sensors and actuators (Dumitrache et al., 2017). CPS aim to facilitate the programming and control of their components, adapting to a variety of situations based on autonomous decision-making algorithms. This results in a transformation of the security, usability, and scalability of any project in which they are implemented (An et al., 2017). Additionally, the diverse approaches to CPS design are shaped by two fundamental aspects: systems requirements, such as the imperative to operate in real-time, ensure safety, or exhibit resilience, and the specificity of the application itself, which may span domains such as manufacturing, electric grids, and so on (Shah & Singh, 2023).

Thanks to the adaptability of CPS, the agricultural sector is an area of opportunity for its application. Its implementation in this sector can help improve irrigation efficiency, natural resource management, crop quality, and production profitability, contributing to cost reduction and enhancing agricultural sustainability (Tovar Soto et al., 2019). Furthermore, effective water resource management in agriculture is challenging, hence CPS systems emerge as an integral solution to deal with this problem (Tushar et al., 2023). Thus, horticulture is considered a key agricultural sector involved in supplying fresh products to market, positively impacting the quality of life and benefiting the mental health of the population.

In the same way, the ornamental sector as part of horticulture holds a globally significant socio-economic value (Bulgari et al., 2021); that is why, ornamental plants receive the same care regarding production and pest control as any other agricultural product. The difference lies in their presence in more segmented spaces to facilitate their production. Therefore, horticulture is considered one of the agricultural branches with great potential for the application of CPS, given its composition of small greenhouses with a large number of plants sharing similar characteristics, making it conducive to the implementation of controlled environments with the assistance of technologies (López Amaya & Montero Flores, 2018).

Thanks to CPS, sustainability in the agricultural sector and pest prevention can be achieved through irrigation control, depending on the type of crop. Ornamental plants, in particular, are an easy and quick target for pest incidence, especially by types of mites, causing concern in greenhouse environments. Consequently, the proliferation of these pests leads to defoliation, resulting in the loss of plant vigor and a reduction in flower production (Cachago Llamatumbi, 2019).

An example of this broad category of pests is the red spider mite. It is not only a significant pest for ornamental plants, but also stands out for its high resistance to commercial acaricides, leading to the use of increasingly toxic treatments for its control.

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Furthermore, this mite species has gained global notoriety as it has primarily affected ornamental crops in greenhouses and open fields (Vitela García, 2019). In a humid environment, this organism does not thrive, so it is recommended to clean the affected areas with water to reduce dust on the foliage and consequently prevent mite formation. It is considered a pest favored by warmth and dryness in the environment. In fact, in a crop with sprinkler irrigation, there are no red spider mites (Jimenez Lara, 2022).

For this reason, to counteract this issue, the implementation of controlled sprinkler irrigation systems through CPS can be a method of control to reduce the distribution of the red spider mite and other species of mites that proliferate in dry and dusty areas. These systems contribute to the preservation and improvement of the aesthetics and value of ornamental plants. This involves washing and cleaning, as well as maintaining a temperature below 30°C and relative humidity above 65%. Below this humidity level, the development of these organisms is facilitated (Cachago Llamatumbi, 2019).

Moreover, the applicability of CPS in irrigation automation extends beyond, achieving efficiency in water usage by maintaining precise control over the supply, thus avoiding excessive waste and insufficiency of these water resources in irrigation (Karpagam et al., 2020). With this automation, the decision algorithms employed in CPS, based on information obtained from associated variables, determine when and how much water to supply to crops to optimize growth and minimize resource wastage (Meena et al., 2020).

The models developed to manage uncertainty are key tools for precisely determining the optimal water supply for each crop through irrigation systems, thereby increasing the sustainability of water use in agriculture (Tushar et al., 2023). Furthermore, it is crucial to underscore organic and sustainable agricultural practices, along with research aimed at developing more efficient and environmentally friendly methods for fertilization and pest control (Hamzah et al., 2023).

Therefore, this article proposes the design of a CPS for the automation of irrigation in ornamental horticulture, aiming to efficiently utilize water resources in the production of ornamental plants. As a result, the implementation of this proposal aims to provide a series of significant benefits in the field of irrigation automation that go beyond mere labor reduction. Some of these benefits include:

– **Optimization of water consumption** by allowing precise and controlled use of irrigation water based on data obtained from sensors, providing an analysis of environmental conditions. This, in order to minimize resource waste and ensure that plants receive the appropriate supply of water when needed.
– **Labor saving** by reducing the time and management associated with manual irrigation.
– **Technological advancement and sustainability** by introducing automation mechanisms into strategic crop irrigation processes, contributing to the sustainability of the sector, promoting environmentally efficient practices, and resource use.
– **Prevention of mite-type pest formation** by maintaining a suitable environment to reduce the probability of their development and proliferation

For its validation, this proposal is based on a case study in the state of Colima, Mexico, specifically in the rural production society “Ornamentales de Colima SPR de RL de CV ", founded in 2009 with the purpose of commercializing ornamental species. The society consists of ornamental producers associated with the “Consejo Estatal de Productores de Plantas de Ornato de Colima " (COEPPLANTS). Due to its growth and expansion, challenges related to the efficiency of its operations emerged, with one of the main issues being pest control and irrigation management.

The present article is organized as follows: the “Literature review” section provides an analysis of research works aiming to offer a solution primarily for irrigation automation; the “Methodology” section outlines the architectural design of the CPS proposed for irrigation automation, employing a prototyping approach that accommodates time constraints.

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The "Results" section ultimately presents the obtained design encompassing syntax, semantics, and network communication architecture of the CPS. It includes the connection diagram of the IoT device, facilitating cyber-physical control and monitoring. The Kalman algorithm is utilized as a statistical estimation algorithm enabling process automation; the "Conclusions" section discusses the potential benefits of this proposal in optimizing irrigation and preventing pests in ornamental horticulture. It also explores potential future directions for the deployment, expansion, and enhancement of this system.

Literature review

The integration of technologies such as IoT, WSN and CPS have contributed to various agricultural processes including automation, pest control, supply and resource management, supporting efficiency, productivity and sustainability in this sector.

In the current context, where water availability has become an increasingly scarce and valuable resource, it is essential to seek methods and technologies that optimize water use in agriculture. Therefore, in this literature review, some solutions applied mainly to irrigation automation are described.

For example, Hurtado et al. (2023) present a prototype of an automated flow irrigation system for home gardens to improve their productivity when facing climate constraints. This allows remote monitoring of ambient temperature and humidity through the DHT11 sensor and soil moisture through a humidity probe; however, the relative humidity and temperature sensor has shown an accuracy of ±5% in humidity and ±2°C (ETC2, n.d.), unlike other sensors in the market with higher accuracy and resolution. On the other hand, they employ Arduino's IT Cloud as a graphical interface, limiting only to data visualization and performance without offering persistent storage for the generation of a historical record (Arduino, n.d.). As communication technology they employ WiFi between the monitoring station and the Arduino cloud. Soil moisture monitoring was achieved by conditional algorithms running a homemade water pump designed in 3D prototyping, lacking a correction mechanism for atypical or noisy measurements.

On the other hand, Cortés et al. (2020) presents an IoT prototype for automated drip irrigation. The prototype uses an Arduino microcontroller and the ESP8266 WiFi module, together with DHT11 sensors for temperature and humidity, which, as mentioned, have disadvantages in accuracy and resolution; in addition, the FC-28 sensor for soil moisture, recording the data in the ThingSpeak platform, which allows the download of information for statistical purposes. The decision making for irrigation is based on an algorithm governed by thresholds to control the operation of the solenoid valves within the system, but there is no evidence of error control or correction for atypical measurements.

Ñamo, M (2019) presents an automated irrigation and remote control system that leverages IoT technology. This one describes the software design of the system, detailing the mobile application designed in the Android Studio IDE and the communication between nodes by creating MQTT clients. For its implementation, Raspberry Pi 3 and Zoul modules are used to register variables and establish communication using the 6LoWPAN protocol stack. Sensing is performed using the SHT25 humidity and temperature sensor and a generic water level sensor.

Similarly, Parra, L (2020) presented an irrigation monitoring and control system designed for a specific farm. The work addresses the problem of accessibility to the existing irrigation system, proposing a solution that combines technologies, network architectures and automation strategies such as the use of information managers. For the implementation of the system, programming languages such as Java and relational databases through DerbyDB were used. In addition, frameworks such as Restlet and Hibernate were used for authentication and interface management. Being all these conformed in an Arduino Uno that contains a RESTful web service that is controlled manually for the activation of the irrigation solenoid valves; however, this work does not specify the type of resulting irrigation.

Chiquito Guale & Paguay Totoy (2020) presented an article that proposes the implementation of an automated irrigation system to optimize water consumption while ensuring adequate crop hydration.

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Unlike traditional practices, this system is based on decision making through a conditional algorithm, based on soil moisture levels. It makes use of a Raspberry Pi to process data obtained from the FC-28 moisture sensor, a 13HP water pump driven by a solenoid solenoid valve and a control sensor for water level.

As can be seen, previous works have made significant advances in irrigation automation in various contexts, especially in agricultural applications. However, it is important to note that most of these studies have used sensors with a high level of noise in the measurements such as the DHT11, without the implementation of algorithms that allow smoothing the calibration range in the measurement; which limits the efficiency in irrigation systems by presenting possible unrequired actions in the face of atypical measurements, highlighting the need to improve the processing of the data collected.

In addition, to our knowledge, the solutions presented do not address a critical aspect: the prevention of mite pests through irrigation actions that control the production environment. As a result, the integration of pest control strategies into automated irrigation systems is an area of research that could significantly benefit agriculture, addressing both adequate water quantity and crop protection.

Methodology

The research and development methodology is present below.

Research methodology

The architectural design of the proposed CPS is based on the technological research presented by De la Cruz Casaño (2016) in the field of engineering. This methodology aims to use knowledge as a basis for transforming reality, either through improvements in the existing or the creation of new elements such as machines, structures, software or processes. It comprises the following stages: study approach, which includes the formulation of the problem, objectives and their justification; theoretical framework, aimed at establishing the background, theoretical foundations and key definitions; hypothesis; design or development methodology, which includes the necessary resources, tools and materials; and finally, implementation and evaluation.

Development methodology

On the other hand, the construction of the CPS from design to deployment, follows the prototype development methodology, also known as the spiral model by Pressman (2022) (see Figure 1). The central concept of this methodology revolves around the idea that development is a continuous process and that the requirements can undergo modifications as the system construction progresses. Therefore, it is suitable for the development of prototypes or technological systems, such as the one presented in this work.

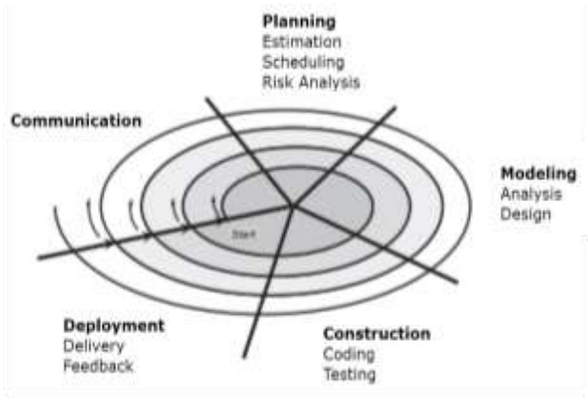

Figure 1 Representation of the development methodology
Source: Pressman (2022)

As depicted in Figure 1, the spiral methodology is based on an iterative, trial-and-error approach to system development. Given its incremental and iterative nature, it is divided into the following five stages:

1. *Communication:* this stage emphasizes the importance of clear and effective communication in delineating project objectives. Consequently, in designing the CPS, interviews were conducted with the case study of this technological research, ORNACOL. Through these interviews, the problems, scope and objectives of the research were identified, along with a survey of the functional and non-functional requirements of the system.

2. *Planning:* this stage defines project objectives, and a detailed plan is created, including a schedule of activities. Potential risks are identified, and alternative plans are developed. Thus, the scope of the project is specified and the results to be obtained are identified, from system design to deployment.

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3. *Modeling:* this stage provides detailed models of the system, which may include flow and sequence diagrams. These models allow understanding the system and anticipating problems before the construction phase. Therefore, in the scope of this article, all the diagrams that allow the modeling of the CPS are annexed, where each of the components, communication and network architecture, as well as diagrams and designs of the CPS prototype are identified.

4. *Construction:* in this stage the system is implemented, tests are performed to ensure its proper functioning. Due to the scope of this article on the architectural design of the CPS system, the construction phase is designated as future work and is outside the scope of this article. However, the tools used correspond mainly to irrigation sprinklers, solenoid valves, temperature and humidity sensors, and, finally, the statistical estimation algorithm.

5. *Deployment:* in this final stage, the project is installed in a production environment and put into operation. A final evaluation is carried out to ensure that the software meets the requirements and functions properly. However, considering the scope of this article, this stage is presented as future work.

The implementation of the spiral model involves a series of evolutionary deliveries in each iteration, leading to modeling with increasingly advanced features and specifications. In other words, the system versions become progressively more comprehensive with each iteration, approaching the goal. Therefore, this article presents the iteration corresponding to the architectural model of the CPS. In this regard, considering the scope of the paper and the development methodology, all necessary elements have been identified to establish the foundations of the proposed CPS architectural design, including the planning for its construction. The conceptual model of the architecture, messages syntax of sensed data, connection diagram of each entity into de CPS, and the design of the statistical estimation algorithm responsible for conditioning events for the control of the automated sprinkler irrigation system have been created.

These deliverables, described in the result section, represent significant advances in preparation for the construction stage, providing a solid foundation that details how future implementation will take place. This contributes to a design capable of extrapolation to other agricultural systems.

Results

This section presents the results of the architectural design of the CPS for ornamental horticulture irrigation.

Communication architecture design

The conceptual model provides a clear and abstract representation of the communication architecture and the interaction of the physical and digital components of the proposed CPS system.

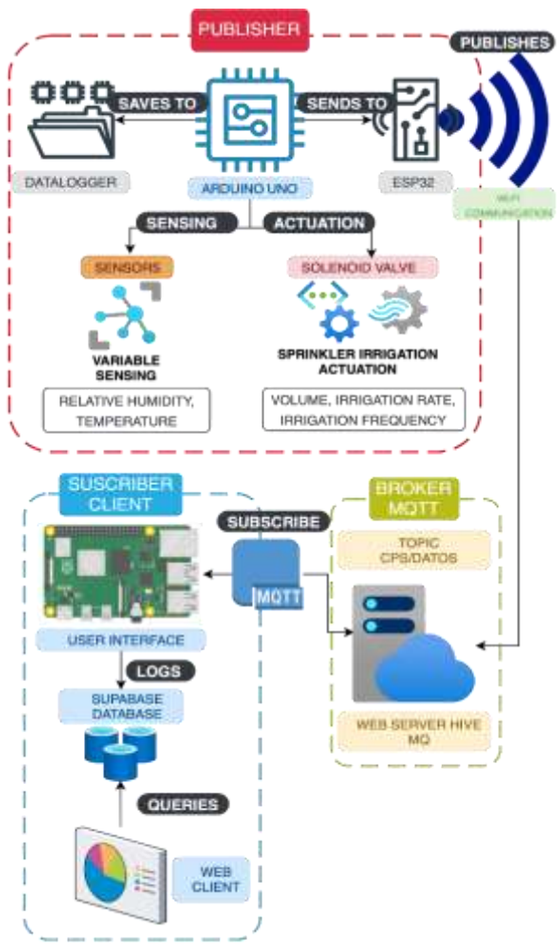

Figure 2 CPS architectural communication model
Source: Own Elaboration

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As depicted in Figure 2, the architecture of the CPS follows a publisher-subscriber communication model based on the MQTT (Message Queuing Telemetry Trasport) messaging protocol. The utilization of MQTT enhances the adaptability of the system for future expansions, enabling the incorporation of additional sensor nodes without requiring modifications to the architecture. Moreover, it provides communication advantages by being lightweight, secure, and ensuring quality of service. This communication model is represented by three modules: publisher, MQTT broker, and subscriber-client.

The publisher undertakes the collection and processing of sensed data such as temperature and relative humidity, as well as the actuation with the environment through a micro-sprinkler irrigation system. This system comprises an Arduino Uno microcontroller, a DHT22 temperature and humidity sensor, a flow sensor, a solenoid valve, and an adjustable flow sprinkler (see Figure 6). As a device overseeing critical activities, the DHT22 sensor has demonstrated reliable performance in diversus conditions, and it is particularly effective in environments where accurate measurement of humidity and temperature is essential. Thus, using this sensor and the Kalman statistical estimation algorithm, atypical measurements are smoothed and corrected, facilitating the automation of the irrigation system. This, in turn, allows for the determination of the irrigation rate and frequency to maintain a temperature below 30°C and a relative humidity above 60%, thereby contributing to pest control in environments prone to pests, such as the red spider mite, that proliferate in dry and dusty conditions.

The sensed data is transmitted via WiFi technology using an ESP32 microcontroller, enabling the publisher to send information to the HiveMQ broker (HiveMQ, s.f). The publication of temperature and humidity data is established using the JSON format for the generation of a historical record. This structure corresponds to a lightweight and easily readable data exchange format used for transmitting information between different components of a system, such as a client application and a server. The following is an example of measurement using the JSON format:

```
{
 "timestamp": 1631527512,
 "id_node":      30:AE:A4:07:0D:64,
 "measurements": {
        "temperature": {
                "value": 25.5,
                "unit": "°C"
         },
         "humidity": {
                "value": 60.2,
                "unit": "%"
         },
         "flow": {
                "value": 3.2,
                "unit": "l/s"
         },
         "solenoid_valve": true
  }
}
```

Figure 3 JSON structure for sending data to the broker
Source: Own Elaboration

As illustrated in Figure 3, the data transmission message structure is divided into three main objects: timestamp, corresponding to the UNIX timestamp format; id_node, representing the MAC address of the node responsible for transmitting the data; measurements, which encapsulates all the readings from sensors integrated in the system, specifying each sensor along with its corresponding measurement at the time of transmission.

This specifies a straightforward format for data exchange with the broker, which is received through a topic. This topic may be hierarchically segmented, with the first term corresponding to the overall system, followed by a "/" character to identify sublevels. Following the official recommendations of the HiveMQ broker, a topic defined as "CPS/data" is chosen, as the hierarchical levels established in the topic structure allow for control over the data. This choice aligns with best practices to ensure a clear and accessible subscription to the shared data.

Finally, the subscriber client is responsible for receiving notifications from the broker and recording the information in Supabase as a means of persistent storage. In addition to this, the web client enables ubiquitous access to CPS sensing resources from any location, device and at any time. With the retrieved information a user interface is established for dynamic data visualization.

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Design of the decision making algorithm

To ensure the decision making process regarding the operation of automated irrigation, the Kalman statistical estimation algorithm is employed. This algorithm, based on the sensing of humidity and relative temperature, will facilitate the activation and deactivation of the automated irrigation system. It considers the correction of atypical measurements by statistically relying on previous readings to reduce noise and identify abnormal measurements. Once the solenoid valve is triggered, the controlled water resource will pass through a flow sensor, measuring the amount of water being supplied.

To illustrate this decision making process based on the Kalman algorithm, the flowchart of the information flow process for the automated irrigation decision is presented (see Figure 4).

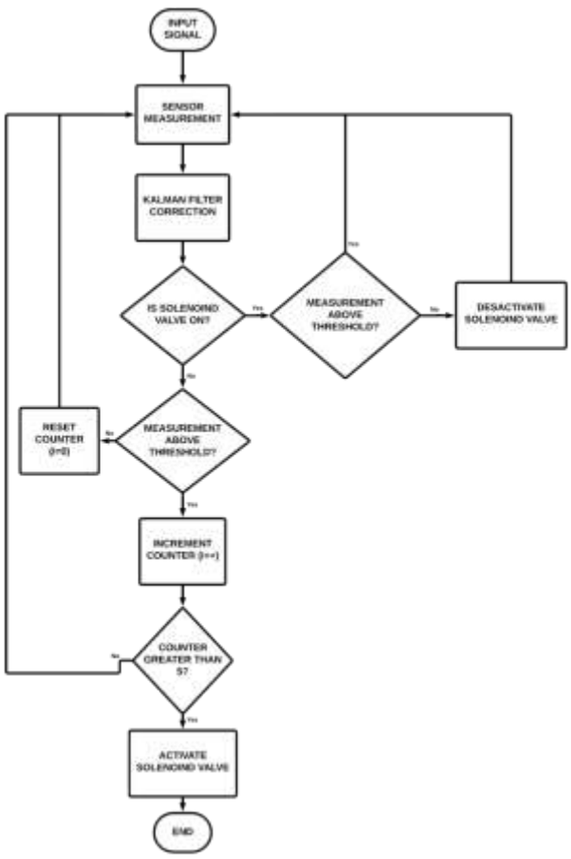

Figure 4 Flowchart of decision-making algorithm
Source: Own Elaboration

In the previous figure, the decision making process involves several steps. It starts with the measurement of variables by the temperature and humidity sensor.

Subsequently, these readings undergo processing through the Kalman filter, which is tasked with smoothing and correcting atypical measurements.

The first decision pertains to whether the solenoid valve is currently activated, as there are two different scenarios with distinct solutions. In the first scenario, if the solenoid valve is on and the measurement is already within the desired parameters, irrigation is deactivated. If the measurement is still unregulated, the process returns to the beginning of the measurement flow to continue monitoring.

The second scenario occurs when the solenoid valve is off. If it is off and the measurement does not meet the desired threshold, indicating proper control, a counter is reset, serving as a second control filter. If the solenoid valve is off and the measurement exceeds the threshold, the counter is incremented. Subsequently, it is checked whether the counter has surpassed a set value (e.g., greater than 5). If so, the solenoid valve is activated; otherwise, the process returns to the beginning of the flow, waiting for the measurement to continue above the threshold to keep increasing the counter and reach our desired second control filter for irrigation activation.

The Kalman filter is a technique that improves measurement accuracy by estimating the true value of a variable from noisy measurements. It operates in two phases: prediction, where an initial estimate of the value is made, and the variance is calculated, taking into account the uncertainty of the measured process; and correction, where a Kalman gain is calculated based on the variance of the initial estimate and the current measurement.

This gain is used to combine the previous estimate with the new measurement and calculate a corrected estimate of the true value. Subsequently, the previous estimates are updated, and both the original measurement and the corrected estimate are displayed. This technique is crucial in applications requiring precise measurements, such as irrigation control in IoT systems, as it helps reduce the effect of noise on measurements and provides more reliable estimates.

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Sprinkler system design

Regarding the design of the sprinkler system, the irrigation connection diagram is presented, playing a crucial role in understanding the infrastructure and its operation. This diagram provides a clear visualization of how all the components of the irrigation system interconnect, starting from the water source to the micro-sprinklers, through pipes, valves, and controllers.

Finally, the end devices, micro-sprinklers, are responsible for dispersing water under pressure in a cloud-like pattern to achieve effective sprinkler irrigation.

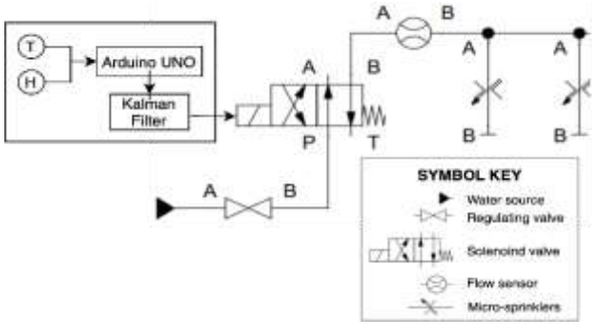

Figure 5 Physical Components Diagram for Water Flow
Source: Own Elaboration

Examining Figure 5 closely, the water flow in the system can be observed starting with two external elements: the water source, corresponding to any input of this resource, and the shut-off valve, also known as the regulating valve, responsible for functioning as an emergency cutoff. Next is the main component, the solenoid valve, which serves as an automated regulator for water flow control. This solenoid valve will be controlled by pulses sent from our decision making algorithm based on the Kalman filter. The microcontroller is responsible for activating the solenoid valve and through a pulse sent to a relay, it determines the opening or closing of the valve. This pulse will only be generated when the decision making algorithm, based on the Kalman filter, requests it, ensuring precise and efficient control of irrigation, based on environmental conditions.

Design of the IoT device

Likewise, below, a visual representation of the interconnection of key components comprising our CPS is presented.

This diagram will serve as a fundamental guide to comprehend the architecture and data flow in our system, providing an overview of how the various elements communicate and interact to achieve efficient irrigation control in agricultural environments.

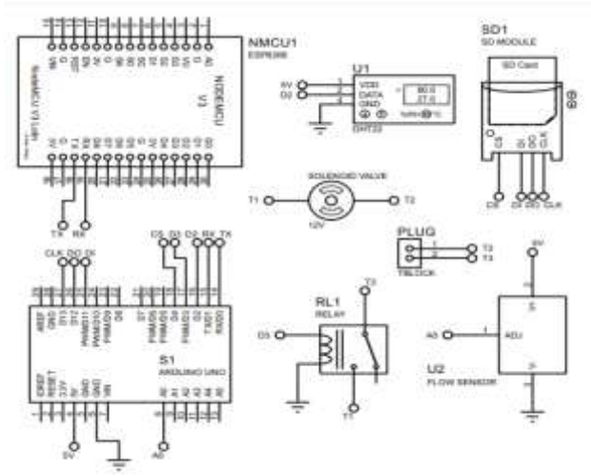

Figure 6 IoT device connection diagram
Source: Own Elaboration

The schematic diagram consists of a wide variety of essential components that, collectively, determine the entire process of collection and processing information. These components are interconnected in a specific manner.

First and foremost, the Arduino Uno microcontroller serves as the system's core, responsible for processing the acquired data. The Arduino runs programming code comprising recurring functions to control the signals and pulses necessary for the CPS system's operation. Connected to the Arduino through the serial port is the ESP32 module, tasked with sending data to the online broker via a WiFi connection. Similarly, for measuring the processed environmental variables, we have the DHT22 sensor.

This sensor measures temperature and humidity, digitally sending the data to the microcontroller. Additionally, it includes a flow sensor that measures the supplied water amount, allowing for a historical record of irrigation variables. Furthermore, the system also features an SD card module responsible for storing all data in JSON format as a backup before sending it to the online broker.

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Regarding control components, a relay receives signals based on decisions made by the Arduino using the Kalman filter. The relay, in turn, activates the final control component: the 12V solenoid valve. This solenoid valve is connected to all physical components of the water flow system and is responsible for regulating the water flow according to the algorithm's decisions. Collectively, these components work in a coordinated manner to achieve efficient irrigation control in our CPS system.

Conclusions

This paper presents the architectural design of a CPS system for the automation of irrigation processes for ornamental horticulture. This design includes the conceptual model of the communication architecture, and the connection diagram of physical components for the irrigation system and IoT device. Operational specifications, such as the structure of information flow and an explanation of decision making through the Kalman statistical estimation filter, are noteworthy.

The flexibility and adaptability of the employed architecture are emphasized, making it particularly suitable for constantly evolving IoT projects. It is crucial to underscore the significance of customized solutions. They provide complete control over architecture, scalability, security, and user experience. In more complex scalable IoT projects, these customized solutions are often the preferred choice.

Similarly, the Kalman filter has been demonstrated as a fundamental tool in decision-making for irrigation control in IoT systems. The Kalman filter's ability to estimate hidden states and reduce noise in collected data is valuable in managing humidity and temperature in agricultural environments. This approach not only contributes to maximizing water efficiency but is also essential for pest control of mites type and disease prevention in crops.

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Prediction model of the terminal efficiency of Computer Engineering at the Autonomous University of Tlaxcala applying Data Mining

Modelo de predicción de la eficiencia terminal de Ingeniería en Computación de la Universidad Autónoma de Tlaxcala aplicando Minería de Datos

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Abstract

This work presents the design of a prediction model of the terminal efficiency of the Computer Engineering Degree Program, belonging to the Autonomous University of Tlaxcala. For the development of this work, the KDD (Knowledge Discovery from Databases) process was used, which provides a complete representation of the life cycle of a Data Mining project; and to obtain the prediction model, the data mining technique of linear regression was used. Personal and academic data from two generational cohorts of the educational program were used to adjust and validate the model. It was determined that it is necessary to develop a specific model for each semester, in order to identify the academic variables that have the greatest influence on whether or not the student can graduate from his or her career.

Data Mining, Terminal Efficiency, Linear Regression, Prediction Model, Weka

Resumen

En este trabajo se presenta el diseño de un Modelo de predicción de la eficiencia terminal del Programa Educativo de la Licenciatura en Ingeniería en Computación, perteneciente a la Universidad Autónoma de Tlaxcala. Para el desarrollo de esta trabajo se hizo uso del proceso KDD por sus siglas en inglés (Knowledge Discovery from Databases) que provee una representación completa del ciclo de vida de un proyecto de Minería de Datos; y para la obtención del Modelo de predicción se hizo uso de la técnica de minería de datos de regresión líneal. Se usaron los datos personales y académicos de dos cohortes generacionales del programa educativo para el ajuste y validación del modelo. Se logro determinar que es necesario realizar un modelo específico por cada semestre, pudiendo identificar cuales son las variables académicas que tienen mayor influencia para que el alumno pueda egresar o no de su carrera.

Minería de Datos, Eficiencia Terminal, Regresión Lineal, Modelo de Predicción, Weka

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1. Introduction

There is a great interest in applying Data Mining techniques and methods in higher education environments. Data mining offers a large number of statistical models that are able to detect patterns and trends in databases that cannot be detected by traditional exploration. Its application includes transforming data into useful information to support decision making [1]. According to Kabakchieva, there is a growing use of data mining techniques in universities to analyse educational data in order to extract information and knowledge to support educational decision-making [2].

Data mining is a powerful tool for predicting terminal efficiency in different educational contexts. It allows the analysis of large volumes of data collected from students and the use of statistical techniques and machine learning algorithms to identify patterns, trends and key factors that influence terminal efficiency. By analysing data collected from students, it is possible to identify patterns, trends and factors that influence academic performance.

2. Background

Educational institutions have mass data that continues to grow, which translates into more valuable information with new possibilities and needs for analysis to reinterpret reality in order to identify strategic institutional solutions. Different disciplines of scientific research have been used to analyse big data in order to solve complex problems.

Daza Vergaray, in his research work carried out at the Universidad Privada César Vallejo, using data mining techniques, proposed a model to predict desertion or abandonment in private higher education. For which it used the CRIPS-DM methodology with the commercial tool spss clementine 12.0, using the data mining technique decision trees, where they used 1761 student data with 27 attributes for each of them that are related to student dropout. For the project they used the decision tree algorithm where they did the training, validation and testing with 100 new data obtaining an accuracy of 89% [3].

In Maya's work, they present the design of a predictive model developed using Data Mining (DM) techniques and methods, the model aims to identify patterns and influencing factors in student dropout in Higher Education Institutions (HEI) in the state of Mexico. This model provides a solid basis for decision-making and the implementation of preventive strategies to address the phenomenon of dropout or failure in universities [4].

At the Faculty of Engineering of the Pontificia Universidad Javeriana they designed an application combining data mining techniques to identify the factors that influence dropout. The application runs two models, K prototypes and Boosting in the student databases of the faculty of engineering. They also designed a model combining techniques in order to extract as many factors affecting dropout as possible, and determined that the combination of techniques can improve the accuracy of the classifiers.

In the analysis of dropout, they took into consideration the student's own information, the classes they take, as well as information on the degree of preparation of the teachers who teach them, and finally it was discovered that academic performance is significantly linked to the teachers and even the schedules in which they take the subjects [5].

At the Universidad Arturo Prat, Chile, using data mining techniques, they obtained a model to classify dropout students from the socioeconomic and academic data of undergraduate students, they used the CRISP-DM methodology and analysed three classification models: decision trees, Bayesian methods and neural networks, in order to evaluate their behaviour, finding that Random Forest is the algorithm with the best overall performance and the Naive Bayes algorithm turned out to be the most appropriate to meet the business objectives. They determined that the academic entry variables of the students are not significant in explaining first year dropout. [6].

At the UATX, a paper was presented at the 2nd International Congress of Technological, Scientific and Innovation Entrepreneurship of the Faculty of Engineering 2023, at the Autonomous University of Queretaro, which showed the Design of a Predictive Model Applying Data Mining to determine University Terminal Efficiency.

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A model was obtained that allowed predicting the terminal efficiency of the Bachelor's Degree in Law programme at the Autonomous University of Tlaxcala. The variables that were identified as influencing the result of whether a student graduates or not were: average, number of subjects taken, number of subjects failed, number of periods taken, number of credits accumulated and number of periods with scholarship, identifying that they are variables related to the student's academic data. However, when using the same model to predict whether an enrolled student could graduate or not, it was identified that the model could not be used. Therefore, it was decided to design a new model now applied to another degree and obtained by semester. For which two generational cohorts were used and new variables were generated, where it is important to determine the temporality of applying the model.

Therefore, in this article data mining is used with the purpose of analysing and identifying the factors or aspects that affect the terminal efficiency of students, taking the case study of the Bachelor's Degree in Computer Engineering at the Autonomous University of Tlaxcala.

3. Data Mining (DM)

Data mining is defined in [7] as the process of extracting useful and understandable knowledge, previously unknown, from large amounts of data stored in different formats. One task of data mining is to find intelligible models from the data. It can be said that the aim of data mining is to convert data into knowledge.

Data mining is divided into three main stages: data cleaning, analysis and modelling. In the first stage, data is cleaned and prepared for processing. In the second stage, the data is analysed to extract useful information. Finally, in the third stage, models are built to predict future events or behaviour from the analysed data.

There are several types of techniques used in data mining, such as clustering, classification, regression and association. Clustering is used to divide data into similar groups, while classification is used to assign a label to the data. Regression is used to predict future values from past data, and association is used to find patterns in the data.

Data mining is a valuable tool for improving decision making in a variety of fields.

4. Data Mining Techniques and Methods

Rodriguez and Diaz, refer that Data Mining techniques and methods apply supervised learning algorithms. Unsupervised algorithms do not take as a basis a dependent variable, endogenous or variable to be predicted, in which Clustering or grouping (EM, Simple k-Means, Cobweb, etc.) and association rules (A priori, FilteredAssociator and FPGrowth) are integrated. [8]. While the Supervised ones have a dependent variable, endogenous or variable to predict, in which they are grouped:

a) Classification techniques: decision trees, decision table, rule induction, Bayesian, neural networks, fuzzy logic, genetic techniques. In decision trees, the variable to be predicted or dependent variable is categorical and the results obtained can represent a logistic regression. [9]

b) Prediction techniques: regression (prediction) tree, regression, kernel estimator. A regression tree is analogous to a linear regression where the predicted or dependent variable is numerical (discrete or continuous). [9]

Data mining techniques applied to the task of prediction, aim to develop a model that allows predicting the value of the input variable (dependent variable) as a function of a set of predictor variables (independent variables).

5. Methodology

For the development of this work we made use of the KDD process (Knowledge Discovery from Databases), mentioned in [7], which defines a methodology that provides a complete representation of the life cycle of a Data Mining project. Figure 1 shows the KDD process which is divided into five main phases, described as follows:

– Data integration and collection: here it is decided where the data to be used later on will be obtained from, i.e. which sources of information are useful. All data are then transformed into a common format, as they may come from heterogeneous sources, usually by using a data warehouse.

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– Selection, cleaning and transformation: the data collected in the warehouse may contain errors in their values, or some of the values may be missing or erroneous. In this phase, an attempt is made to correct or even delete this data and a decision is made as to what to do with incomplete data. A selection is also made of those data that are relevant to the knowledge extraction process to be carried out.

– Data mining: this is the main phase dealt with in this research, in which it must be decided which task (grouping, classifying, etc.) is to be carried out, and the method and algorithm to be applied are chosen.

– Evaluation and interpretation: In the data mining phase, the results, e.g. the patterns observed in the data, are to be reported. Here these patterns are evaluated and interpreted, in order to be able to understand the result obtained.

– Dissemination and use: this is the last phase of the KDD process, its objective is to use the new knowledge acquired and to make this knowledge available to all possible users.

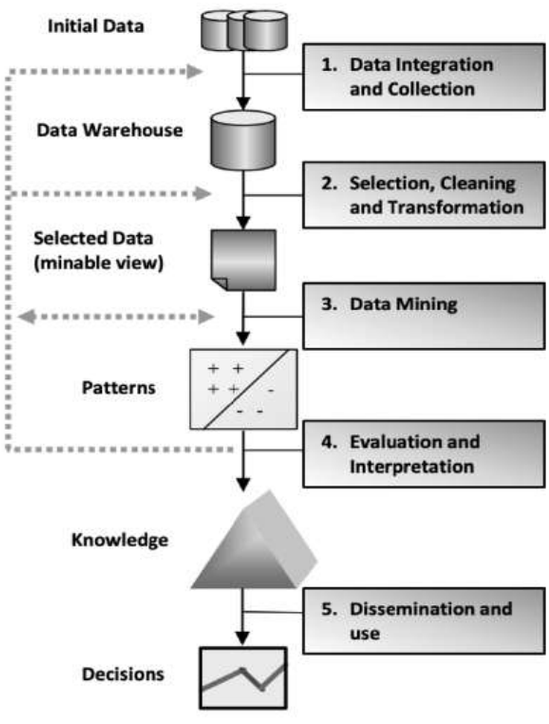

Figure 1 Phases of the knowledge discovery process in databases, KDD

6. Research Development

Integration and data collection:

In this phase, the activities prior to the data mining process are carried out:

a) Data Collection. The data is generated with a SQL query to the database of the Integrated Administrative Information System of the Autonomous University of Tlaxcala, and exported in a CSV file. The selected sample corresponds to 2 generational cohorts, being from Autumn 2009 to Autumn 2010 of the Bachelor's Degree in Computer Engineering, the data are preprocessed in the first instance, reviewing the data required for analysis of variables or factors that affect the university terminal efficiency. In this phase it is determined to make the query by semester, because it is desired to obtain a predictive model that applies to enrolled students.

b) Determination of variables. From the data collected, 38 variables were examined, selecting 21 representative variables of the students, being the following:

Gender, Marital Status, Semester, Semester Completed, Semester Average, Cumulative Semester Average, Subjects Completed in the Semester, Total Subjects Completed Cumulative Semester, Subjects Failed in the Semester, Total Subjects Failed Cumulative Semester, Subjects Passed in the Semester, Total Subjects Passed Cumulative Semester, Total Subjects Passed Cumulative Semester, Total Subjects Passed Cumulative Semester, Total Subjects Passed Cumulative Semester, Total Subjects Passed Cumulative Semester, Total Subjects Passed Cumulative Semester, Total Subjects Passed Cumulative Semester, Total Subjects Passed Cumulative Semester, Total Subjects Passed Cumulative Semester, Total Semester Passes, Total Semester Credits Earned, Total Semester Credits Earned, Total Semester Credits Earned, Total Semester Credits Failed, Total Semester Credits Failed, Total Semester Credits Passed, Total Semester Credits Passed, Total Semester Credits Passed, Low Average, High Average, High Fail and Late.

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Selection, cleaning and transformation:

In this phase, the minable view and training input patterns are generated, for which the following is done:

a) Selection and Cleaning: the imported CSV data file is checked for null or erroneous data, where unnecessary data, i.e. that will not participate in the training of the modelling, is collected, modified and removed.

b) Transformation to variables: the data are prepared with the 21 selected variables described in the second column of Table 1, which represent the Input Variables, being the basis of the training for the model, where linear regression functions are applied in SW WEKA [10].

c) Pre-processing of variables, the categorisation of the variables identified with numerical values is carried out.

ID de la Variable	Variable Description
Clgener	Gender
Clestadocivil	1 Male
Semester	2 Female
Semester_completed	Marital status
Average_semester	1 Single
Cumulative_semester_average	2 Married
Mat_coursed_semester	3 Divorced
Tot_mat_coursed_accum_sem_total	4 Widowed
Mat_reproved_semester	5 Unmarried
Tot_reproved_sem_subjects_failed_sem_year	Semester Completed
Mat_passed_semester	0 Not completed
Tot_approved_sem_subjects_approved_sem_term	1 Completed
Credits_approved_semester	Semester Average
Tot_cred_approved_acum	Values from 0 to 10
Credits_reproved_semester	Cumulative average for the semester
Tot_cred_reproved_acum	Number of subjects taken in the semester
Credits_taken_semester	Total number of subjects taken cumulative to the semester
Tot_cred_accum_cred_academic_reproved_acum	Number of subjects failed in the semester
Low_average	Total number of failed subjects accumulated during the semester
High_reprobation	Number of subjects passed in the semester
Low	Total number of subjects passed cumulative number of subjects per semester

Table 1 Input and Categorised Variables for Modelling

Data mining:

For the application of the proposed data mining techniques, the WEKA program (Waikato Environment for Knowledge Analysis) developed by the University of Waikato in New Zealand will be used. WEKA [10], is a free to use program (GNU License) and is composed of a set of algorithms that implement most of the data mining techniques....

Evaluation and interpretation:

To evaluate the predictive models on the outcome (Semester Completed, Semester Not Completed) of the Fall 2009 to Fall 2010 generational cohorts of the Bachelor of Computer Engineering to obtain the model for the first semester, the Cross Validation-10 folds method will be used. Linear regression is applied to estimate the predictive model that best fits the data, selecting predictor variables that are statistically significant. For the purposes of this article, Figure 2 shows the linear regression model obtained for the first semester.

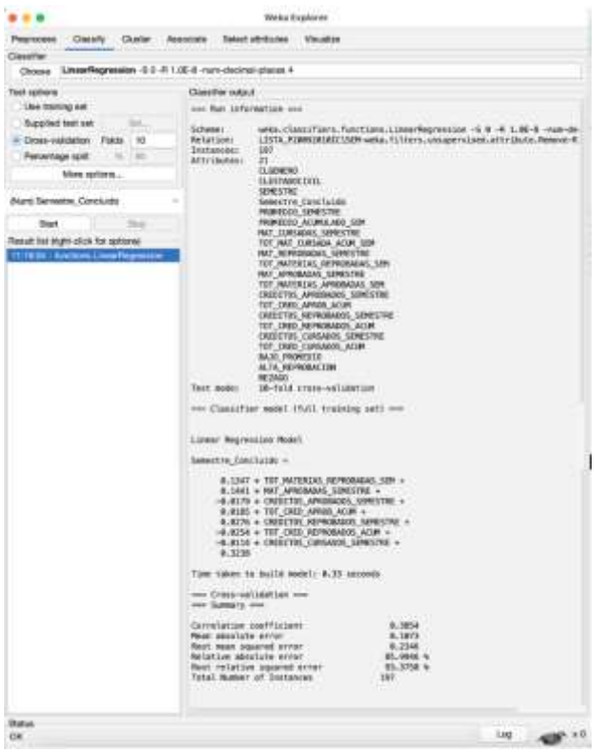

Figure 2 Model for the First Semester

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Dissemination and use:

Once the model has been built and validated, the model is going to be applied to different datasets. To obtain the observed and estimated frequencies of each generational cohort according to the model, the corresponding tests were carried out with the Fall 2011, 2012, 2020, 2021 and 2022 generational cohorts. Table 2 shows the observed and estimated frequencies per generational cohort. As can be seen in the Total column, the actual total number of students who completed the first semester is represented, in Corrected the number of correct answers obtained by applying the model obtained in Figure 2, in Observed the actual number of students who completed the first semester and the number who did not complete the first semester, and finally in the Estimated column, the number of students who completed the first semester and the number who did not complete the first semester obtained by running the model**.**

Cohort	Total	Cohort	Observed		Dear	
			Sem Concluded	Sem Unfinished	Sem Concluded	Sem Unfinished
Autumn 2011	75	70	68	7	68	2
Autumn 2012	84	70	68	16	68	2
Autumn 2020	77	70	63	14	63	7
Fall 2021	62	57	54	8	54	3
Autumn 2022	62	53	51	11	51	2
	344	320	304	56	304	16

Table 2 Observed and estimated frequencies of statuses by Generational Cohort

Table 3 shows the percentage of students who complete the semester, with the Observed column being the actual percentage of students who completed the semester and the Estimated column being the estimated percentage of students who completed the semester as reported by the model. It is observed that according to the model there is an R of 85.99% and an R-squared of 93.37%, which infers an acceptable degree of statistical reliability, which is reflected in the results obtained in the Percentage of Success column.

Cohorte	Sem Efficiency Completed (%)		
	Observed	Dear	Hit Percentage
Autumn 2011	90.66	97.14	93.33
Autumn 2012	80.90	97.14	83.33
Autumn 2020	81.81	90.00	90.90
Autumn 2021	87.09	94.73	91.93
Autumn 2022	82.25	96.22	85.48

Table 3 Efficiency of semester completed, observed and estimated by Generational Cohort

A model has been obtained that predicts for the first semester of the Computer Engineering programme whether or not a student completes the semester. According to the tests, the prediction of the model is acceptable and can be used to adequately estimate the semester completion of the cohorts that have completed the first semester of the educational programme, being a benchmark for the consecutive semester.

7. Conclusions

Data mining techniques prove to be effective tools to obtain models to predict the completion of the semester per student of the Computer Engineering programme at the Autonomous University of Tlaxcala. The variables that the obtained model considers are: Total number of failed subjects accumulated during the semester, Number of subjects passed during the semester, Number of credits passed during the semester, Total number of credits passed during the semester, Number of failed credits during the semester, Total number of failed credits accumulated during the semester and Number of credits taken during the semester, with this information it is possible to determine more accurately whether a student concludes the semester or not. The tests were taken at the end of the semester. The next part of the work is to generate models for consecutive semesters in order to be able to predict the student's terminal efficiency, according to their semester progress.

Funding

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Prototype of a mobile application for monitoring childhood immunizations

Prototipo de aplicación móvil para el seguimiento de vacunación infantil

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Abstract

The objective of this research is to develop a mobile application in order to notify parents about the dates established for childhood vaccination, as well as to inform about the biological to be applied. The methodology used is Extreme Programming (EP); It consists of 4 phases: Planning, design, coding and testing. This prototype allows the interaction of a user, due to the fact that an informative scope was initially defined; but interaction with doctors and nurses is foreseen thanks to the proposal that is proposed to be made with the Sanitary Jurisdiction No. 10 of Huejutla de Reyes, Hidalgo in the Huasteca Hidalguense. It is intended to reduce different causes that affect the health of the child population, and that is that most parents do not vaccinate their children according to the schedule recommended by health institutions due to different circumstances. As a result, infants do not receive the vaccine when appropriate; Therefore, the risks they could take are dangerous to their health, affecting their future growth. This tool will prevent the loss of information derived from the loss of the vaccination card, as well as the duplication of the information regarding the applications made.

Prototype, Web, Vaccination

Resumen

El objetivo de esta investigación es desarrollar una aplicación móvil con la finalidad de notificar a los padres de familia sobre las fechas establecidas para la vacunación infantil, así como informar sobre el biológico a aplicar. La metodología utilizada es Programación Extrema (PE); consta de 4 fases: Planeación, diseño, codificación y pruebas. Este prototipo permite la interacción de un usuario, debido a que inicialmente se definió un alcance informativo; pero se prevé la interacción con doctores y enfermeras gracias a la propuesta que se plantea hacer con la Jurisdicción Sanitaria No. 10 de Huejutla de Reyes, Hidalgo en la Huasteca Hidalguense. Se pretende disminuir diferentes causas que afectan a la salud de la población infantil, y es que la mayoría de los padres no vacunan a sus hijos de acuerdo con el calendario recomendado por las instituciones de salud por diferentes circunstancias. En consecuencia, los infantes no reciben la aplicación de la vacuna cuando corresponde; por lo tanto, los riesgos que podrían contraer son peligrosos para la salud, afectando su crecimiento a futuro. Esta herramienta evitará la pérdida de información derivada del extravío de la cartilla de vacunación, así como la duplicidad de la información referente a las aplicaciones realizadas.

Prototipo, Web, Vacunación

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Introduction

Immunisation is the process by which a person becomes resistant to a disease, either through contact with certain diseases, or through the administration of a vaccine. Vaccines stimulate the body's immune system to protect a person against infection or disease.

Immunisation is important because it prevents vaccine-preventable diseases, disabilities and deaths, such as cervical cancer, polio, measles, rubella, mumps, diphtheria, tetanus, pertussis, hepatitis A and B, bacterial pneumonias, rotavirus diarrhoeal diseases and bacterial meningitis (PAHO, 2023). (PAHO, 2023).

The research "Prototype of a mobile application for the follow-up of childhood vaccination" involves in its first stage the development of a tool that speeds up and promotes the application of vaccines in infants in the Huasteca Hidalguense region, so its use so far is informative; in later stages, the management of the history record will be implemented to ensure the integrity of the information of each immunisation application by medical personnel, with the use of norms and standards corresponding to the processing of medical information.

The prototype was created to operate in a mobile environment, due to the advantages involved in the use of this type of device today.

The use of the technological tools, React Native, Visual Studio Code and Mongo DB was necessary for the development of a digital child vaccination booklet that notifies parents of the information corresponding to the vaccines that are available for application to infants.

Since misinformation is one of the main causes that prevent health units in the Health Jurisdiction No. 10 of Huejutla de Reyes, Hidalgo from satisfactorily complying with child immunisation campaigns, the initial objective of this research is to communicate to the population the personalised calendar of application of the different biologicals; with the intention of including functionalities in a later phase that complement the interaction with more users such as doctors and nurses to manage medical records in an appropriate, controlled and secure manner.

This article includes the following sections: Problem that indicates the circumstances that originated the development of this research work, the following section corresponds to the justification where the possible solutions, benefits and impact that this project will bring as a consequence are indicated, continuing with the objective to be achieved.

The theoretical foundations that include the necessary information that gives notion and facilitates the perception of the reader for the understanding of the subject treated, the methodology indicates the stages that must be developed to carry out the creation of the prototype; then, the development specifies each one of the activities carried out within these phases.

It also includes the results obtained compared to the project approach with the established objective, the conclusions obtained from this research, as well as the acknowledgements and references used.

Problem

The Universal Vaccination Programme (PVU) in Mexico is a benefit aimed at the general population, whose objective is to protect against diseases that are preventable through the application of vaccines.

Unfortunately, for parents living in the Huasteca Hidalguense region, information on child vaccination campaigns is only available through the traditional means used by the Ministry of Health, most of them printed, which are insufficient and difficult or impossible to access due to the fact that health units are often far from the indigenous communities of the region.

Although nowadays it is increasingly common for people to acquire some type of mobile device with which they can access an internet connection point, in this demarcation there is no tool through these terminals that notifies and keeps the population informed about current immunisation campaigns for children, which leads to incomplete and deficient coverage.

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In addition, the loss, renewal or duplication of child immunisation cards are other causes that particularly occur, and the need to go to a health centre to request a new one or to update the history to determine which biologics have already been applied and which have not, requires time to verify the previous records that the health unit has, resulting in a conflictive situation to resolve for both medical staff and parents.

Justification

Information and Communication Technologies (ICTs) have been surprisingly fast-moving. The resources, tools and programmes available for learning, sharing and disseminating knowledge through different technological supports, applied to clinical practice with the aim of improving the care of children, adolescents and their families surround and amaze us.

The technology that we see most widely used and applied in paediatric practice is mobile devices and their applications. The term "mobile health" refers to the use of these devices for the practice of medicine and public health. Mobile Health is the use of mobile devices (mobile phones, tablets, iPods, etc.) in the health sector, regardless of whether we are a patient, medical professional, institution, government or company (Sociedad Chilena de Pediatría, 2019).

The development of this mobile application has the solution of specifically scheduling vaccination dates and notifying the population in advance about the application of the vaccine to infants, in order to facilitate the important responsibility of protecting the health of all children.

Its benefits have an important impact because, in the first instance, a large part of the population will be able to receive notifications about the vaccination schedule from their mobile device; and subsequently they will be able to count on a tool that will allow quick and secure access to the information corresponding to the vaccination history by parents and medical personnel, avoiding loss or duplication of records.

Objective

To develop the prototype of a mobile application, through the use of the technological tools, React Native, Visual Studio Code, React Navigation, Mongo DB, for the creation of a digital child vaccination booklet that notifies parents of the information corresponding to the vaccines that are available for application to infants.

Theoretical foundations

Immunisation

Immunisation is a simple and effective way to protect children and reduce the spread of serious infectious diseases in this group. Comprehensive immunisation programmes are a cornerstone of prevention and stand out as one of the most cost-effective public health interventions (Hernandez, Palacio, Hernandez, Charvel, 2020). Vaccines differ from medicines in their biological nature, as they are designed to prevent disease and are generally administered to healthy people; thus, their manufacture, distribution, control and regulation require special knowledge and procedures.

They are distributed and marketed through programmes with well-organised health structures, and require post-vaccination surveillance to provide information on events not recorded in clinical trials (Tuells, 2016).

Universal Vaccination Programme in Mexico

The Universal Vaccination Programme (PVU) is one of the Federal Government's main tasks in preventing, eradicating and eliminating diseases from Mexican territory.

The purpose of the Universal Vaccination Programme (PVU) is to reduce morbidity and mortality from vaccine-preventable diseases, to achieve and maintain vaccination coverage of 95 per cent for each biologic and 90 per cent coverage with a complete schedule in each age group (Government of Mexico, 2019). But over the past 12 years, the number of vaccines included in the basic schedule tripled, resulting in increased pressure on primary health care systems to ensure a continuous and adequate supply of vaccines for the 2.2 million children born each year in our country. (Vaccine Alliance, 2023).

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Vaccination in the state of Hidalgo, Mexico

The National Centre for Child and Adolescent Health (CeNSIA) presented the sectoral coverage of vaccination schedules for the year 2022 for children under 1 year (figure 1), 1 year (figure 2), 18 months (figure 3), 4 years (figure 4) and 6 years (figure 5). The information corresponds to the registry of doses applied for Hidalgo and on a sectoral basis (Government of Mexico, 2023).

For children under one year of age, the figures are as follows:

Figure 1 Sectoral vaccination coverage in children under 1 year of age in Hidalgo, 2022
Source: Government of Mexico

Vaccination results obtained for one year olds:

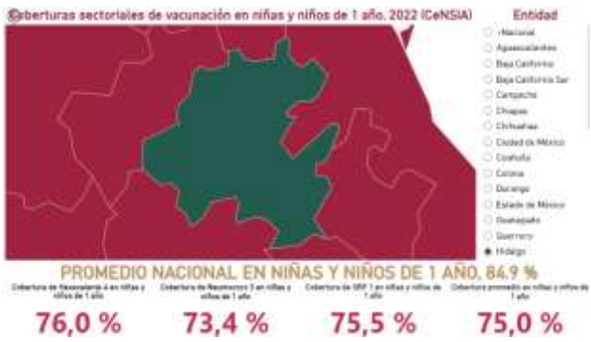

Figure 2 Sectoral immunisation coverage of 1-year-old children in Hidalgo, 2022
Source: Government of Mexico

Immunization coverage for 18-month-old children:

Figure 3 Sectoral vaccination coverage of children aged 18 months in Hidalgo, 2022
Source: Government of Mexico

State and national average vaccination coverage of 4-year-olds:

Figure 4 National and state (Hidalgo) averages for childhood immunisation up to 4 years, 2022
Source: Government of Mexico

State and national average of vaccination of children aged 6 years old:

Figure 5 National and state (Hidalgo) average of childhood immunisation up to 6 years, 2022
Source: Government of Mexico

Statistics show that child immunisation coverage percentages in the state of Hidalgo, in most scenarios, are below the national average, with the exception of the sector composed of infants aged 4 and 6 years.

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Although in this state the percentage of immunisation for the 18-month-old sector is higher than the national average, it is important to highlight that only 47.8 per cent of children of that age have received the vaccines they are entitled to, which is a very worrying figure.

For the other sectors, although vaccination coverage is higher than the national average, it is also desirable that the percentages can reach the levels proposed by the federal government through the Universal Vaccination Programme (PVU); for this it is necessary to have the support of mobile devices to facilitate and increase the reach in the dissemination of information regarding vaccination campaigns for the largest possible number of the population.

Mobile health

Mobile health (mHealth) is one of the most sought-after terms in the area of health sciences today; however, its definition as an interdisciplinary technological tool could be confused between the concepts of electronic health (eHealth), which is where it originates, or ubiquitous health (uHealth), which uses more complex technological elements to achieve monitoring through sensors and devices (Rodríguez, Gogeascoechea, 2022).

ICTs represent the set of resources based on digital equipment that actively process information. Some of their objectives are: to assist in education; to enable the exchange of information; to solve health problems; to improve referrals and counter-referrals at different levels of care; to prevent and promote health; and to serve as strategic allies of public health (Pan American Health Organization, 2016).

In the last decade, mobile health, the branch of eHealth broadly defined as "the use of mobile communication and computing technologies in healthcare and public health", has been steadily expanding. Mobile health applications can target heterogeneous audiences such as doctors, nurses, patients or even healthy individuals (Free, Phillips, Felix, Galli, Patel, Edwards, 2010).

The biggest advantage of using mobile devices, and in particular mobile phones, for health is that they are personal, smart, connected and always with people (Whittaker, 2012 and Fogg, Adler, 2009).

In addition, Short Message Service (SMS) text message reminders have been shown to be a simple and efficient option for health services to use to improve service delivery, resulting in health benefits for the patients who receive them (Guy, Hocking, Wand, Stott, Ali, Kaldor, 2012). Nowadays, various instant messaging applications are also available for user notifications.

In this regard, information and communication technologies (ICTs) can play an important role in providing easier and more affordable access to health and treatment services.

With people's increased interest in this communication tool, an opportunity has been created for health experts to educate people and increase the health of society. In addition, smartphone services can overcome the limitations of time and place and make healthcare more accessible, especially for people living in remote areas. This technology also provides a suitable ground for the fair delivery of health services to all along the entire care chain (Zare, Hajizadeh, Mahmoodi, Nazari, Shahmoradi, Rezayi, 2023).

In Mexico, the outlook is encouraging in terms of the number of people with smartphones. The estimated number of users for 2026 (Figure 6) is 118.1 million inhabitants (Statista, 2023), suggesting that these devices will be a key tool for the development of health-focused applications.

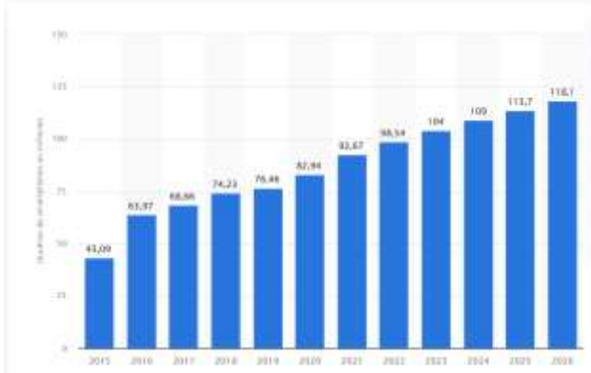

Figure 6 Number of smartphone users in Mexico from 2015 to 2026
Source: Statista (2023)

Methodology

The Extreme Programming (EP) methodology was chosen for the development of this research. It encompasses a set of rules and practices that occur in the context of four framework activities: planning, design, coding and testing.

The decision to choose EP is because this research required little time for its realisation and an important characteristic of the work is that the development is done in pairs.

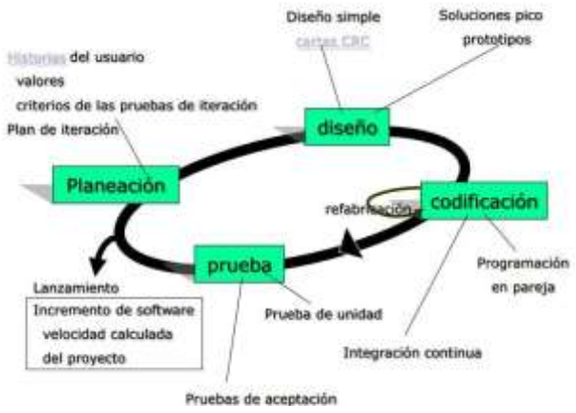

Figure 7 Extreme Programming (EP) process

The planning activity begins by creating a series of stories (also called user stories) that describe the features and functionality required for the software to be built. They are assigned a cost, which is measured in development weeks.

Once the first release of the project (also called software increment) has been delivered, the EP team calculates the project velocity. Put more simply, project velocity is the number of customer stories implemented during the first release.

The SP design rigorously follows the MS (Keep It Simple) principle. A simple design is always preferred over a more complex presentation. In addition, the design provides an implementation guide for a story as written.

For coding, the EP recommends that after designing the stories and doing the preliminary design work the team should not move to coding, but should develop a series of unit tests that exercise each of the stories to be included in the actual release (software increment).

Once the unit test is created, the developer is better able to focus on what needs to be implemented. When the code is complete, the unit can be tested immediately, thus providing instant feedback to the developers.

PE acceptance testing, also called customer testing, focuses on the overall features and functionality of the system, elements that are visible and reviewable by the customer. Acceptance tests are derived from user stories that have been implemented as part of a software release (Pressman, 2006).

Development

In the first phase, the project requirements and the activities to be carried out during the development of the project were identified, as well as the time allocated for each user story.

The user stories developed for the prototype of the mobile application for monitoring child immunisation were defined for the users who would initially use this tool: Administrator (table 1) and Parent (table 2).

An example story for each user is shown below:

Administrator	
Number: 1	User: Administrator
Name Story: Insert data	
Priority in the system: High	Development risk: High
Estimated points: 7	Assigned Iteration: 1
Programmer in charge: Adrián Bautista Cortes and Adrián Hernández Bautista.	
Description: The administrator requests to be able to insert new data into the system.	
Validation: The administrator will be able to insert new data.	
Iteration: User history of the administrator to insert data. Elaboration time: 30 May to 03 June 2023.	

Table 1 User History Administrator

User	
Number: 5	User father
Name History: Infant Data Record.	
Priority in the system: High	Development risk: High
Estimated points:	Assigned Iteration: 1
Programmer in charge: Adrián Bautista Cortes and Adrián Hernández Bautista.	
Description: The user requests to be able to register infant data.	
Validation: The user will be able to register data.	
Iteration: Parent's user story to register the infant's data. Processing time: 27 to 29 June 2023.	

Table 2 User Story Parent

Subsequently, the Planning Poker was used. The purpose of this process is to calculate the effort required to carry out the different user stories, by means of a consensus between the members in charge of carrying out the different tasks that make up each phase.

The technique consists of each team member choosing an option from the Modified Fibonacci, which represents the estimated value of the effort he/she considers for the task without showing it to his/her teammate so as not to influence his/her decision.

The values of the Modified Fibonacci are: 1, 2, 3, 5, 8, 13, 20, 40, 100. In the Planning Poker (table 3) the values of each team member and the average estimate of each user story are observed, as well as the priority of each one of them.

User History	Member		Average estimate	Priority
	A	B		
HU01	40	100	70	High
HU02	20	13	16.5	Medium
HU03	13	8	10.5	High
HU04	20	5	12.5	Medium
HU05	40	20	30	High
HU06	20	13	16.5	Medium
HU07	20	5	12.5	High

Table 3 Planning Poker

Once the estimate in hours was defined, sprints were organised based on user stories to develop the different functions.

As shown in table 4, 7 weeks were used to develop the mobile application, which included 35 working days, which in turn established 7 hours of work per day; therefore, the total number of hours for the sprint was 245.

Sprint size	7 weeks (35 working days)
Work per day	7 hours.
Sprint hours	245 hours.

Table 4 Sprint of the user stories

It can be seen in table 3 that several stories have different priorities, so when this situation arises, it is up to the team to select those with high importance.

The sprint planning considers the maximum number of hours established, in this case 35. If the work required to finish a user story exceeds this time, more iterations will be carried out until the responsibility is completed.

For user story HU01, 70 hours were needed, so two iterations were enough to complete the estimated time. It is worth mentioning that in the first sprint, the first 35 hours were worked, while in the second sprint, the 70 hours were completed to finish the activities of HU01. Tables 5 and 6 show the information corresponding to the time spent for HU01.

Maximum hours per sprint:	35
Total hours used:	70
Remaining hours per sprint:	0
History: HU01	Estimated hours: 70
Iteration:	1

Table 5 First iteration for user story (HU01)

Maximum hours per sprint:	35
Total hours used:	70
Remaining hours per sprint:	0
History: HU01	Estimated hours: 70
Iteration:	2

Table 6 Second iteration for user story (HU01)

In user story HU05 (table 7), the estimated hours for its completion were 30; because the iteration consists of 35, there was a resulting gap of 5 hours that were used for the development of other functions of the mobile application.

Maximum hours per sprint:	35
Total hours used:	30
Remaining hours per sprint:	5
History: HU01	Estimated hours:: 30
Iteration:	1

Table 7 First iteration for user story (HU05)

This procedure was applied for each of the user stories established in the development of this project.

Figure 8 shows the work carried out in the design stage, where the sketches were created for the development of the tool corresponding to the mobile application of the digital children's booklet.

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The forms show the section for the registration of infant data, as well as the information on the immunisations that are available, the diseases that prevent each one of them and the dates of application in order to notify parents in a timely and clear manner.

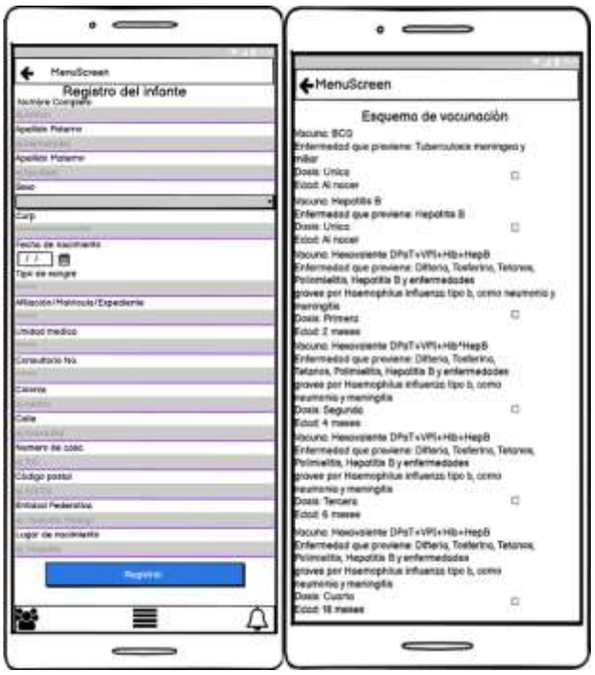

Figure 8 Sketch of the graphic interface of the mobile application

For the coding of the interfaces of the mobile application, it was developed in a Framework (React Native), using a code editor (Visual Studio Code), designing the application with a library (React Native Paper). For the functionality of the application, it was connected to a non-relational Mongo DB database to process the data registered by the user.

Figure 9 shows the appearance of the forms at the end of development and a unit test performed.

Figure 9 Graphical interface of the mobile application

The end-user acceptance tests were conducted with the intention of verifying that the different modules of the mobile application work according to the needs established in the initial requirements of this research.

Figure 10 presents the results of the parent and infant registration test; these were satisfactory and in accordance with the requirements.

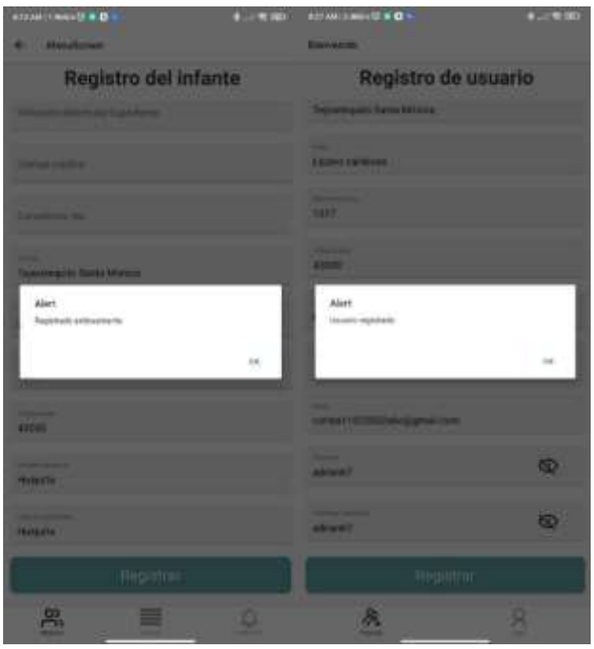

Figure 10 Test registration of Father and Infant

Together with the prototype of this mobile tool, the technical and user manuals are included, which are indispensable for the updating and extension of future functions foreseen for this project.

Results

During the phases of the development of the "Prototype of a mobile application for monitoring child vaccination", each of the processes necessary to obtain the prototype in the estimated time were analysed. The expected results for this project were very successful as the delivery of a prototype for this tool was achieved.

In the first instance, information was gathered on the needs of the medical units located in Health Jurisdiction No. 10, with coverage in the municipalities that make up the Huasteca region of Hidalgo, which reported the problems related to the difficulties in carrying out the application of biologics to infants, mainly because the publications related to vaccination campaigns were not sufficient in terms of coverage within the population.

In the same way, information was obtained from the health authorities regarding the inoculations that include child vaccination cards and the dates of application of each one of them.

Once the main need was determined, it was determined that a mobile application was the best option to solve the problems, largely due to the fact that people who have a mobile device have the possibility of receiving personal notifications with information regarding their children's health.

Next, once the necessary requirements were established, it was determined that Extreme Programming (EP) would be used to develop the prototype in question, as it is a methodology that adheres to agile development.

We started with the creation of the user stories (UH), which would be the essential foundation for the creation of the mobile tool's modules. Subsequently, the sketches of each of the sections were designed to create the functions of the software from the user's point of view. The designs had the characteristic of being practical and pleasant for the beneficiary.

Within the coding, the integration of the increments was carried out through the specification of sprints. The forms that make up the graphical user interface were developed using different programmes such as Visual Studio Code, JavaScript in the React Native Framework and Mongo DB as a database administrator.

The unit tests were applied correctly, using Expo as a framework that operates on React Native, in order to be able to run the application and observe the changes that were being made. Also, database registrations were done properly, sending the data captured in each of the forms.

The elements of the graphical user interface met the usability requirement in the acceptance tests, where the user interacted between screens easily and quickly, having a very pleasant environment for the user contemplating a palette of appropriate colours for the user.

Conclusions

The mobile application is intended to have a great impact on society, as it will help many parents to avoid forgetting the dates set for their children's vaccinations. The development process of this project was based on the Extreme Programming (EP) methodology, because it follows a strictly rigorous order of the stages for the implementation of the mobile application.

In the planning stage, the problems were identified and the objectives, goals and characteristics of the development of the mobile application were determined; the requirements to carry out the project and perform the activities described in the user stories were also analysed.

For the design, the sketches of the graphic interface were created, the sketches of how the application sections were planned to be visualised, the forms together with their respective backgrounds and user-friendly colours.

Coding involved the development of the established designs, inclusion of the colour palette, ensuring that the functionalities adhered to the established needs; all of this was supervised under unit tests that ensured the correct functioning of the prototype.

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Finally, the acceptance tests were successfully applied, resulting in a practical and easy-to-use tool that meets the expectations of the end user.

As a proposal, the extension of functionalities is established. In this first stage, this digital immunisation booklet is intended to be a notification tool for parents about the dates and vaccines available for their children, but it is considered to add other functionalities that will allow health personnel (doctors and nurses) to carry out complementary actions to child vaccination campaigns.

Acknowledgements

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Geolocation mobile application for delivery of agrochemical packages

Aplicación móvil de geolocalización para entregas de envases agroquímicos

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Abstract

In recent years, the agricultural sector has boosted crop production and, consequently, the consumption of agrochemicals. This creates a serious problem, since it compromises the environment, and increases the levels of risks to the health of the population when the containers are exposed. The project proposes to implement a mobile application to promote the recovery of empty phytosanitary containers, offering options to locate safe collection points. It also includes digital receipt inquiries that cover deliveries. The application was developed according to the iterative and incremental life cycle using the Unified Modeling Language (UML). Coding was done in Android Studio, with access to a MySQL database installed on a Web server with PHP implementing the Volley library. The Google Maps API was also integrated with location options and access routes. This initiative attempts to reduce damage to the environment and impacts on health, promoting social commitment.

Agrochemicals, Crops, Phytosanitary, Agricultural, Implementation

Resumen

En los últimos años, el sector agrícola ha impulsado la producción de cultivos y, en consecuencia, el consumo de agroquímicos. Esto genera un grave problema, ya que compromete el medio ambiente, y además aumenta los niveles de riesgos a la salud de la población cuando los contenedores quedan expuestos. El proyecto propone imple7mentar una aplicación móvil para promover la recuperación de envases fitosanitarios vacíos, ofreciendo opciones para ubicar puntos de recolección seguros. También incluye consultas de recibos digitales que cubren las entregas. La aplicación fue desarrollada según el ciclo de vida iterativo e incremental utilizando el Lenguaje Unificado de Modelado (UML). La codificación se realizó en Android Studio, con acceso a una base de datos MySQL instalada en un servidor Web con PHP implementando la biblioteca Volley. También se integró la API de Google Maps con opciones de ubicación y rutas de acceso. Esta iniciativa intenta reducir los daños al medio ambiente y los impactos en la salud, promoviendo el compromiso social.

Agroquímicos, Cultivos, Fitosanitarios, Agrícola, Implementación

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1. Introduction

Sustainable food supply is essential; However, population growth and scarcity of space and water for agriculture are major obstacles to producing enough food (Bratovcic et al., 2023).

Gul & Beedu (2023) state that the agroecosystem is currently compromised due to exponential population growth, food demand, massive water extraction, energy use and inappropriate application of agrochemicals driving environmental degradation.

Bratovcic et al. (2023) states that the application and use of agrochemicals and synthetic fertilizers also generates the loss of soil biodiversity and the development of pesticide-resistant pathogens.

In recent years, the use of agrochemicals, as well as genetically modified seeds, has been increasing. The consumption of agrochemicals and fertilizers has contaminated streams that affect fauna and aquatic ecosystems (Marrochi, 2018). It has been shown that the inappropriate use of agrochemicals affects the ecological balance (Moreno, 2017). Physical contact with agrochemicals also causes diseases in workers (Castellanos et al., 2022). Exposure can cause serious diseases such as leukemia, cancer, malformations, and spontaneous abortions during pregnancy (Moreno, 2017).

Modern agriculture implements, among other solutions, nanotechnology through the development of more efficient and sustainable food production systems. The use of smart sensors, as well as nanofertilizers, to improve soil and crop performance with a controlled release of agrochemicals, promotes nutrient supply and disease and pest management (Bratovcic et al., 2023).

The fruit industry also faces challenges with high production costs caused by inefficiencies and errors. A small-scale pilot project was carried out in Sri Lanka to implement a system that monitors fruit crops from the initial stages, including agrochemical spraying. The developed system provided higher quality results at a lower production cost (Imdaad, 2023).

Ochoa-Ornelas & Gudiño-Ochoa (2023) state that pesticides are necessary, since they maintain levels of productivity and profitability in the field, however, they generate dangerous contaminants, so it is important to classify the containers and assign them appropriately to a destination final, avoiding its exposure to the population.

The project proposes an environmental management plan that involves the use of an accessible and simple mobile application for primary users or producers that was developed to offer consultations with information about packaging collection points and their geographical location. It also guarantees the consultation and download of digital receipts that support the corresponding delivery. Access to the information is made through a connection to the central database installed on a Web server, which is continuously managed.

The application was developed for the company AMOCALI, A.C., which represents manufacturers of agrochemical products whose objective is to protect crops and provide the correct final disposal of empty phytosanitary containers in Mexico.

The article includes the theoretical framework with a description of the software libraries used for the development of the application, as well as the methodology in each of the phases. Subsequently, the results obtained, conclusions, acknowledgments and bibliographic references are presented.

2. Theoretical framework

2.1 Android Studio

Gironés (2019) states that an Android Studio project is made up of several modules and generates applications in different SDK versions. Each of the modules is represented by a specific folder:

– Manifest
– Java
– Resolution
– Gradle scripts

Gradle automates the creation of projects, managing packages and libraries and other elements necessary for software development.

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2.2. Volley

The REST API (Representational State Transfer) accelerates the development, creation, publication, and consumption of Web services through JavaScript Object Notation (JSON) to exchange data (Lachgar et al., 2018). The need to combine Web services and mobile devices has driven application development. Volley is developed by Google in 2013, it implements the HttpStack interface and the expansion of JsonObjectRequest achieving support for Web services with SSL/TLS protocol requests (Shulin & Jieping, 2014).

2.3. Google Maps

A Geographic Information System (GIS) was developed to measure the criminal area of the city of Palembang district using Google Maps API technology. The information system shows the location of the crime point and generates notifications to the user when entering and leaving the area (Lukman et al., 2019).

Maps have been used for crisis management in natural disasters such as earthquakes, fires, floods, among others. They provide a source of data to even locate hotels and help travelers determine locations. In combination with MySQL and PHP databases they can generate the development of a cartographic service (Ibrahim & Mohsen, 2014).

2.4. GitHub

It is a social application platform where users publish open-source projects, generating an academic search system (Shao et al., 2020).

GitHub allows improving collaboration and learning in complex, large-scale distributed activities, inferring technical objects or editing code, and coordinates work by improving skills and optimizing times (Dabbish et al., 2012).

2.5. PHP

PHP (Hypertext Preprocessor) is a language for developing dynamic Web pages along with HTML. Some PHP developments are forums and MediaWiki, being a different option than ASP.NET/C#/VB.NET Microsoft (Putra et al., 2019). It was created by Rasmus Lerdorf in 1995. Initially PHP was called FI (Form Interpreted), it used a set of scripts to interpret forms on the Web (Juledi, 2021).

2.6 MySQL

MySQL is a DBMS (Database Management System) used to program Web applications. It is distributed under GNU/GLP (General Public License). Compatible with Windows, Linux, Unix, FreeBSD, Mac OS, among others. It employs a relational database system with indexes that can retrieve table information or group-related information. Access to data is high speed since it works with ISAM tables to use query caches, through indexing and search algorithms (Souza, 2019).

2.7. UML

The Unified Modeling Language (UML) is a standard used to visualize, design, and document systems software models. It also describes the behavior of the actors that interact with the system (Jaya et al., 2018).

3. Methodology

– **Data collection**: Collect data through interviews, observation forms and other sources related to the research.

– **Analysis and design**: Applying the iterative and incremental UML model, structure and behavior diagrams of the application were designed, decomposing the most important components. Figure 1 presents the general use case diagram of the application.

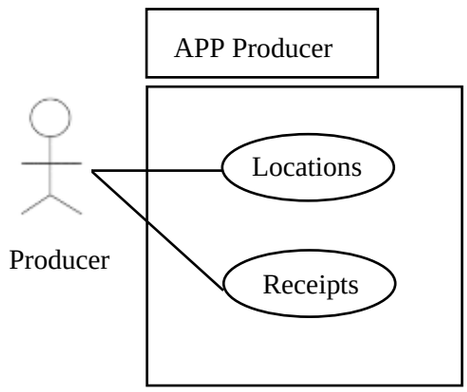

Figure 1 General use case diagram

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– **Implementation**: The code is created in Android Studio and PHP to access the data, using the Volley library. The proposed application requires the Internet, since it connects to a MySQL database centralized on a Web server. It represents a Client/Server architecture, the cell phone is the client, while the server combines MySQL, Database API Scripts and PHP code, see Figure 2.

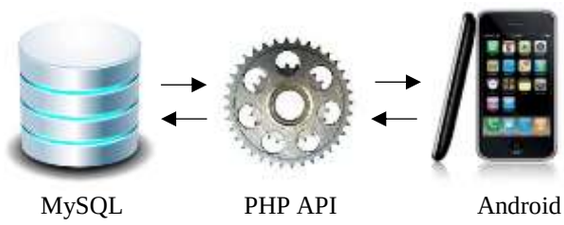

Figure 2 Client/Server Architecture

The mobile application includes operations with Google Maps to display information about the location of pickup points, as well as plot a route. For this process, the use of an API KEY provided by Google is implemented when using the map service.

Regarding the PHP API, its functions are described below:

– Execute query requests through commands applied to the MySQL database installed on a Web server.

– Format the output as a JavaScript object in notation (JSON).

– **Testing**: Unit, functional and integration tests were carried out, detecting some defects that were addressed in a timely manner.

– **Deployment**: The testing phase continues even during deployment, when the application is used by the end user, especially if problems are experienced that were not detected during initial testing. In this phase, some minimal adjustments were made, until the application was released. The implementation was direct, publishing the developed application on Google Play.

4. Results

Figure 3 presents the general query of the locations of the temporary collection centers by state, displaying general data such as address, telephone number, observations, and the option to view the location map.

Figure 3 Consultation of locations of temporary collection centers

Figure 4 displays the map of the location of all the collection centers that correspond to a state. By clicking on each red balloon, a label is displayed with additional information related to the temporary collection center.

Figure 4 Location of temporary collection centers

Figure 5 shows the directions for the routes to get there, with information on each means, as well as the corresponding distances and times.

This consultation makes it easier for producers to access the reception locations for empty agrochemical containers.

Figure 5 Path to locations

Figure 6 presents a query of the receipts issued to a producer during deliveries. The delivery sheet is shown that includes the date, details of the containers delivered, place where it was delivered, number of pieces and kilos. Finally, in the Receipt column there is the option to display the receipt on the screen.

Figure 6 Consultation of delivery receipts

Once the receipt is presented in PDF format, the option is offered to download it and share it through media such as WhatsApp, Teams, among others.

This receipt contains the folio, date, place of delivery, quantity, weight as well as observations related to the empty containers of agrochemicals delivered. See Figure 7.

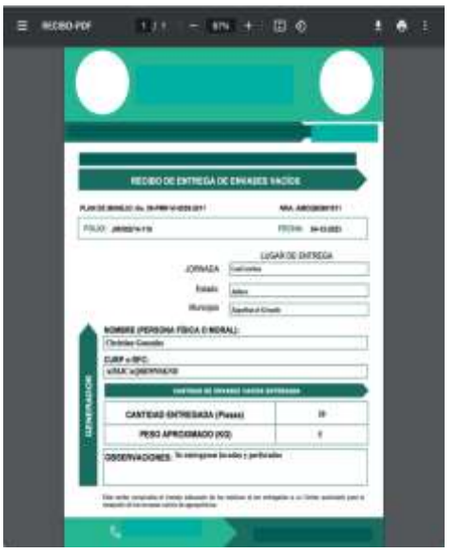

Figure 7 Download receipt

5. Acknowledgments

We thank the Tecnológico Nacional de México for contributing to the registration and authorization of the research project carried out, as well as the company AMOCALI, A.C. for their willingness and support for the development of the project.

6. Financing

This work has been funded by TecNM [Número de proyecto 17887.23-P].

The application represents a strategy that facilitates the deliveries of empty agrochemical containers made by agricultural producers. Reviewing the location of collection points is key to the active and responsible participation of a community, avoiding the abandonment of containers in rivers and roads. The database installed on the Web server is continuously managed, feeding the locations and consequently recording packaging deliveries, in addition to allowing the mobile application to make different types of queries at any time. The development of this project contributes to guaranteeing the productive and environmental sustainability of natural resources in the tasks carried out by the agricultural sector, adopting best practices in the field, protecting the environment and people's health.

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7. Conclusions

The application represents a strategy that facilitates the deliveries of empty agrochemical containers made by producers. Consulting the locations of the collection points is key to active and responsible participation, preventing containers from being abandoned. The database installed on the Web server is continuously managed, feeding locations and recording packaging deliveries, allowing the mobile application to make different types of queries at any time. The development of this project contributes to guaranteeing the productive and environmental sustainability of natural resources in the tasks carried out by the agricultural sector, adopting best practices in the field, protecting the environment and people's health.

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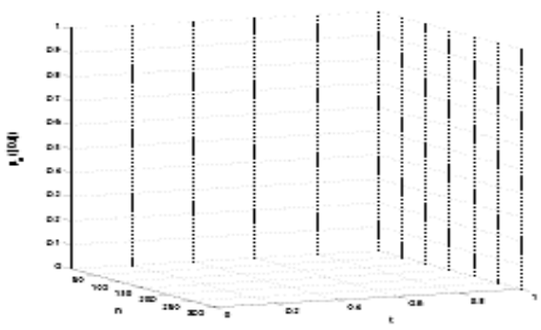

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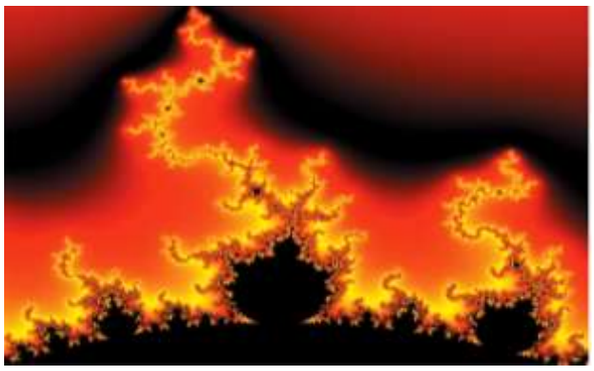

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