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A Platform for Inpatient Safety Management Based on IoT Technology

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Abstract: There is a need to integrate advancements in biomedical, information, and communication technologies with care processes within the framework of the inpatient safety program to support effective risk management of adverse events occurring in the hospital environment and to improve inpatient safety. In this respect, this work presents the development of a software platform using the Scrum methodology and the integrated technology of the Internet of Things for monitoring and managing inpatient safety. A modular solution is developed under a hexagonal architecture, using PHP as the backend language through the Laravel framework. A MySQL database was used for the data layer, and Vue.js was used for the user interface. This work implemented an RFID-based nurse call system using Internet of Things (IoT) concepts. The system enables nurses to respond to each inpatient within a given time limit and without the inpatient or a family member having to approach the nursing station. The system also provides reports and indicators that help evaluate the quality of inpatient care and helps to take measures to improve inpatient safety during care. In addition, diet management is integrated to reduce the occurrence of adverse events. A LoRa and Wi-Fi-based IoT network was implemented using a LoRa transceiver and the ESP32 MCU, chosen for its low power consumption, low cost, and wide availability. Bidirectional communication between hardware and software is handled through an MQTT Broker. The system integrates temperature and humidity sensors and smoke sensors, among others.

Keywords: inpatient safety; IoT; adverse event; hexagonal architecture

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1. Introduction

Patient safety is one of the most critical programs within Colombia's healthcare institution for hospitalized patient care. Every day, medical staff and nurses strive to monitor and be attentive to prevent adverse events that jeopardize the health and integrity of the patient. Adverse events are considered alterations or injuries resulting from patient care that can cause temporary or permanent disability and sometimes death. These events are divided into preventable and non-preventable events. The former may occur if the WHO (World Health Organization) standards for patient care are not respected. The latter occurs even when WHO standards have been correctly applied [1].

The WHO is interested in guaranteeing safe patient care that minimizes the occurrence of adverse events and their consequences. This is reflected in various initiatives, including the WHO Patient Safety Program. As a WHO member country, Colombia has a national patient safety policy led by the Obligatory System for Quality Assurance in Health Care, which aims to prevent the occurrence of situations that affect patient safety and to reduce or eliminate the occurrence of adverse events to enable safe facilities that are internationally competitive. However, the occurrence of these events and incidents is still frequent, and the use of assistive technologies in patient safety management is still limited [2]. Therefore, the primary purpose of this work is the development of an integrated hardware and software platform for in-hospital care in healthcare centers in the city of Cartagena, which contributes to the improvement of care services as part of the patient safety program by integrating various technologies, including the Internet of Things (IoT), cloud computing and a hexagonal software architecture.

Throughout history, technologies have positively impacted healthcare processes, specifically patient safety [3]. Massive advances in materials science and futuristic technologies over the past 25 years have enabled improvements in constructing innovative medical devices. Their development is occurring at an astonishing pace. A system implementing hardware and software technology to support patient safety management is mentioned in [4]. This shows that personalized medicine relies on sensors of various sizes and instruments produced using sophisticated manufacturing techniques and technology, including bones, steel, exoskeletons, valves, neck bones, tissues, organs, etc.

Innovations facilitate the development of uniquely personalized medical products, including software design and advanced production methods in 3D additive printing. By the end of 2020, IoT is projected to be a USD 163 billion market in healthcare, making a significant contribution to the healthcare industry and benefiting patients, families, doctors, and hospitals [4].

The latest advances in nursing communication systems enable optimized and personalized communication between patients, doctors, and caregivers to increase patient satisfaction and improve the quality of care. Simplified nursing workflows are achieved through intelligent devices and management software, enabling real-time indicators from intra- and inter-team communication and patient-triggered calls. Also integrated is continuous access to the patient's clinical data, including lab results and monitoring data for vital signs. Examples of manufacturers and systems are West-Com Nurse Call Systems Inc, Amplion, Inform emergency call system from Cornell Communications Inc, Intelligence Nurse Call Communication System, Vocera Communication Platform, and Provider 790 Nurse Call System from Jeron Electronic Systems Inc, among others. In addition, there are also worldwide patented integrated systems that implement hardware and software technologies in patient monitoring [5].

Some companies have been working on patented systems that integrate IoT. For example, the patent entitled US20180174682—System and method for protocol adherence [6] from General Electric, refers to a system and method that provides an integrated and automated workflow, sensor, and reasoning system that automatically detects protocol violations, generating alarms and records of these infringements appropriately, which facilitates the staff to comply with the standards and thus also allows for studying different protocols by comparing the effectiveness of the care provided by each protocol. The system provides real-time alerts to medical staff on actual care processes, thus reducing the number of adverse patient events and improving staff behavior related to protocol compliance. It deploys an optical-based sensor system that determines the location and trajectory of people, the presence of particular objects, scenarios, and the status of configured devices, which singularly or in conjunction with other analog and digital data sources, informs a reasoning engine that calculates the position of the monitored people and objects. Another essential patent is the "Nurse call system", which relates to calling a nurse from anywhere in a hospital while the patient is carrying a mobile phone. The nurse call system includes mobile telephones carried by inpatients, connected to a controller via a base station, and mobile phones carried by the nurses [7].

Patient safety during the hospital care process continues to be a challenge for institutions; there are many reasons why this is still the case, as reported in [8–10]. The authors highlight the figures related to medication application, effective monitoring, timely reporting of adverse events, rates of patient falls that can generate cost overruns in care, and permanent sequelae for patients, the latter representing 30% of the cause of fracture among older adults. Given the above, it is crucial to implement technical tools that include specialized software and use the IoT to support monitoring to minimize all factors contributing to avoidable adverse events and thus provide safe and comprehensive care.

This document presents the results of developing a patient safety management platform. Section 2 describes the background, including the hexagonal architecture for software development. Section 3 describes the methods, techniques, and materials used. Section 4 details the results, presenting the development of the software and hardware components, the use of LoRa technology, and the integration of the components into an overall system. In Section 5, the discussion is presented. Finally, the conclusions are stated in the last section.

2. Background

In computer science, architectural design refers to the relationship between the most relevant structural elements, architectural styles, and design patterns that guide software design and development, aiming to guarantee quality aspects and compliance with product requirements [11]. Through the architecture, technologies and integrations can be defined according to the project's needs, ensuring scalability at the level of functionalities and technology changes. Likewise, the architecture must ensure that the software solution is not tightly coupled. In this regard, the hexagonal architecture (Figure 1) allows the implementation of an application structure that is easily scalable and where components are not tightly coupled to the system [12]. It promotes separation of the application by encapsulating the logic into different layers or regions defined with their responsibility, allowing for higher level isolation, stability, and control over the specific business logic. Each layer of the application has a set of responsibilities and requirements. This creates more apparent separations between logic and functionality and how those layers interact. The layers of the architecture are domain, application, and infrastructure. The domain layer represents the application's core, responsible for maintaining the consistency of the state of the domain objects and business rules modeled in the software, which are uniquely determined by the domain services. The domain layer and its business logic define the behavior and constraints of the application in terms of how the other layers communicate with this layer.

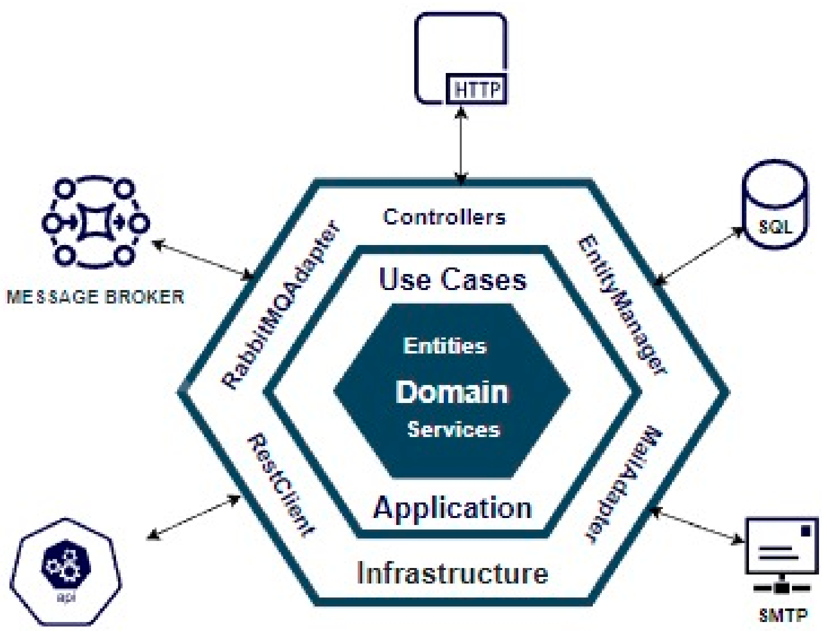

Figure 1. Hexagonal Architecture.

The application layer is where the application's use cases live (register area, register diet, add a bed, etc.). This is considered the entry point to the business logic. Finally, the infrastructure layer corresponds to code that changes based on external decisions. This layer transforms the communication between external actors (vendors) and the application logic so that both become independent; this means that SOLID's dependency inversion principle is applied, and thus external dependencies can be decoupled.

This architecture applies the dependency rule that determines that the code in each layer should only know the classes located in the layer immediately following, understanding the order of the layers from the outside to the inside of the circle: Infrastructure -Application -Domain. The inner layers of a clean architecture should know nothing of the outer layers. This means that the core is seen as an API with well-specified contracts. Defining ports or entry points and interfaces (adapters) allows other modules (UI—Graphical User Interface, DB—Database, Test—Test) to implement them and communicate to the business layer without the business layer having to know the origin of the connection.

3. Materials and Methods

The presented research has a qualitative methodological approach. The research approach is application-oriented, seeking to solve problems related to the occurrence of adverse events in the process of hospital care by implementing technological tools in the timely management of patient safety in the hospitalization area. It is based on a series of epistemological precepts related to software development, IoT, and cloud computing. This adds an important differentiating factor that reduces preventable adverse events during inpatient care.

To achieve the objective of developing a prototype of an integrated care system in the hospitalization areas of the city of Cartagena, which contributes to the quality-of-service provision within the framework of the patient safety program, it was necessary to propose a methodology structured in a series of phases that define a clear research path. The steps are the characterization of processes, construction of the platform, development of hardware components, and validation of the integrated system.

This paper presents results related to the development of the hardware component and its management through a mobile application, the construction of the platform, and the integration of hardware components.

Figure 2 shows a graphical abstract of the elements and actors that make up our final product. It is focused on patient care in the inpatient area of a hospital. This system seeks to minimize the adverse events that occur in the care process, associated with incorrect administration of medicines, failures in the infrastructure and biomedical equipment, administration of the wrong diet, and accidents caused by the patient himself. Our product consists of hardware elements such as temperature and humidity sensors among others. In addition, devices such as the multi-functional button, corridor light and toilet button have been developed. These hardware elements are integrated with the software component which has a web platform for diet administration, biomedical equipment maintenance, patient management and medication administration. It also consists of a mobile app that displays sensor indicators, and the nurse call dashboard is displayed via a smartTv that sits in the nursing lounge.

3.1. Process Characterization

The characterization of the process is necessary for the development of any software solution, as this is part of the phase of "analysis and understanding of the business" and allows one to know the problem firsthand, to understand the real needs of the client and how he currently provides a solution to the problem. This way, aspects that can be improved are identified, and possible solutions are devised with the help of engineering.

This first phase characterizes the adverse event management process in hospital clinics in the city of Cartagena, Bolivar department in Colombia. It involved determining the baseline of the product and collecting information that determines the starting point for the construction of the platform. This was followed by an in-depth study at the client's site, the purpose of which was to gain in-depth knowledge of the client's requirements, their current situation, and the project's scope. This also included visiting health entities that allowed observations and interviews to be conducted to gain direct knowledge of the current status of the adverse event management process and the implementation of the patient safety policy.

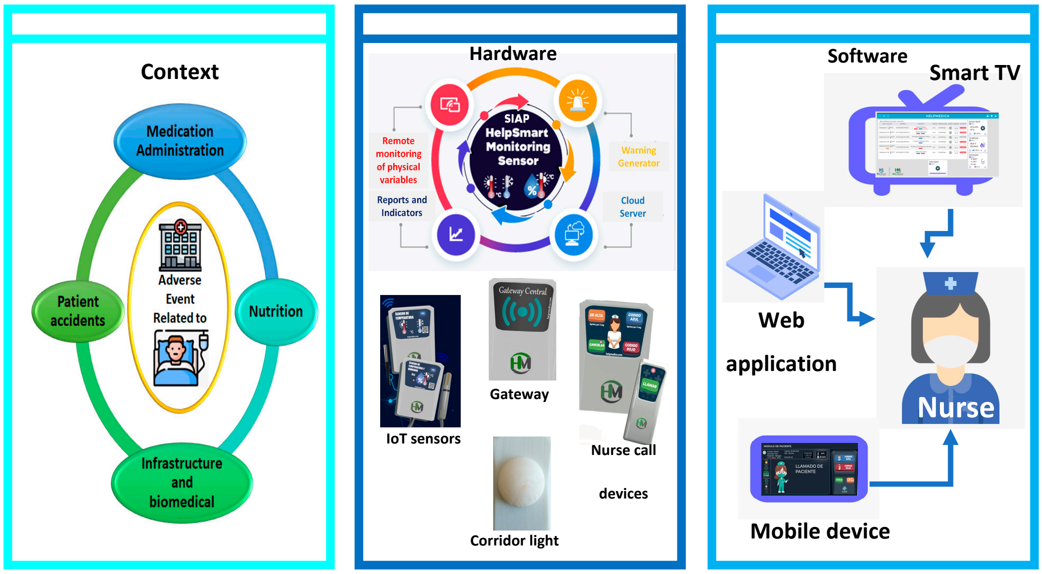

Figure 2. Graphical abstract.

This stage made it possible to understand the concept of adverse events, the context in which they occur, the factors involved, and the types of events. Adverse events are those complications that unintentionally happen in the hospital care process. Type four events are related to infections associated with the care process, mainly due to invasive procedures, deficiencies in hand hygiene, and noncompliance with hospital protocols and standards. Adverse events related to medication administration, falls, and postural changes are also identified. It is, therefore, necessary to implement mechanisms for continuous monitoring and follow-up by healthcare personnel.

3.2. Platform Development

This phase involves the development of the Web and Mobile Platform for Patient Care Management. It combines the software and hardware development process by implementing an agile development framework called Scrum [13]. This has been widely used in software development teams, allowing daily progress on the project through stand-up meetings and weekly or fortnightly deliveries of a minimum viable and functional product that generates value for the end user, being refined and increased in each iteration. The Scrum framework seeks to identify requirements, prioritize them, and define the criteria to be developed or refined in each iteration (sprint). Each deliverable is shown to the project stakeholders at the end of each sprint so that early feedback on the product is obtained, allowing for timely correction of possible deviations in the expected scope of the product [14].

Project planning aims to estimate resources, costs, and time. The development of this activity comprises a general analysis of the project characteristics and, consequently, the identification of the main elements of the development process. This project proposes using the Scrum methodology (see Figure 3) as a guide for software development [15]. The activities of the Scrum methodology that were adopted for this work were:

- "Sprint Planning", which consists of a meeting with the entire Scrum team in which the "Backlog" is inspected to define the items to be delivered in each "Sprint", and to verify the status of the activities assigned and which are recorded in the project management tool Jira.
- "Daily Scrum", which consists of a 15-min daily meeting. In this case, it was held at the end of the day. The software development team members briefly explained the current progress and difficulties in this meeting.
- "Sprint Review". A presentation showing the finalized functionalities and, therefore, the increment achieved in each "Sprint" was given every 15 days.
- There was a team of backend, frontend, and database software engineers. In addition, there was a "Scrum Master" in charge of guiding the implementation of the Scrum methodology and ensuring that the meetings took place. The "Product Owner" was also part of the team, communicating with the client and collecting business knowledge.

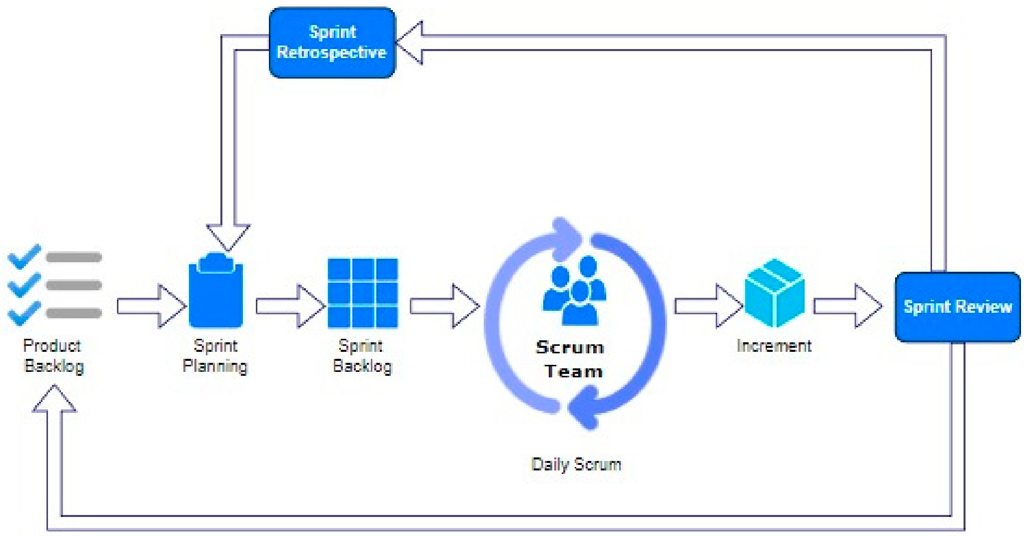

Figure 3. Agile Development—Scrum.

Requirements engineering consists of methods that allow the collection of information to better understand the project requirements. Surveys, questionnaires, and interviews allowed a complete understanding of the institutions' needs and the project's requirements. The identified requirements were captured in user stories. User stories allow the informal detailing of software functionality from the user's perspective, like the software requirements of traditional methodologies. The basic structure of a user story contains the profile, which indicates the end user's role and the need, which describes the purpose of the functionality in the software. The user story ends with the goal, which is why the user requires the functionality. In a nutshell, user stories are elements that allow the requirements to be broken down into more minor functionalities, structured as follows: the role of the user is indicated, the action or task to be performed in the application, and the purpose of this action. Generally, a primary user story reads as follows: "I, as a Role, want/need to execute an action destined to a specific end". An example of a user story within the project can be seen in Figure 4.

The user stories were created in the project management tool Jira, and the following was added to each story [16]: mockups (graphical interface design), an explanation of the expected flow, i.e., how the user interacts with the application, and the specifications of the data fields. This becomes the input for the development team to develop the functionality described in the user story. In Jira, the development team's tasks are recorded, including user stories, test cases, and defects, so the planned tasks can be tracked.

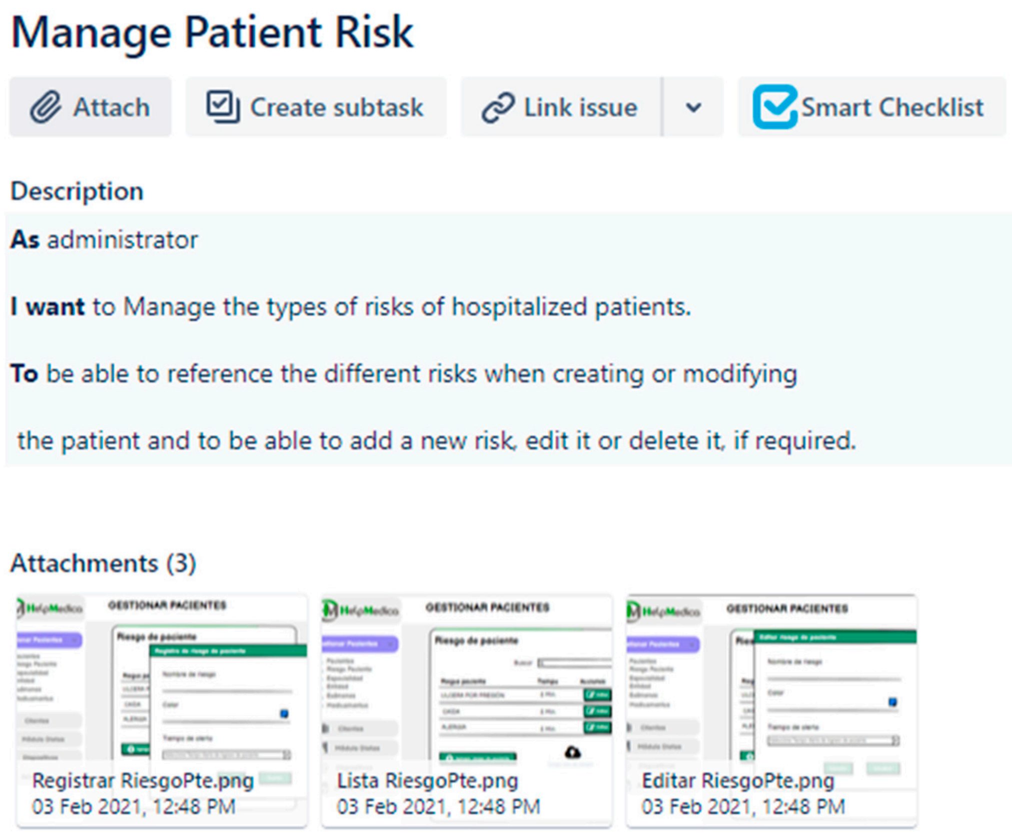

Figure 4. JIRA User Stories—Manage Patient Risk.

Figure 5 shows a report of one of the "Epics" statuses and the user stories. It was possible to complete around 95% of all user stories. A score of incidents is constantly active because bugs reported by end-user were added to the dashboard to be assigned and resolved by the software development team.

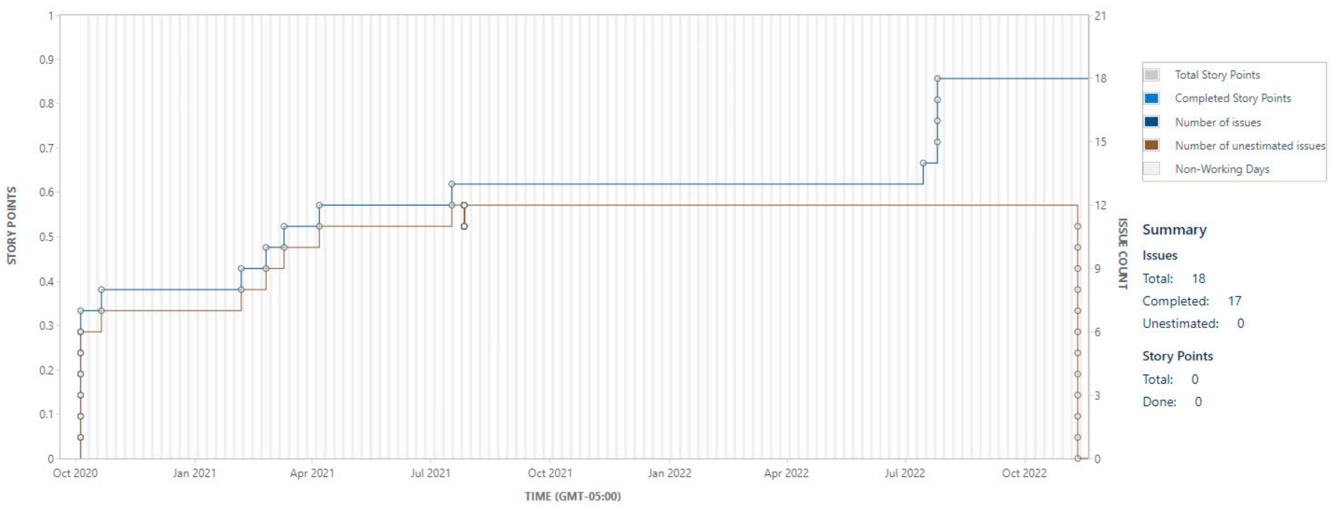

Figure 5. Jira Epic Report.

Additionally, we present in Figure 6 the status of all the "Epics" defined in the software project, which had six large "Epics" containing elements such as user stories, issues, bugs, and tasks assigned to the Scrum team members. Each "Epic" summarizes a set of functionalities that result in one or more modules. The "Configurations" Epic corresponds to the general configuration of the application, such as company, devices, areas, and services of the hospital. The Epic "Control of Attendance" corresponds to managing attendance, schedules, and calendars. "General Parameters" allows us to connect with other applications and extract information from the general configuration of the application. "Page from which the patient is monitored" contains functionalities related to monitoring. "Patient Management" groups together patient, diet, and pharmacy management.

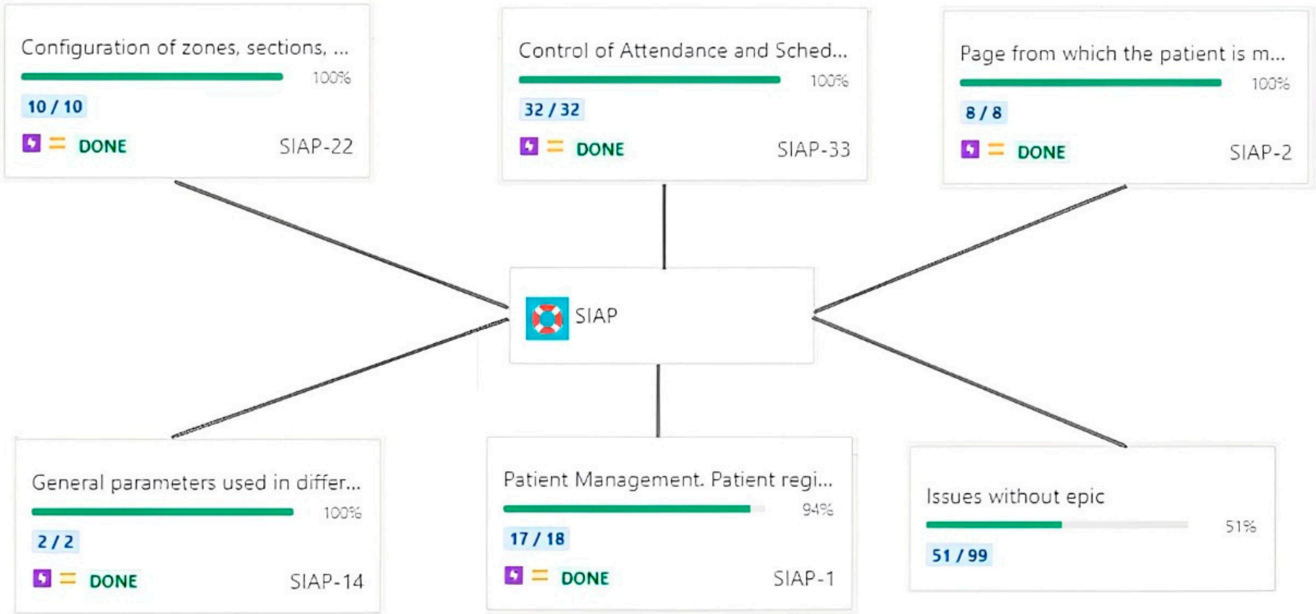

Figure 6. JIRA- Project Epic Map.

The process continued with the design of the system components by defining the information and process architecture, the system architecture, and its structure in terms of requirements. The patterns and components of the system were also determined. Subsequently, developing the functionalities continued using the PHP programming language, the Laravel framework [17], and Vue.js [18]. In addition, the development model was implemented based on the hexagonal architecture.

3.3. Architecture Design

When analyzing the project's needs, a modular solution was proposed under a hexagonal architecture [12], shown in Figure 1. The application's core contains the business logic implemented by different modules. The adapters are located around the core, which are in charge of communicating with the outside (e.g., database access components, message handling components, and web, among others).

In this work, the hexagonal architecture was implemented in PHP and the Laravel framework, shown in Figure 7.

Figure 8 shows the "src" folder, which is the application's core. Inside it are the different modules and the domains or entities inside each module. For example, the folder "Areas" clearly shows the three layers of the hexagonal architecture: Infrastructure, Application, and Domain.

The Application layer includes the controllers responsible for presenting the content to the user. The module's business rules, behavior, and restrictions are defined in the domain layer. The infrastructure layer is responsible for the communication and interaction of external services with our application. In this layer, we used Eloquent, an ORM (Object-relational mapping) that maps the relational database structure implemented with MySQL to classes in PHP.

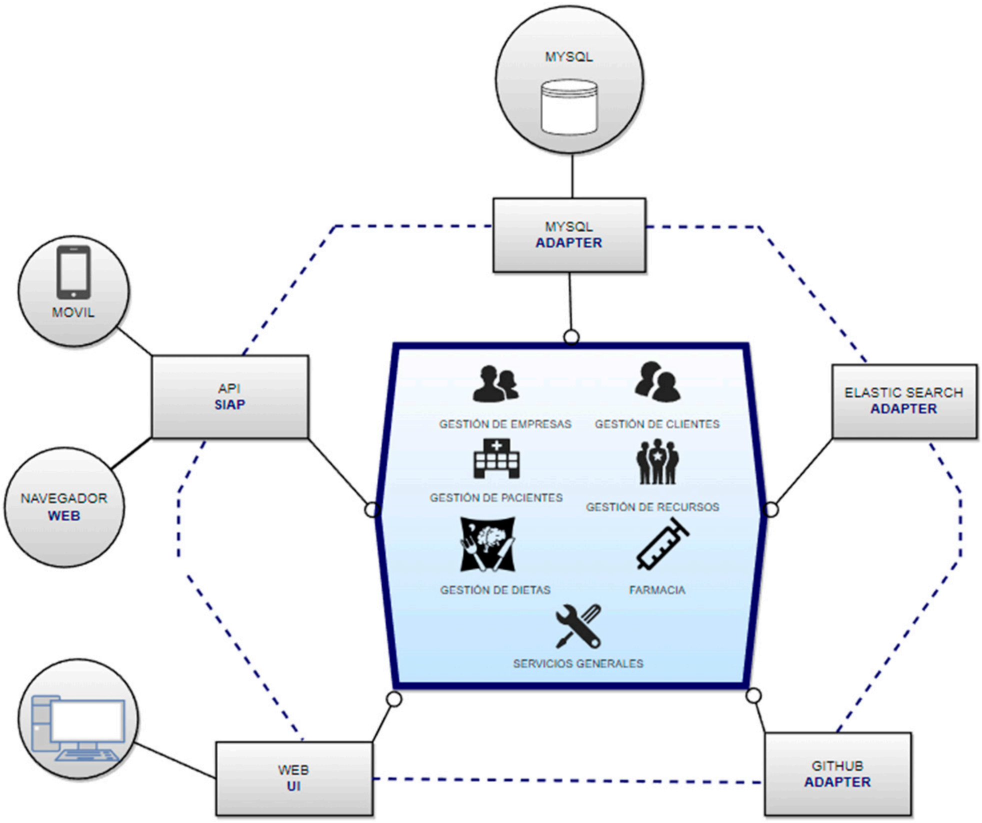

Figure 7. SIAP Hexagonal Platform Architecture.

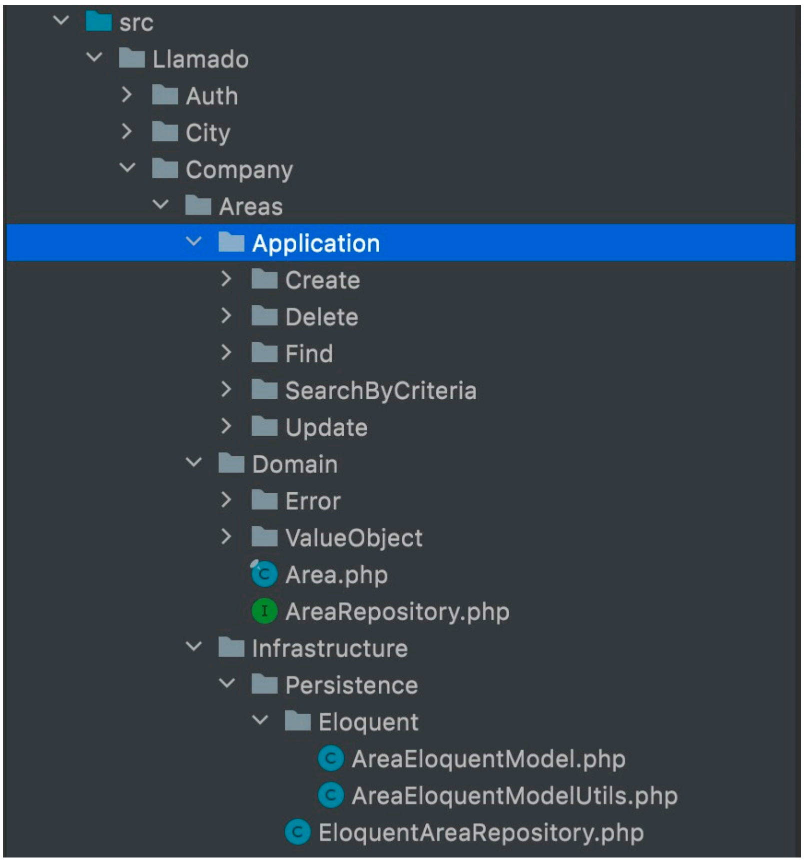

Figure 8. Project Structure.

3.4. Component Diagram

Figure 9 shows the components of the system, as well as their communication and integration. Starting with the IoT devices responsible for measuring environmental parameters: temperature and humidity, or devices that emit information, including nurse call devices. These devices are connected to an MQTT broker functioning as a server and providing a method for sending messages to the devices using a Publish–subscribe pattern. Therefore, it accepts messages published by clients and broadcasts them to subscribed clients.

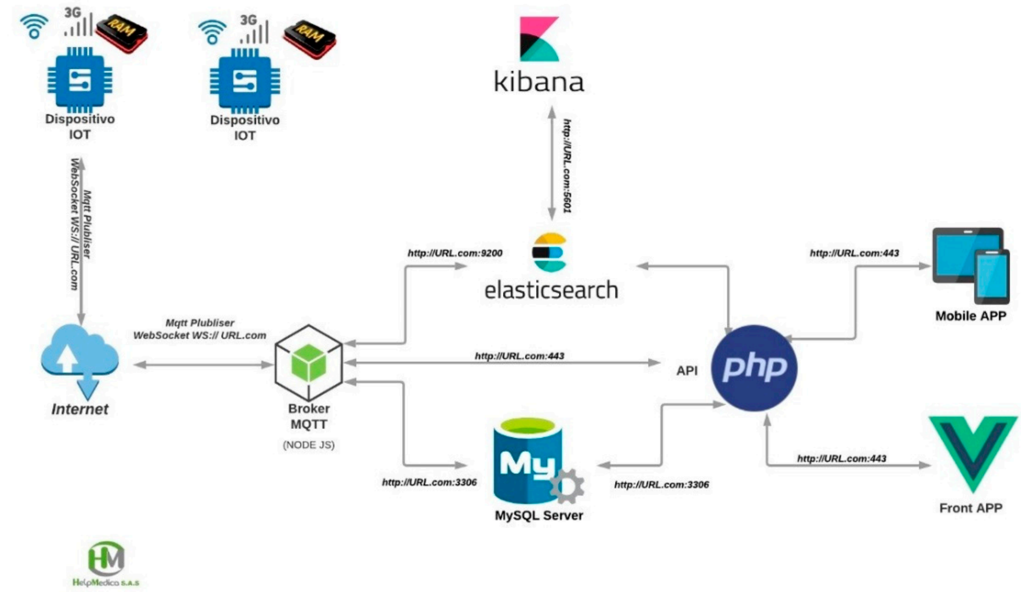

Figure 9. Components Diagram.

The MQTT connection diagram in Figure 10 details the MQTT communication protocol [19] that works over TCP/IP or other network protocols with bidirectional and lossless data support. The data output by the MQTT Broker is indexed in Elasticsearch [20], performing search and analysis on all types of data, including text, numeric data, geospatial, structured, and unstructured data. During an indexing operation, raw data, log files, or message files are converted into internal documents and stored in a data structure similar to a JSON object.

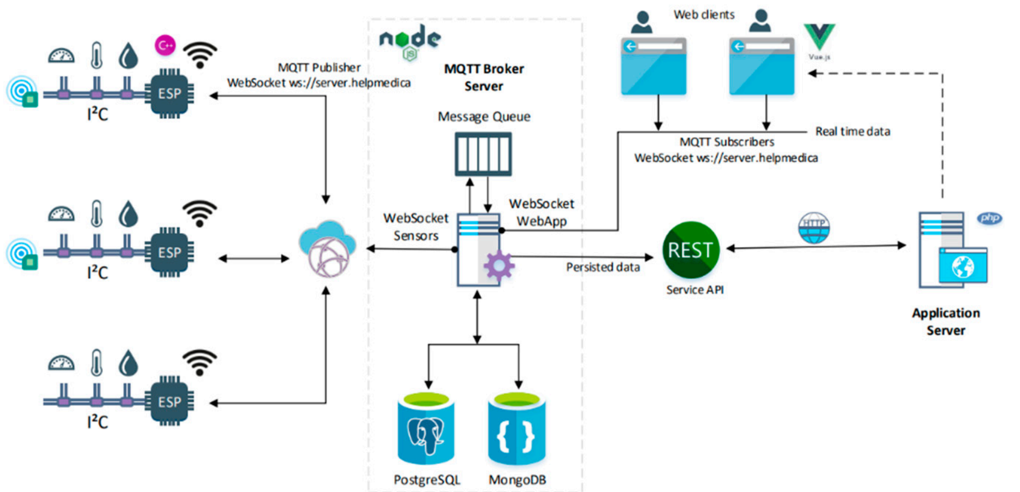

Figure 10. Hardware Component Diagram.

Kibana visualizes information from the MQTT Broker indexed in Elasticsearch [21]. Kibana enables visual analysis of data from an Elasticsearch index or multiple indexes. The Kibana interface allows users to search data in Elasticsearch indexes and visualize the results through standard charting options. On the other hand, Elasticsearch consumes the API by sending information to the database each time it is re-requested or by querying the data stored in the database. This API is developed in the PHP framework Laravel.

This data is sent through the API to the MySQL database, a relational database management and administration system that can execute multiple tasks simultaneously. All queries to the database are made through the API, which stores all the information sent from Elasticsearch and is used later when making queries or generating reports. Finally, Vue.js is the framework used in developing the web user interfaces. It is designed from scratch and can be used incrementally [22], achieving a web application capable of managing all services: creating users, creating hospitals, adding IoT devices, generating reports, and viewing historical data from the devices.

4. Results

4.1. Development of Hardware Components

This phase includes the design of wireless electronic modules and cases using the system components. Such as selecting sensors required for temperature and humidity measurement, fire alarm coupling circuit, system coupling, the image processing module, and construction of the patient button. The prototype devices developed are a corridor light, fire alarm, image processing system monitor, toilet button, and patient button. The development of the nurse call system relies on sensors used in different areas of the institution. The electronic design automation software (Proteus Design Suite v. 8.12) and the software environment used in the design of electrical circuits (KiCad EDA) are used. All the printed circuit boards designed are governed under the IPC-2222 B standard [23], raising the quality and reliability of the product's production.

The ESP-WROOM-32 (ESP-32S) is a microprocessor module that incorporates Wi-Fi and Bluetooth using the popular ESP32 chip. This ESP-WROOM-32 module is an SoM (System on Module) manufactured by Espressif that integrates the ESP32 SoC, the FLASH memory, the oscillator crystal, and the Wi-Fi antenna into one module on the PCB and also includes a metallic shielding cover against external interference [24]. Its function in the Integrated Patient Care System is to detect the push of the buttons incorporated in the multifunctional, central, bathroom, and corridor light cards and to execute synchronization actions between cards, send messages between cards using different communication protocols, and measure variables, among others. Another critical aspect of the ESP32 is its ability to enter deep sleep mode, where its current consumption is reduced to a few microamperes. It wakes up by applying a voltage signal on one of the pins compatible with this function, called hardware interrupts. Because of this, the cards must take into account the use of these pins. In this case, the voltage signal that wakes up the ESP32 must come from the LoRa transceiver because when it receives a message from another card, the ESP32 must interpret it and execute the corresponding action [25].

Considering the need for the devices to be physically protected and easy to use by providers and patients, the protective casings are designed using 3D design tools using ABS IP67 material, complying with international standards for the degree of protection against water and dust permeability during complete immersion. Once the tracks have been defined on the corresponding electronic components, the external surfaces are roughened using Computer Numerical Control (CNC), and the tracks are then printed. For each of the modules required in the Integrated Patient Care System, a manufacturing methodology is proposed as follows: Construction of the printed circuit board and assembly of the electronic components, attachment of the wireless transmission module, bonding of the 3D-made protection and verification of the mold on the maximum surface of the printed circuit board and attachment of the image processing camera and validation of the communication between the prototype and the camera in digital form.

The verification of errors and failures of the prototypes is subjected to continuous testing during hours and scenarios of maximum consumption, sending, and receiving data. The communication evaluation will wirelessly link the prototypes inside the patient room and their external modules before bidirectional communication to the patient center.

4.2. LoRa Network for Communication

In this work, the data transmission is wireless via a LoRa network, shown in Figure 11. Each device connects or sends data to a central gateway connected to the internet and to the MQTT broker, where the data is processed. The broker is the one who connects to the hardware and software, thus receiving and responding to requests.

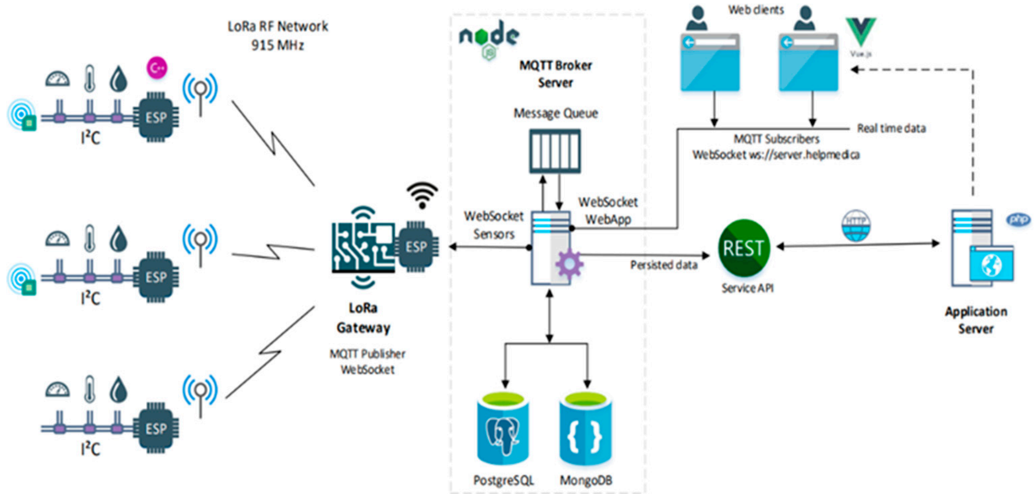

Figure 11. IoT Architecture on LoRa Network.

The LoRa network was selected because of the advantages it offers. It operates in the industrial, scientific, and medical non-commercial radio frequency bands called ISM, which are bands reserved initially and intended for use in industrial, scientific, and medical devices—widely used because no license fees are required. Because of this, equipment operating in these bands must have high immunity to interference, requiring communication protocols and equipment to have error tolerance and interference protection mechanisms, such as spectrum spreading techniques.

LoRa is a technology that uses CSS (Chirp Spread Spectrum), a frequency spread modulation method. These chirp pulses cause the LoRa frequency to increase or decrease over time continuously, and data transmission is transmitted by sequencing these chirp pulses. LoRa typically uses three frequency bands: 433 MHz, 868 MHz, and 915 MHz base frequency. These ISM band frequencies allow a more extended range than the 2.4 GHZ and 5 GHZ frequencies used, for example, in Wi-Fi and Bluetooth communications, with better penetration against line-of-sight obstacles and longer connection distances. The allocation of each of the frequencies is defined according to the regions assigned by the International Telecommunication Union—ITU. Region 1, which essentially corresponds to Europe, Africa, and some other countries, uses the frequency of 868 MHz, region 2, which corresponds to America, uses the frequency of 915 MHz and region 3, which corresponds to a large part of Asia, commonly uses the frequency of 433 MHz [26].

In Colombia, 433 MHz and 915 MHz versions of LoRa are commonly used. The 868 MHz and 915 MHz frequencies commonly use the same hardware. In some cases, only a configuration and programming adjustment of the devices to be used in the other frequency band is necessary. The 433 MHz band has a better range than the higher 868 MHz and 915 MHz bands, but because it is already used by many devices, including RF remote controls, and other similar devices, it can present more interference and data loss problems than the higher bands [27,28].

4.3. Integration of Hardware and Software Components

The integration of the Hardware Components and the Web and Mobile Platform of the Integrated Patient Care System consists of identifying the electronic modules of the system, establishing an integration matrix within the physical spaces in a hospital environment, and planning a bidirectional connection between the end devices and the monitoring center through the visualization of a web and mobile platform that allows the user and hospital staff to have traceability of the adverse events proposed in the Integrated Patient Care System.

4.3.1. Nursing Call

The nurse call system comprises a set of devices that alert nursing staff of an emergency or patient request so that care can be provided on time. It is a wireless system that, in addition to having the essential elements of the nursing call systems, is accompanied by quality management software that allows institutions to measure response times in care, reduce effective bed occupancy intervals and optimize some hospital indicators, as well as to involve all administrative and care staff who are interested or involved in patient care processes. Figure 12 below shows the in-room nurse call system.

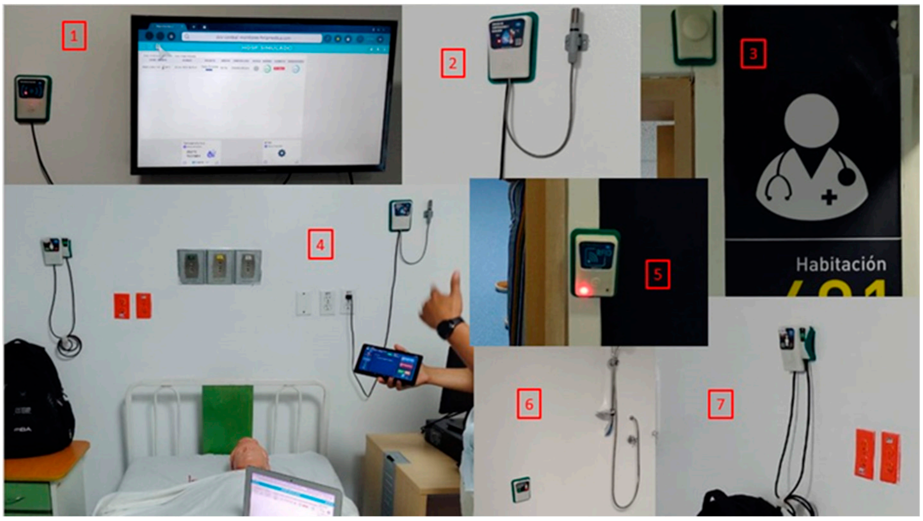

Figure 12. IoT-based nurse call system. 1. Central gateway and Smart TV in central monitoring 2. Temperature, humidity, and comfort sensor 3. Corridor light 4. data display from Tablet 5. RFID sensor 6. toilet button 7. multifunctional patient call button.

First corresponds to the central portal and Smart TV in central monitoring in the nursing station, followed by the sensors for monitoring environmental variables. Third, there is the corridor light that shows the generated alert in different colors. The fourth image shows the patient's room with the nursing call devices and display of indicators on a tablet, image 5 shows an RFID device for use by healthcare personnel who must mark their entry and exit from the room for patient safety. patient. Image 6 shows the emergency call button located in the bathroom of the room. Finally, the multifunctional button is shown that allows timely attention to each of the calls made by the patient and the healthcare team. In this way, the system manages to have a historical and statistical record of these services through management software, contributing to decision making.

This system can be coupled to electric hospital beds, allowing externalization of the alerts generated by the sensors that these bring, substantially reducing adverse events caused by falls. It has a discharge button, which allows the complete care and administrative team in charge of this process to be informed in real-time when inpatients are discharged, which translates into improved bed availability and better economic income for the healthcare institution.

4.3.2. Multifunctional Button

- The device called the "multifunctional button" has four buttons: "Discharge", "code blue", "cancel", and "code red" which, when pressed, send a radio frequency signal to the corridor light device and the nursing reception.
- The code blue button's function is to alert nurses to the presence of cardiac or respiratory arrest. Nurses should activate it. The code red button alerts to the occurrence of bleeding. The discharge code button must be activated when the doctor indicates discharge, and from that moment, the time is counted until the patient is physically discharged and the bed is released. The last button corresponds to the cancel button that stops the call of the button that has been pressed.
- Additionally, a hand-held button was developed that allows the patient to call the nursing staff. This device requires a power supply of 3.3 volts, using two AA-size batteries (LR6) of 1.5 V DC. Approximate power consumption when active or in use is less than 50 microamps and less than ten milliamps in standby mode, having a battery life of about one year.

4.3.3. Bathroom Button

This device is used to alert when the patient is in the bathroom and requires the nursing staff. It has two buttons: call and cancel. The device has wireless connectivity.

4.3.4. Central Gateway

The central gateway receives the transmissions sent by the sensors using LoRa communication and transmits them to the software via serial communication (emulated on a USB port). The size of this device is L: 117.4 mm $\times$ W: 85 mm $\times$ H: 27.8 mm.

4.4. Measuring Energy Consumption

When programming the modules within the hardware processing unit, the main objective is to support the connection between the nodes within the local network and the central monitoring station. The programming is structured so that, once the individual modules have been linked, they can recognize each other and operate compactly. The protocols used allow the devices' battery performance to be improved, saving on data transmission and reception.

Within the integration, a strategy is developed that can measure the energy consumption of each module connected to the monitoring center, detailing the sampling time of reading/sending information and recurring operating profiles of patients. It also makes it possible to verify errors in the sent and received data, allowing problems to be solved due to data loss, as can be seen in Table 1. Finally, a test was carried out on the Integrated Patient Care System prototype in the hospitalization areas of the city of Cartagena, with all the modules connected to the monitoring center, web, and mobile platform.

Two current consumption tests were carried out on the multifunctional card, which allowed the estimated current consumption of each card to be determined. The results are shown below:

Table 1. Power consumption test.

Test	Power Mode ESP32	LoRa	Power Consumption
Test 1	deep sleep	active	4.32 mA
	active	sending	69.2 mA
	active	receiving	53.1 mA
	active	standby	43.9 mA
Test 2	active	active	65.9 mA
	active	sending	71.1 mA
	active	receiving	54.4 mA
	active	standby	44.3 mA

5. Discussion

The main advantages of wireless communications include savings in economical cost [29,30] and space in the deployment infrastructure over networks that use guided transmission media [31,32]. In the development of this work, it was possible to integrate hardware and software components in a control and monitoring system for patient care in the framework of the patient safety program by implementing IoT technologies in devices for the nursing call. LoRa technology is selected over other technologies because it uses the sub-GHz ICM (Industrial, Scientific, and Medical) band of 868 MHz (Europe) and 915 MHz (America), achieving more excellent radio propagation coverage than higher unlicensed frequencies (e.g., 2.4 GHz, 5.8 GHz) because it has lower attenuation due to the size of its wavelength. As LoRa is characterized by its low channel capacity (bps) and extensive signal coverage, the Sub-GHz band is best suited to it [33–35].

According to the Ministry of Health in Colombia, the developed system is successfully applied in more than 30 patient rooms distributed in 5 hospitals with the highest complexity levels. These hospitals are in the city of Cartagena de Indias, the capital of the Department of Bolivar, where the system's functionality has been achieved in all its features for uninterrupted daily use, incorporating improvements to the nursing call system described above. Furthermore, the review of state of the art between 2015 and 2020 shows that the highest concentration of patents at a geographical level reveals a technological dominance of three countries: Japan, the United States, and China, which allows these nations under constant monitoring to identify new developments related to the object of study. This can be the starting point for establishing relations and contacts that lead to cooperation agreements or any other technology transfer mechanism with the leading companies in producing patents in these countries.

Concerning identifying the main competitors, the presence of a variety of companies dedicated to manufacturing and commercializing nurse call systems in Colombia stands out, which reveals the boom and importance it has in the country's health system. However, it is crucial to encourage technological production in this area at the national level (Colombia) and, above all, through the management of low-cost equipment, as well as to make use of legal protection mechanisms, including patents, to increase the levels of innovation in the health sector.

6. Conclusions

This paper proposes an approach to software development using Scrum methodology and IoT integration, selecting mobile wireless and LoRa networks for communication technology to achieve hospital monitoring and help to avoid accidents or adverse events during patient's attention.

We have created and implemented a functional prototype consisting of sensors and hardware devices connected to a mobile and web application. The web platform is a robust and scalable tool with functions for monitoring and controlling patient care to prevent adverse events. Successful results were obtained in the evaluation of the performance of the used sensors and the type of communication, LoRa, in terms of transmission speed, low latency, low power consumption, and low cost, generating technological and economically added value, making the developed product the potential to be implemented in many Colombian hospitals and can be replicated or adopted in other countries.

The development of this project had limitations during its execution, associated with the occurrence of the COVID-19 pandemic, which limited face-to-face contact with the hospital hospitalization areas, making it difficult to gather requirements or user histories. Regarding the final limitations of the products built, it was identified that because the platform is connected to the cloud, it requires the client to have 24/7 internet availability. Additionally, when implementing tablets in each room, it was identified that these devices must be connected to the backend firebase at all times, which may involve additional monthly charges. In terms of wireless transmission over the LoRa network, it is identified that the signal can be considerably reduced when there is electrical interference or very thick walls. This system must operate in existing healthcare facilities, which in many cases do not have mains power at the point of installation of the device. Therefore, all call devices and sensors were designed to be battery powered. With the implementation of the low power modes, estimated battery lifetimes of at least 12 months under normal operating conditions are possible.

It is recommended for future work to develop a hybrid system that allows to work in decoupled mode and thus does not depend on the permanent internet connection, allowing to have local databases that operate without internet and that, from time to time, perform the synchronization with the cloud to keep the data updated. It is also recommended that an external server does not handle the platform's notifications to reduce the operating costs of connecting to the firebase backend and that this service is configured on a local server of its own. For the implementation of systems to detect patient falls, cameras were used for detection in the initial development phase. Future developments should preferably use IMUs (Inertial Measurement Unit) and embedded motion detection applications, which will reduce the cost of the devices (they can be used in a wristband) and minimize the privacy risks associated with the use of cameras.

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