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IoT and MQTT-based cardiovascular parameter monitoring system for medical alerts

Sistema de monitoreo de parámetros cardiovasculares basado en IoT y MQTT para alertas médicas

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Abstract

This paper presents the development of a computing platform for the real-time monitoring of cardiovascular parameters derived from bioelectrical signals. A comprehensive analysis of primary users was conducted, leading to the identification of both technical and functional requirements. The interface design was guided by Sommerville's methodology. The system architecture is based on a microservices model, incorporating a relational database and enabling integration with data transmitted from Internet of Things (IoT) devices. The platform was evaluated through incremental stress testing, starting with zero users and increasing in steps of 100 up to 5,000. A total of 22,132 requests were processed at a peak rate of 440.4 requests per second, with an average response time of 930 ms and 95% of responses occurring within 2,300 ms. The system demonstrated error-free performance with up to 1,700 concurrent users. At 5,000 users and 26,393 total requests, a minimal error rate of 0.16% was recorded, confirming the platform's stability under high workloads. These findings validate the feasibility of the proposed solution for remote biomedical monitoring, offering an efficient, scalable, and robust tool for real-time health supervision.

Keywords: HTTP, MQTT, biomedical parameters, Computing platform

Resumen

Este artículo describe el desarrollo de una plataforma informática destinada al monitoreo en tiempo real de parámetros cardiovasculares a partir de señales bioeléctricas. Se realizó un análisis de los usuarios principales y se identificaron los requisitos técnicos y funcionales necesarios. Asimismo, las interfaces fueron diseñadas aplicando la metodología propuesta por Sommerville. La arquitectura del sistema se basa en microservicios, incorporando una base de datos relacional y permitiendo la integración con datos provenientes de dispositivos del Internet de las Cosas (IoT). La evaluación del sistema se llevó a cabo mediante pruebas de simulación de carga, iniciando con 0 usuarios y aumentando en intervalos de 100 hasta alcanzar los 5000 usuarios. Durante las pruebas, se procesaron 22 132 solicitudes, con una tasa promedio de 440,4 solicitudes por segundo, manteniendo un tiempo de respuesta medio de 930 ms y logrando que el 95 % de las respuestas se ubicaran por debajo de los 2300 ms. Se comprobó que el sistema opera sin errores hasta un umbral de 1700 usuarios concurrentes. Con 5000 usuarios y un total de 26 393 solicitudes, se registró un porcentaje mínimo de error del 0,16 %, lo que evidencia su capacidad para gestionar altas cargas de trabajo de manera estable. Estos resultados confirman la viabilidad de la plataforma para el monitoreo remoto de parámetros biomédicos, ofreciendo una solución eficiente y escalable para la supervisión de la salud en tiempo real.

Palabras clave: HTTP, MQTT, parámetros biomédicos, plataforma informática

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1. Introduction

Experts in Information and Communication Technology (ICT) are increasingly transforming biomedical research to enhance disease prevention and monitoring efforts [1,2]. Interdisciplinary collaboration among specialists in ICT, electronics, automation, and medicine is essential to drive technological innovation in the healthcare sector.

In Ecuador, there is substantial potential for the development and implementation of information platforms tailored to the healthcare sector. However, current initiatives often lack effective integration between Internet of Things (IoT) capabilities and real-time monitoring systems. This gap underscores the need for a technological solution that facilitates accessible, efficient, and continuous monitoring of vital signs using IoT-enabled devices.

Dr. Tedros Adhanom, Director-General of the World Health Organization (WHO), has emphasized the importance of leveraging digital technologies to ensure universal access to healthcare services. According to his perspective, these tools should not be regarded as ends in themselves, but rather as essential means to advance public health [3]. Among their most impactful applications is the monitoring of vital signs, which plays a critical role in enhancing medical care [4].

A systematic review conducted by García et al. evaluated the clinical effectiveness of ICT-based interventions in the management of chronic diseases. The study included 24 investigations focused on asthma, hypertension, diabetes, heart failure, and cardiovascular prevention. The findings indicated that the use of ICT enhances the detection and monitoring of cardiovascular conditions, reduces mortality rates, and improves the efficiency of healthcare services [5].

Cardiovascular parameters such as heart rate and blood pressure provide critical insights into a patient's systemic condition, particularly following clinical procedures [6]. This highlights the need to develop both software and hardware tools specifically designed to support cardiovascular healthcare [7].

In this context, the Internet of Medical Things (IoMT) has emerged as a key technology, enabling the interconnection of medical devices with software applications via network infrastructures [8]. IoMT significantly enhances healthcare by facilitating remote patient monitoring, diagnosis, and treatment [9,10].

Additionally, applications integrated into smartwatches and smart rings have been developed to record data such as heart rate, oxygen saturation, and body temperature. However, these devices are primarily intended for tracking physical activity and sleep patterns. Their specifications explicitly state that they are not classified as medical devices; consequently, the data they provide are for informational purposes only and should not be used for clinical, diagnostic, or research applications.

In the province of Santa Elena, a device was developed for home-based monitoring of biomedical parameters. Although the acquired data were displayed on a test IoT platform, a customized information system for comprehensive data management was not implemented [11]. Nevertheless, such devices hold considerable potential to actively engage physicians and specialists in the continuous monitoring of patients' health status.

This article presents the progress of a multidisciplinary research project titled "Research on IoT Applications in Bioelectric Signal Acquisition" (CUP: 91870000.0000.389571), led by the Technology, Science, and Education (TECED) research group of the Faculty of Systems and Telecommunications at the State University Peninsula of Santa Elena. The project supports the specific objective of integrating the bioelectric signal acquisition system with a database-free platform. Within this framework, information technologies are leveraged to develop an innovative tool for continuous patient monitoring, incorporating clinical evaluation of the patient's health status.

The primary objective was to develop an information platform for monitoring heart rate, oxygen saturation, and body temperature, which are derived from bioelectric signals.

This article is structured as follows: Section 2 details the materials and methods employed in the design, development, and evaluation of the mobile application and web platform; Section 3 presents the results obtained following the implementation of the proposed infrastructure; and Section 4 outlines the conclusions and acknowledgments.

2. Materials and Methods

2.1. Methodology

This article addresses the design and development of an information platform for visualizing data transmitted from an IoT device that reports heart rate, oxygen saturation, and body temperature, which are derived from bioelectric signals [11,12].

As part of the user analysis, two primary profiles were identified: physicians and patients. According to a 2023 report published by the United Nations, over 75% of the global population owns a mobile phone, and 65% has internet access [13]. These figures supported the decision to prioritize the development of a mobile application for patients. Furthermore, recent studies [14,15] show that physicians spend most of their workday using computers, justifying the implementation of a web-based application tailored to healthcare professionals.

For data transmission, the Message Queuing Telemetry Transport (MQTT) protocol was selected, as it is widely used in IoT applications at the application layer [16]. This protocol is distinguished by its ability to support continuous data transmission while optimizing bandwidth and minimizing latency [17].

Asaad et al. demonstrated that an IoT-based remote health monitoring system, integrating GSM, Wi-Fi, and MQTT, is highly effective for patient follow-up in rural areas beyond the coverage of hospital networks. The system achieved a 99.89% success rate in data transmission, with a round-trip time of 7.5 ms and a total energy consumption of 900 mWh, using MQTT as the primary communication protocol [8].

For real-time data visualization in the user interface, MQTT over WebSocket was implemented, drawing on findings from the Internet Engineering Task Force (IETF) working group, which identifies WebSocket as an efficient solution for bidirectional client-server communications, eliminating the need for multiple HTTP requests in web applications [18]. Oliveira et al. compared MQTT and WebSocket using ESP8266 modules and Node.js servers for data exchange, concluding that WebSocket is preferable in environments with round-trip times exceeding 1 ms [19].

Similarly, in the IoT system design proposed by Jun-Oh Seo, MQTT was employed for sensor data collection, and WebSocket for bidirectional communication in low-energy scenarios, thereby validating the combined efficiency of both protocols. Accordingly, in this project, MQTT over WebSocket was adopted for real-time data visualization in the user interface, while MQTT was also used for communication between the broker and the PHP service responsible for database storage, as illustrated in Figure 1. This configuration prevents the generation of multiple HTTP requests that would otherwise occur if data were sent directly from the application to the database.

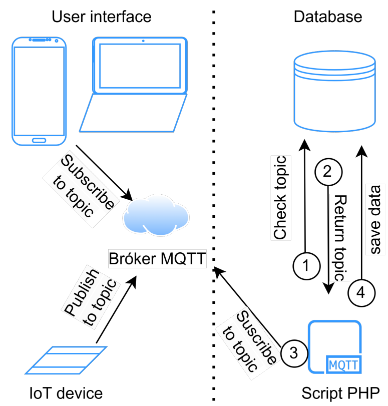

Figure 1. Data connection architecture

Once the corresponding analysis was completed, the system's functional requirements were defined. These requirements provide an overview of the platform, promote clear and consistent communication among stakeholders, support a comprehensive understanding of the system, and establish a robust foundation for the design phase. Additionally, the general use case of the system is depicted in Figure 2.

The functional requirements were organized into specific modules tailored to specific user roles, such as physician or patient, as well as general modules applicable to all users.

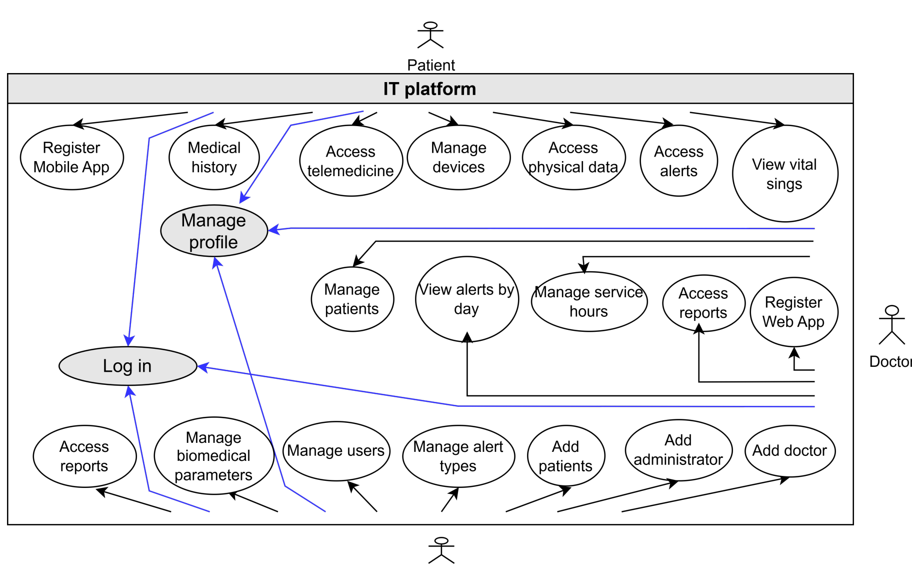

Figure 2. System Use Case

General Modules.

- **Authentication Module:** All users (physicians, patients, or administrators) must authenticate to access the system. Access permissions and visible information vary depending on the assigned role, ensuring both privacy and security. Patients may create their accounts exclusively through the mobile application, while physicians are required to register via the web platform. The system also supports credential recovery by allowing users to enter their email address. A verification code is then sent, which, once validated, permits the user to update their login credentials.
- **Profile Module:** This module allows users to customize and update their personal information, including phone number, email address, and profile picture. It also enables users to modify authentication parameters.
- **Reports Module:** Physicians can access detailed reports on the number of patients seen and consultations conducted. Patients can view their medical prescriptions and clinical history. Administrators can query aggregated system data, including the total number of registered devices, patients, and physicians. Information is presented in both tabular and graphical formats to support data analysis.

Administrator Role Modules.

- **Administration Module:** Administrators are provided with tools for comprehensive user management, including physicians, patients, and other administrators. They can create, enable, disable, and edit user accounts. Additionally, administrators can manage alert types and define new biomedical parameters.

Patient Role Modules.

- **Medical Module:** This module allows patients to select physicians by specialty and healthcare facility, and to configure access permissions for their medical data.
- **Telemedicine Module:** This module enables redirection to WhatsApp and Telegram for conducting consultations, video calls, and sending direct messages to the physician via the platform.
- **Biomedical Data Module:** This module displays real-time values for heart rate, body temperature, and oxygen saturation. It also allows patients to manage additional health data, such as weight and height, annotate alerts, and view their complete alert history. Only the assigned physician has access to the patient's data. Patients can disable a malfunctioning device and register a replacement.

Physician Role Modules.

- **Patient Module:** Physicians can access the complete list of assigned patients and review their vital signs, including heart rate, temperature, and oxygen saturation, along with the history of generated alerts. During consultations, physicians can record clinical observations, issue electronic medical prescriptions, and generate detailed reports for each biomedical parameter. They can also communicate with patients via WhatsApp, Telegram, or through direct messaging on the platform.

One of the core functionalities represented in the general use case diagram is the visualization of biomedical parameters, as shown in Figure 2. To illustrate the underlying system logic, a channel diagram was developed and is presented in Figure 3. This diagram outlines the sequence of activities required to perform this function, along with the actors or components involved in the process: patient, system, server, and user interface.

Each actor is responsible for specific actions, represented by activity rectangles that illustrate the flow from data acquisition to its presentation to the end user. The diagram is vertically segmented into parallel lanes, each delineating the responsibilities of a given actor. This structure enables a clear visualization of the vital signs display process and how it unfolds sequentially [20].

To visualize vital signs on the interface, the user must first place their finger on the IoT device. Once the device processes the data, it is published to the MQTT broker. On the platform, the user then selects the option corresponding to vital signs, which triggers an internal connection to the user's specific topic. The data are subsequently received and displayed in real time on the interface.

In addition to visualizing vital signs, the acquired data are stored in the database and used to automatically generate alerts. To identify abnormal values for heart rate, oxygen saturation, and body temperature, reference ranges were established based on prior studies [21–23]. These thresholds served as the basis for defining the criteria that trigger alert activation.

Once the values are transmitted from the IoT device, they pass through a series of validation filters. If any parameter falls outside the defined normal range, an alert is generated, recorded in the database, and simultaneously sent to both the emergency contact and the assigned physician.

For heart rate, the system first verifies the type of parameter received. If the parameter corresponds to heart rate, the system analyzes the patient's gender and age to classify the value as either appropriate or abnormal. The thresholds established for this classification are presented in Table 1.

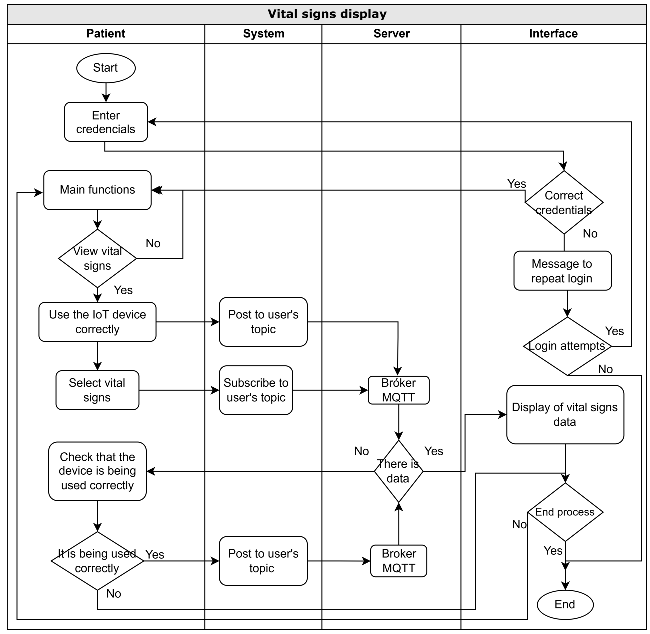

Figure 3. Channel Diagram

Table 1. Heart Rate thresholds by age and gender (beats per minute)

Heart rate		
Age (years)	**Men**	**Women**
20-29	86 or more	96 or more
30-39	86 or more	98 or more
40-49	90 or more	100 or more
50 or more	90 or more	104 or more

If the parameter corresponds to oxygen saturation and the recorded value is below 90%, an automatic alert is triggered, as this level is classified as severe hypoxemia, as shown in Table 2.

Table 2. Oxygen Saturation

Oxygen Saturation Thresholds for Hypoxemia	
Age (years)	**Value**
Mild hypoxemia	90-94 %
Severe hypoxemia	< 90 %

Finally, if the parameter corresponds to body temperature, the system can generate two types of alerts: hypothermia and fever, based on the thresholds established in Table 3.

Table 3. Body Temperature Thresholds for Alert Classification

Temp Body temperature	
Age (years)	**Value**
Hypothermia	< 35 °C
Low-grade fever / Fever	37,2 a 38,9 °C
Hyperthermia	> 40,6 °C

To support a clearer understanding of the alert generation process, the diagram shown in Figure 4 was developed.

After the system requirements were clearly defined, the architecture type was selected. The information platform adopts a microservices architecture model. In this approach, the client layer communicates via HTTP, enabling request and response handling through a FHIR-compatible API developed using Node.js and PHP. This API implements resources such as Patient in accordance with the HL7 FHIR specification and provides RESTful endpoints that consume data in the application/fhir+json format, integrated with a MySQL database.

Additionally, when clients access the application, they subscribe to the topics published on the MQTT broker. The connection is established using the MQTT protocol over WebSocket, enabling real-time data visualization. A PHP script retrieves the relevant topics from the database, manages the subscription process, and stores the received values.

Additionally, a separate PHP script is responsible for automatically sending email alerts once the data have been stored. This architecture was chosen for its ability to manage resources in a distributed manner through independent services. In this model, the client requests a resource over the network, and the corresponding server processes the request and returns a response based on the requested service, as illustrated in Figure 5.

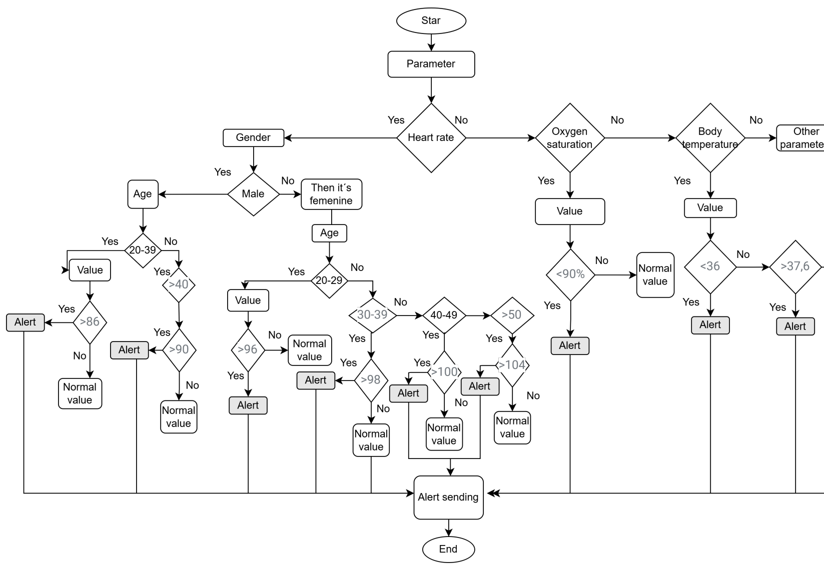

Figure 4. Alert Generation Diagram

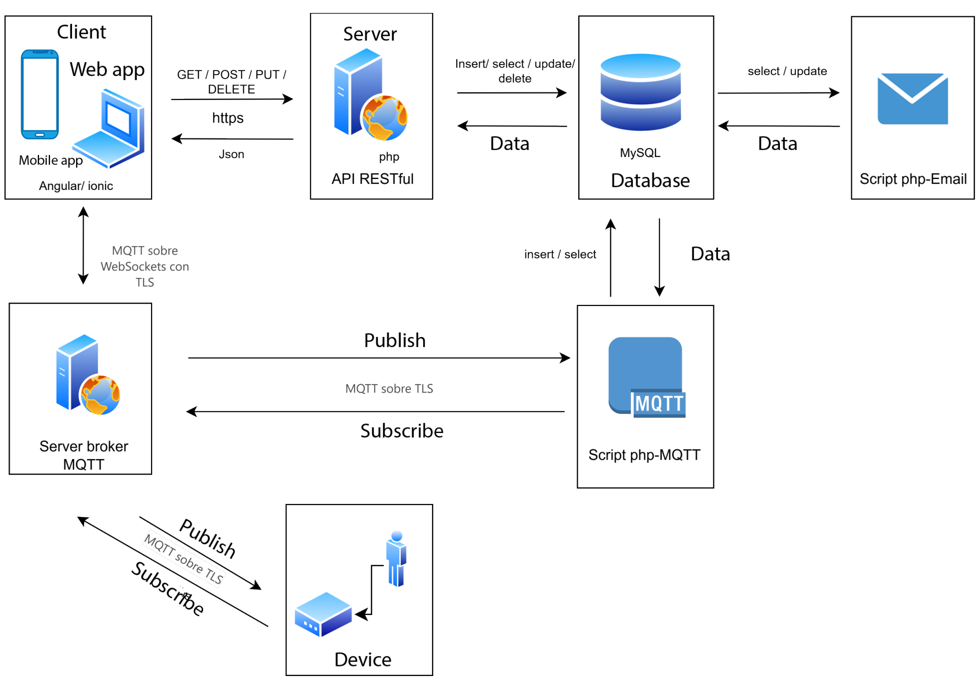

Figure 5. System Architecture

To support real-time data handling and prevent API saturation caused by multiple queries, a PHP script was developed to subscribe to the MQTT broker, retrieve the data, and store it in the database. This process activates triggers that generate additional information, which is subsequently processed by other independent scripts to execute specific actions.

This architectural model allows multiple users to access system resources simultaneously without causing saturation. The various advantages of this approach are detailed in reference [24].

Although this article primarily focuses on the development of the software application, this section describes the components used to build the device responsible for acquiring three bioelectrical signals: heart rate, oxygen saturation, and body temperature, as illustrated in Figure 6.

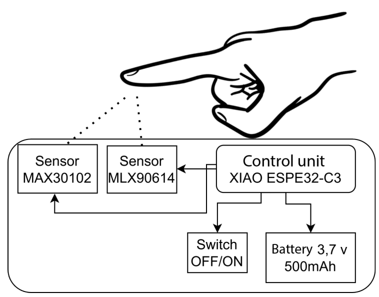

Figure 6. Device components

The device is powered by a 3.7 V battery and a switch, and it includes an XIAO ESP32C3 control unit, a high-performance IoT development mini board designed for low-power applications and wireless wearable devices.

Additionally, the MAX30100 sensor was integrated to measure heart rate and oxygen saturation. This sensor incorporates a discrete-time filter that rejects 50/60 Hz interference, as well as low-frequency and ambient noise.

To measure body temperature, the MLX90614 sensor was used. This sensor offers high accuracy over a wide temperature range (-70 °C to + 380 °C), with a resolution of 0,02 °C, a 90° field of view, and an accuracy of up to ± 0,5 °C at ambient temperature.

Each sensor acquires its respective biomedical parameter values and publishes them to the MQTT broker. The platform communicates with the device via this intermediary. The time required to visualize the data depends on the device itself, as it performs internal calculations to prevent the transmission of erroneous values. Once the device is operational, data are typically received within approximately one minute and are then immediately displayed on the user interface.

To support platform functionality, data modeling was conducted using a relational database model, as shown in Figure 7 [25]. Given the existence of two primary user roles, patients and physicians, a relational structure was required to define their associations and store user-specific data. The advantages of relational databases were leveraged, particularly their ability to link tables through primary and foreign keys.

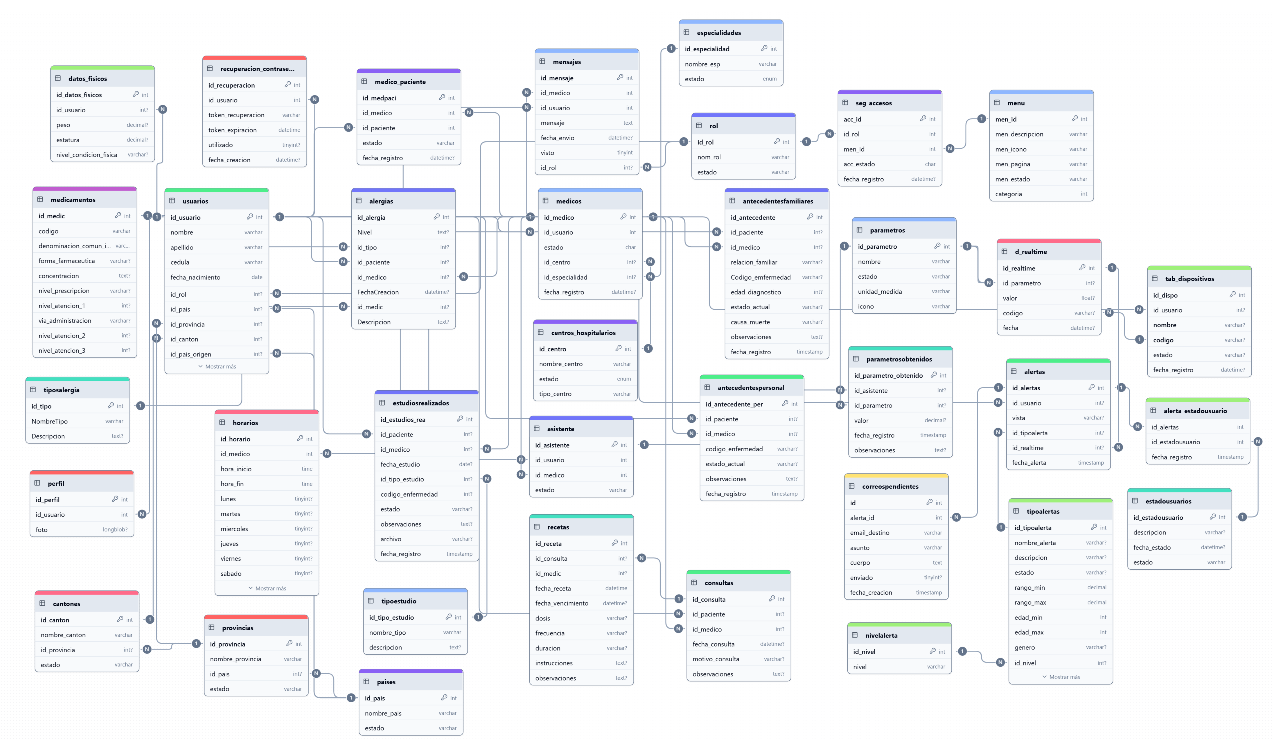

Figure 7. Data model

To ensure proper data modeling, normalization principles were applied to organize information efficiently and eliminate redundancies and inconsistencies. Normalization, introduced by Edgar F. Codd, establishes a set of rules that promote the separation of concepts and minimize anomalies caused by attribute dependencies, thereby reducing data redundancy.

The model design incorporates the first three normal forms: First Normal Form (1NF), Second Normal Form (2NF), and Third Normal Form (3NF). The First Normal Form ensures that all attributes are atomic, meaning they contain indivisible values with no duplications or internal subdivisions. The Second Normal Form eliminates partial dependencies by requiring that all non-key attributes depend solely on the primary key. The Third Normal Form removes transitive dependencies to further enhance data integrity.

These principles guided the construction of the database model, allowing redundancy to be avoided and enabling the use of relationships to implement triggers that execute various functions.

2.2. Interface Design

The interface design for the platform was guided by the methodology proposed by Sommerville. This approach identifies three essential activities required to develop an effective user interface: user analysis, system prototyping, and interface evaluation. Through the completion of these activities, the final product is achieved [26].

For the user analysis, the most frequently used device types were taken into consideration. Additionally, random surveys were conducted with individuals involved in the research project and with potential patients to understand their expectations for an information system. Based on the insights gathered, the interface model was designed, including the selection of color schemes, core functionalities, login screen, and main interface layout. Key elements such as the display of biomedical parameters, alert functionality, and doctor–patient integration were also incorporated into the design process.

The mockups were developed using the Justin mind tool. This stage enabled a clear visualization of the interface design for both the web and mobile applications, facilitating the necessary adjustments to align with the functional requirements and meet the needs of the primary users.

An evaluation was then conducted with members of the TECED research group, which includes faculty, external specialists, and students. Feedback was collected and used to implement targeted improvements. Once these modifications were completed, the final interface design was approved.

The prototype was developed using the incremental development methodology, which structures the project into a series of successive increments [27], as illustrated in Figure 8.

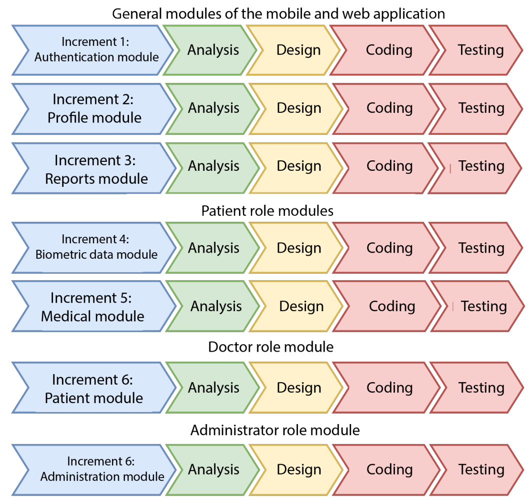

Figure 8. Incremental Methodology

This approach consists of segmenting the overall system functionality according to the requirements provided by subject-matter specialists and performing the corresponding phases of analysis, design, coding, and testing.

2.3. Development Materials of the Software Platform

For the development of the software platform, a computer with 32 GB of RAM and 500 GB of storage was used. The interface designs for both the mobile application and the web version were created using the Justin mind prototyping tool.

For front-end development, Angular and Ionic were used due to their ability to streamline the implementation of both mobile and web applications. This choice facilitated the integration of multiple features and responsive components, allowing the interface to adapt effectively to various screen sizes.

According to the platform's functional requirements, the relationships between physician and patient data were considered. In the design, user roles are queried directly from the database, which informed the selection of a MySQL relational database. For backend development, PHP, the Fat-Free Framework, and Node.js were used, along with the Visual Studio Code text editor, since both PHP and Node.js offer high compatibility with MySQL.

To compile and deploy the mobile application to production, Android Studio was used. This development environment requires a minimum of 8 GB of RAM to operate efficiently.

For real-time data acquisition, records were collected from two IoT devices [11, 12], using the MQTT communication protocol over WebSocket. To store the incoming data, a service was implemented that subscribes to the broker via the MQTT protocol. During the testing phase, data were simulated using Node-RED, alongside real data transmitted by the first device [11] and by another version of the bioelectrical signal acquisition device [12].

3. Results and discussion

3.1. Results

During the development of the software platform, several key aspects were addressed, including communication protocols, user analysis, interface design, system architecture, and database modeling. Upon completion of the development phase, the primary functions associated with the physician profile were defined. These include viewing the patient list, monitoring alerts generated throughout the day, recording consultation data, and generating reports that summarize the number of patients treated and consultations performed.

Figure 9 shows one of the main interfaces designed for physicians, which enables graphical visualization of stored vital sign values and allows users to consult the most recent records. Additionally, the system provides a summary that applies basic statistical calculations such as the mean, median, and mode to support clinical data analysis.

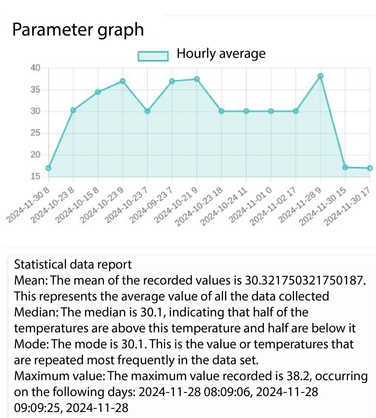

Figure 9. Main interface for the physician

Figure 10 displays the interface for the patient profile, showing recorded vital sign values along with additional features such as alert notifications, access to telemedicine services, and consultation of physical data.

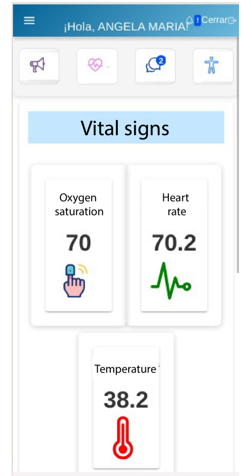

Figure 10. Main interface for the patient

In addition to having a well-designed interface, it is essential to perform stress testing to determine the number of users or requests the system can effectively support.

Resource usage tests for the mobile application were conducted on a smartphone. These performance evaluations were necessary due to the high number of applications commonly installed on mobile devices, which can negatively impact overall performance when running concurrently. To carry out these tests, specialized tools available on the market were used to monitor the resource consumption of installed applications [28].

The Android operating system includes built-in features for monitoring the resource consumption of installed applications. Table 4 presents the data collected during the application's use, demonstrating low energy consumption. This aspect is critical, as users typically prefer devices with extended battery life. Therefore, it is essential for mobile applications to be optimized for energy efficiency [29].

Table 4. Resource usage of the mobile application

Category	Item	Usage
Storage	Application	104 MB
	Data	4,53 MB
	Cache	455 MB
	Total	**109 MB**
RAM	Current usage	143 MB
	Duration	1 minute
	Total memory	**4 GB**
Battery	Foreground usage	8 minutes
	Background usage	5 minutes
	Total usage time	14 minutes
	CPU	6 minutes
	Wifi	6430 packets
	Consumption percentage	0.60%

Stress tests of the platform was carried out using the Locust tool to simulate real-time user traffic. The test began with zero users and progressively increased in increments of 100, reaching up to 5,000 simultaneous users. Each virtual user generated requests and interacted with the platform throughout the test.

Figure 11 shows the blue line representing the number of successful responses per second, which peaked at 600. The red line indicates the number of rejected requests per second. The error rate remained at zero until the test reached 5,000 simultaneous users and a total of 26,393 requests. Beyond this point, a minimal error rate of 0.16% was recorded, corresponding to requests rejected by the server.

Figure 12 shows the progressive increase in the number of users, starting from zero and rising in increments of 100. The platform demonstrated optimal performance, supporting up to 1,700 simultaneous users without generating errors. When the load reached 5,000 users, a minimal percentage of rejected requests was observed, indicating strong overall system performance even under high-demand conditions.

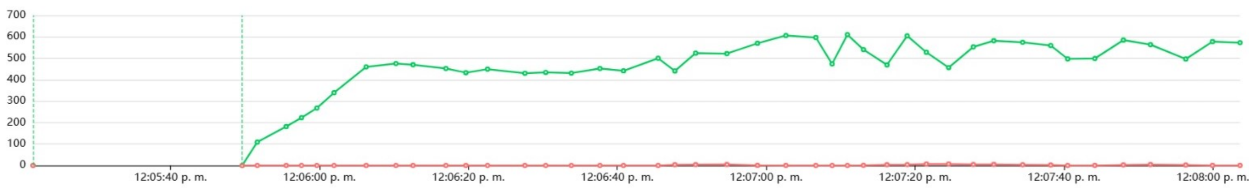

Figure 11. Stress test showing total responses per second

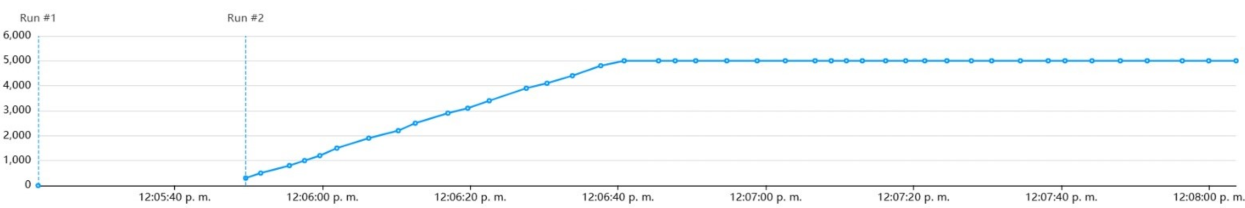

Figure 12. Stress test showing the total number of users

3.2. Discussion

Several studies have focused on the development and implementation of platforms for monitoring physical parameters [30] and biomedical parameters [31]. However, in platforms designed for biomedical monitoring, the doctor–patient relationship is often overlooked. Alerts are typically sent only to the user's device and their designated companion, without direct notification to the attending physician. This omission is significant, as certain data may require specialized medical interpretation.

In [31], data transmission is conducted via Bluetooth, limiting the system's functionality to short-range proximity, as the user must remain near the device to receive information. In contrast, the platform developed in this study transmits data not only to the user and a designated family member but also directly to the attending physician through email and integrated notifications within the information platform. To overcome the range limitations inherent to Bluetooth communication, the system employs a Wi-Fi connection in combination with the MQTT protocol, enabling real-time transmission and remote visualization of vital signs over the internet.

In [30], a backend service for IoT was developed using Microsoft Azure, with a focus on managing data transmitted by an IoT device. However, the scope of that work was limited to backend implementation; no web or mobile applications were developed to support data customization or user interaction, and the API's functionality was validated exclusively using Postman. To overcome these limitations, the platform proposed in this study incorporates not only a database and API but also a comprehensive information system that supports real-time visualization of data acquired from the IoT device, which captures three bioelectrical signals as well as efficient and scalable management of that information.

Numerous studies related to the monitoring of biomedical parameters have been identified; however, most of them primarily focus on the design and implementation of the IoT device, without addressing the development of the accompanying information platform [**?**, 32–38]. During the literature review, commercial devices such as smartwatches and the Galaxy Ring smart ring were also considered, both of which are supported by proprietary applications.

Table 5 presents a comparison of the functionalities offered by existing applications associated with commercial devices such as smartwatches and the Galaxy Ring, in relation to the platform proposed in this study. It is important to note that these commercially available devices use the collected data solely for informational purposes and are not intended for the detection, diagnosis, or treatment of medical conditions.

Table 5. Comparison of the Proposed Information Platform with Similar Systems

Feature	Smart Wristband 3	Samsung Health	Proposed Platform
Web application available for physicians	-	-	✓
Sends vital sign data to physicians or specialists	-	-	✓
Records user's weight	-	✓	✓
Displays heart rate data	✓	✓	✓
Displays oxygen saturation data	✓	✓	✓
Displays body temperature data	✓	✓	✓

The applications linked to these commercial devices are not designed to integrate with medical platforms or transmit data directly to a physician. In contrast, the proposed information platform allows users to designate a healthcare professional who can access information related to their vital signs, generated alerts, and medical history.

Additionally, according to [39], 70% of the evaluated systems exhibit response times between 1.0 and 2.0 seconds. The performance of the proposed platform slightly exceeds this range. However, as Echeverría observes, user-perceived latency tends to increase as system response times lengthen. Therefore, while there is room for performance optimization, the platform still offers a competitive user experience in terms of response speed.

Regarding energy consumption, the mobile application recorded a usage rate of 0.6% over a 14-minute period, aligning with the growing concern about the environmental impact of mobile software. Recent studies [40, 41] emphasize the importance of evaluating the energy consumption of applications on mobile devices.

Although mobile device manufacturers continue to improve energy efficiency through hardware and software innovations, it is equally critical for application developers to address power consumption in their designs. While the energy usage of an individual application may seem negligible, its cumulative impact across millions of devices underscores the importance of optimizing efficiency. Future research could focus on strategies such as interface simplification and code optimization to promote more sustainable software development.

The software platform presented in this study represents its initial version and forms part of the multidisciplinary research project titled "Research on IoT Applications in the Acquisition of Bioelectric Signals" (CUP: 91870000.0000.389571), led by the Technology, Science, and Education (TECED) research group from the Faculty of Systems and Telecommunications.

4. Conclusions

This study presents the development of a scalable software platform that integrates HTTP and MQTT communication protocols for real-time monitoring of biomedical parameters. The system supports comprehensive user management, including both medical professionals and patients, to facilitate continuous remote health supervision.

The platform enables the acquisition and visualization of key biomedical indicators, including heart rate, oxygen saturation, and body temperature. It also supports alert generation, facilitates secure communication between users, and allows physicians to maintain detailed oversight of patients' health status. Designed for scalability, the platform supports the future integration of additional biomedical parameters and the management of high request volumes without compromising performance. Simulation tests confirmed this capability, with an average response time of 930 milliseconds and 95% of responses delivered in under 2.3 seconds.

During load testing, the system successfully processed up to 22,132 requests at the communication endpoint, reaching a rate of 440.4 requests per second without errors. When the number of concurrent users increased to 5,000 and the system handled 26,393 requests, a minimal error rate of 0.16% was recorded, which is considered acceptable given the high concurrency. The platform was confirmed to operate without errors with up to 1,700 simultaneous users.

Compared to previous studies, such as that of González, which indicates that 25% of users abandon applications with load times exceeding 3 seconds [29], the developed platform demonstrated response times well within acceptable thresholds, ensuring a seamless user experience. Similarly, the recorded mobile resource usage data were appropriate, considering the broad range of functionalities provided by the application.

These findings confirm that the proposed system effectively manages high request volumes without compromising stability, positioning it as a reliable tool for the remote monitoring of biomedical parameters.

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Contributor Roles

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- **Ángela Parra Fernández:** Data curation, formal analysis, investigation, methodology, resources, software, validation, visualization, writing – original draft, writing – review & editing.
- **Ronald Rovira Jurado:** Conceptualization, funding acquisition, investigation, methodology, project administration, resources, supervision, validation, writing – original draft, writing – review & editing.
- **Manuel Montaño Blacio:** Investigation, validation, visualization, writing – review & editing.
- **Óscar Gómez Morales:** Conceptualization, investigation, validation.
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