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VISIÓN ELECTRÓNICA

A CASE-STUDY VISION

Design of a cloud computing-based solution for real-time oxygen saturation and heart rate telemonitoring

Diseño de una solución basada en cloud computing para la telemonitorización de la saturación de oxígeno y la frecuencia cardiaca en tiempo real

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ABSTRACT

This article proposes an architectural design based on cloud computing, offering a digital space that integrates everything necessary to provide a solution to the needs of the health service, specifically for real-time heart rate and oxygen saturation telemonitoring. healthcare and life sciences clients looking to aggregate data from multiple sources to determine a patient's condition where a telemonitoring software prototype was developed that uses aggregated data leading to a better understanding of the patient's condition by offering the ability to model the progression of the underlying condition, eventually providing the potential to predict the onset of conditions. This work lays the groundwork to continue exploring new mechanisms to extract data from medical devices, mobile applications, and even chips in our bodies to diagnose patient health more quickly.

RESUMEN

El presente artículo propone un diseño arquitectural basado en computación en la nube ofreciendo un espacio digital que integra todo lo necesario para dar solución a necesidades del servicio sanitario específicamente para realizar telemonitoreo, frecuencia cardiaca y saturación de oxígeno en tiempo real. El diseño del prototipo de software de telemonitoreo le aporta a los clientes de atención médica y ciencias de la vida que buscan agregar datos de múltiples fuentes la capacidad de modelar la progresión de la condición subyacente para determinar la condición de un paciente al observar datos agregados, lo que eventualmente brinda el potencial de predecir el inicio de las afecciones. Este trabajo sienta las bases para continuar con la exploración de nuevos mecanismos para extraer datos de dispositivos médicos, aplicaciones móviles e incluso chips en nuestros cuerpos para diagnosticar la salud del paciente de manera más rápida.

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1. Introduction

Security and scalability must be part of the good design of any telemedicine use case, project or implementation. Leveraging IoT and cloud computing along with data aims to improve current solutions. These results are also essential in many IoT use cases where fundamental principles of healthcare solution design are not taken into account. resilience and fault tolerance is not always met. Proposing a model based on cloud computing satisfies the main purpose of this article as the results of this work can be addressed and adopted by technology companies working for the healthcare sector.

The aim of this project is to provide the Colombian healthcare system with a better understanding of the design, construction and implementation of telemonitoring solutions that guarantee that the systems are 100% operational, being this an architectural piece capable of being implemented in a multicloud ecosystem. To propose a model based on software quality attributes to ensure the ability to respond to scaling constraints, security, interoperability and resilience to failures, as well as to provide a clear vision for the implementation of this design in a multicloud environment for entities in the Colombian health services sector, remote health monitoring is very possible thanks to the Internet of Things, also partially help to solve the increase in chronic diseases, among others due to the aging population (but not only that). Remote health monitoring is also ideal when patients live in remote areas and for cities where there is no high hospital capacity to provide care in times of high demand.

2. Methodology

This section shows the methodology used for the execution of this work, the diagram of activities that represents the project's workflow is presented, detailing the activities carried out in Figure 1.

The methodology used includes the following activities:

- Solution architecture definition: this activity refers to the process of analysis and design of the model's architectural solution. Solution architecture decisions are made in relation to the cloud software components and services that are part of the solution at the 3-layer level (application, database and security).
- Definition of technological infrastructure: this activity refers to the process of defining the cloud technology to be used and defining the main services for user authentication, file storage, definition of gateways, database, notifications, services for the creation and publication of the website domain, services related to the integration of IOT devices, security and roles, monitoring and control, execution of serverless source code.
- Configuration of cloud services: In this stage, the necessary settings and configurations are made for user authentication, file storage, definition of gateways, database, notifications, services for the creation and publication of the website domain, services related to the integration of IOT devices, security and roles, monitoring and control, execution of serverless source code.
- Implementation of saturation and heart rate oximeter sensor algorithm: This stage refers to the description and implementation of the algorithm needed to connect the saturation parameter sensor device to the cloud IOT broker and start with the transmission and ingestion of data to the data model, specifically the following was performed at this stage:

The first step consists in the configuration of the Broker IOT service, the generation of security certificates to open the communication protocol and then the algorithm uses these certificates to connect to the existing Broker topic via MQTT protocol, then the algorithm reads the data provided by the Max30102 device for Oxygen saturation and delivers them to the connected topic.

- Web application prototype implementation: this stage refers to the design and development of the prototype of the specific purpose monitoring application perform patient registration and enroll them to an available IoT device and monitor through a graphical interface the data captured in real time.
- Verification of the model: The verification of the proposed model is performed with real data supplied by the connected IOT devices, to which all the procedures described in the preceding activities were performed. Once this is done, the data is verified graphically on the application or web prototype and the results are interpreted.

3. Development of the topic

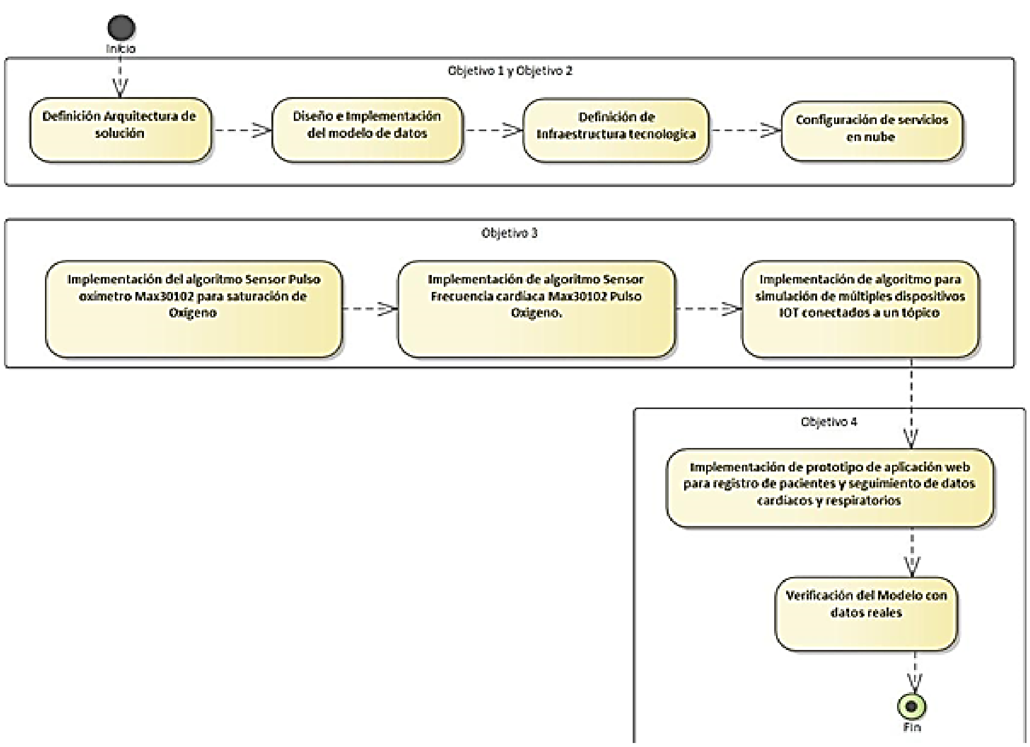
3.1. Solution design

The process of analysis and design of the model architectural solution is based on the technical characteristics identified in the literature found for cloud-based telemonitoring solutions [3], the solution architecture decisions were made taking into account the main components and required technical capabilities found in the systematic review synthesized in [4] focused specifically on the mechanism of data ingestion, data processing and visualization of information below is the conceptual design proposed in Figure 2.

3.2. Multicloud reference designs

We analyzed the services offered by cloud providers AWS, Azure and Google Cloud specifically to meet technical requirements defined for a vital signs telemonitoring solution such as data ingestion of data

Figure 1. Project Methodology.



Source: Own.

[5], [6], user authentication [7], [8], file storage [9], [10], gateway definition [11], [12], database[13], notifications[14], services for website domain creation and publishing[15], services related to IoT device integration [16], [17], security and roles[18], monitoring and control, serverless source code execution [19], [20].

Based on the agnostic concept that is handled by each cloud provider (AWS, Azure, Google Cloud) three high-level reference models of the solution were proposed, the three proposed solutions respond to the attributes of software quality to ensure the ability to respond to limitations of scaling, security, interoperability and resilience to failures Figure 3, Figure 4 and Figure 5.

In section 3.3 of this article, the development of the solution architecture using the AWS cloud will be discussed in more detail.

Figure 2. Conceptual design of the solution.

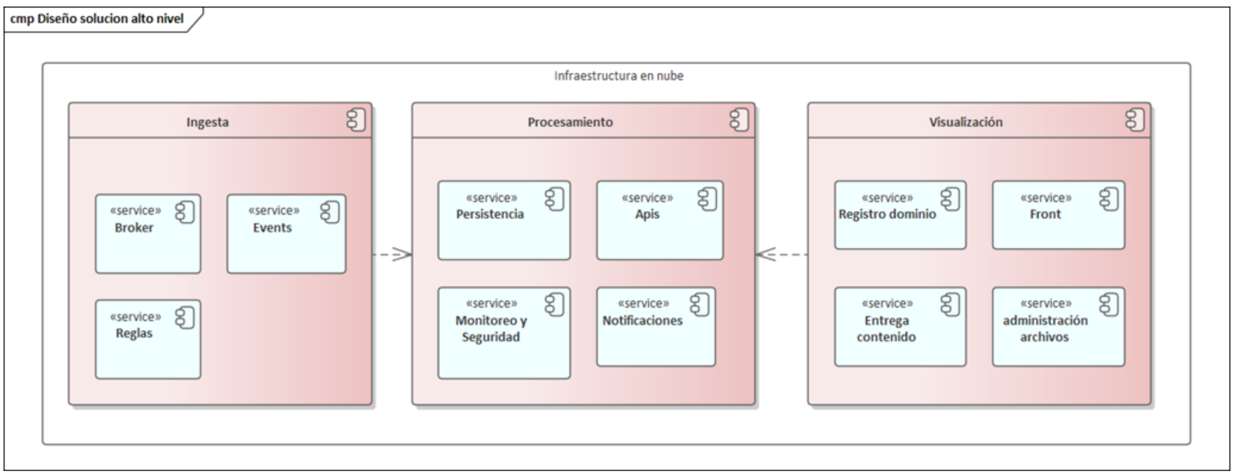


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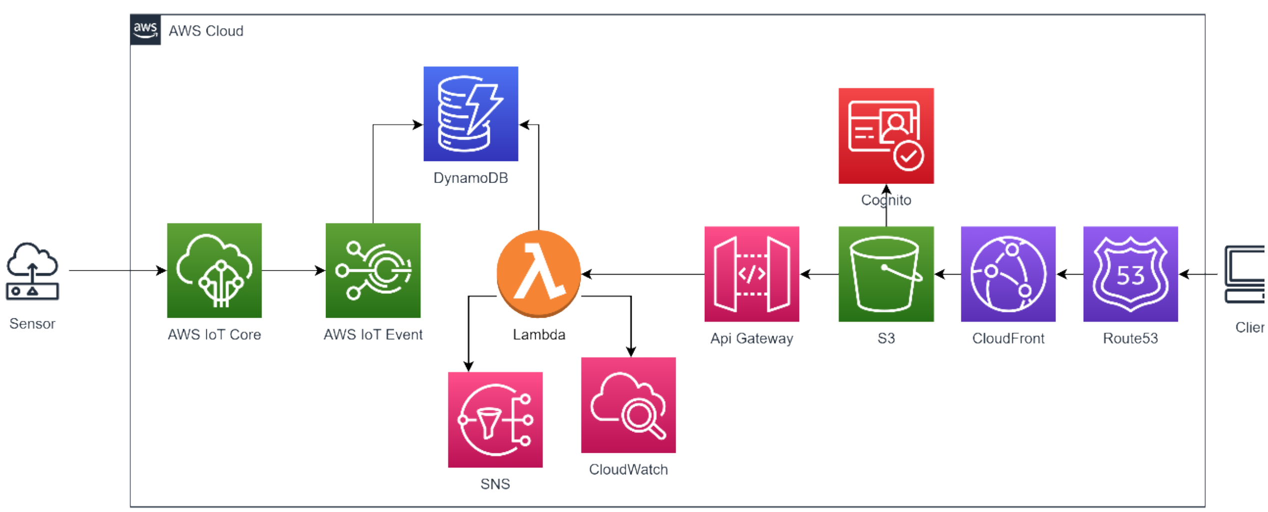
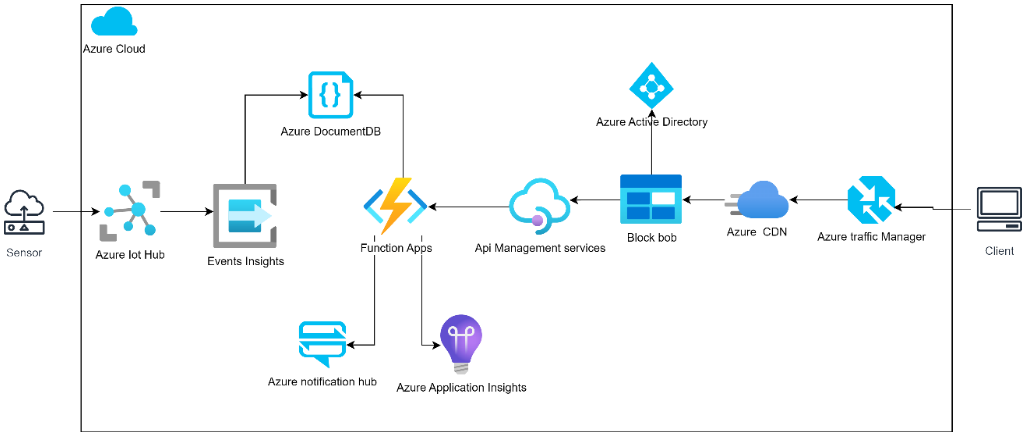
Figure 3. Solution reference design in AWS.



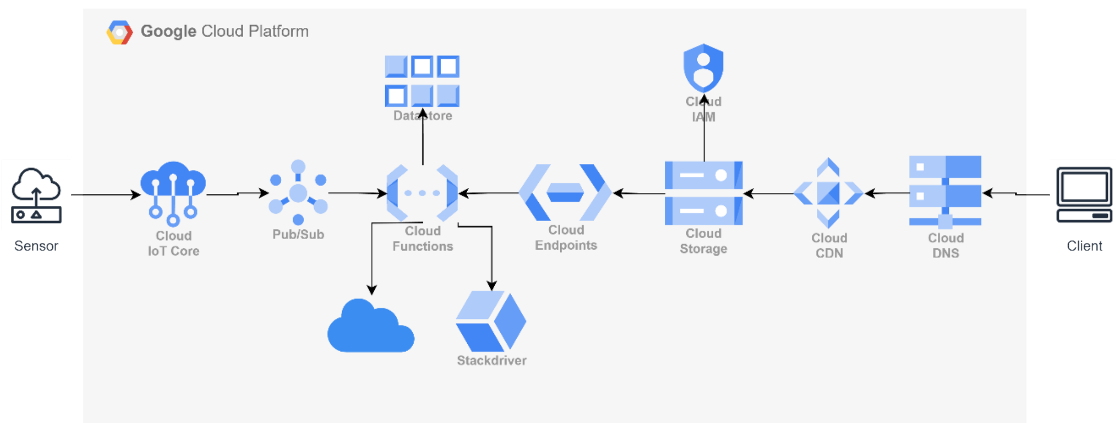
Source: Own.

Figure 4. Azure solution reference design.



Source: Own.

Figure 5. Reference design of the solution in Google Cloud.



Source: Own.

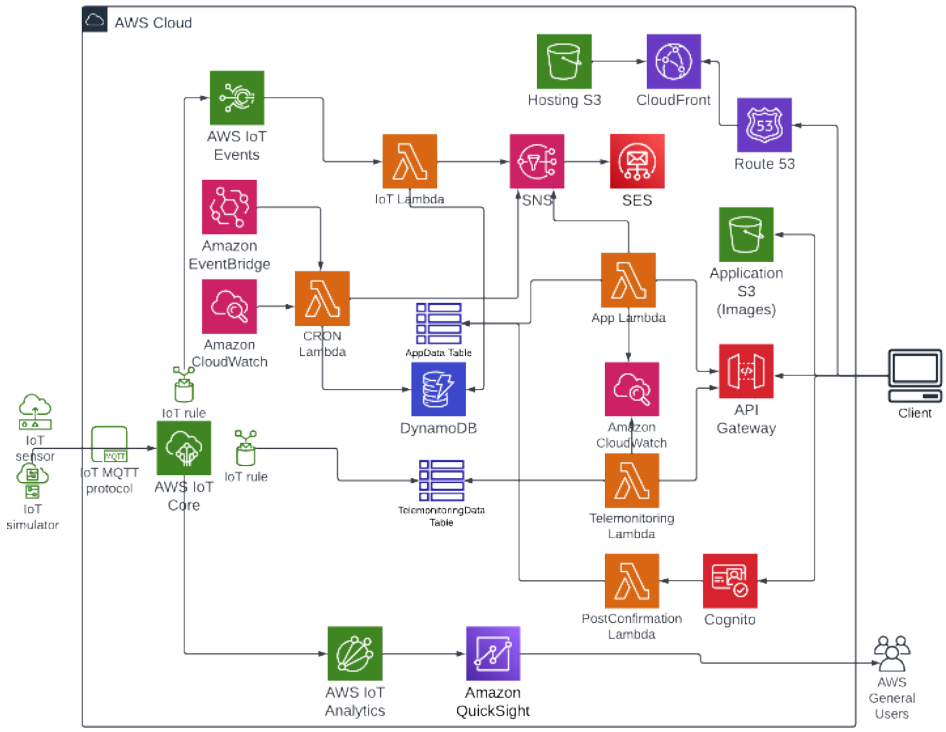
3.3. Solution design on AWS

It is essential to keep in mind fundamental design principles in healthcare solutions [21]. resilience and fault tolerance are not always met [22]. In addition, there are so many approaches to the digitization of healthcare records that having a reference design that provides experience and baseline in the implementation of this type of solutions is of great utility, the design of a modern innovative and fully Serverless solution is presented in Figure 6.

The solution was approached taking into account the capabilities implicit to telemonitoring solutions for data ingestion and processing, visualization and analysis of results, file storage and persistence, authentication and authorization, monitoring and notification, events and rules, content delivery and domain registration [23], [24].

The elasticity and dynamism of resources must be able to be reserved and released according to the customer's needs at any given moment. In fact, for the customer it should be as if they can scale up to virtually unlimited amounts of resources and in real time, In addition, this feature should also be understood as an almost automatic incorporation of new technologies, based on the value delivery of cloud

Figure 6. Design of proposed solution in AWS.



Source: Own.

providers who offer their customers always the latest innovations of their services, then, a detailed description of each service and how it is applied in the proposed design is provided.

4. Results

For the validation of the results, a prototype solution was developed with 2 modules "Patient control" and "automatic recommendations module", it was defined to register 4 users in the system, the first three with patient role and 1 with doctor role in order to validate the scenarios of Normal, moderate and severe health status.

Subsequently, the simulation algorithm Figure 7 was configured to perform three runs for thirty minutes each, the first run was configured with a range of oxygen saturation and heart rate values that would show normal health behavior, the second run a moderate health state and the third run a severe health state (see Table 1 for reference):

Table 1. Vital signs reference

Oxygen saturation (SPo2)	Percentage unit
Normal	95 - 110
Mild Hypoxia	91 - 94
Moderate Hypoxia	86 - 90
Severe Hypoxia	86 <
Heart Rate (HR)	lat/min (PR Bpm)
Normal	60 - 80
Tachycardia	> 100
Bradycardia	< 60

Source: Own

4.1. Simulation algorithm source code

The programming of the algorithm was performed in Python using the SDK for AWS AWSIoTPythonSDK, with the AWSIoTMQTTClient, sys , random, time, datetime, pytz libraries used.

Figure 7. Fragment of source code for device simulation algorithm.

```python
# se realizar la import de librerias y SDK
from AWSIoTPythonSDK.MQTTLib
from datetime
import AWSIoTMQTTClient
import sys
import random
import time
import datetime
import pytz

myMQTTClient = AWSIoTMQTTClient("dojodevice1")
# Configuración del endpoint y puerto
myMQTTClient.configureEndpoint("a3ik0etefnrop4-ats.iot.us-east-1.amazonaws.com", 8883)

# Configuración de certificado de conexión
myMQTTClient.configureCredentials("./AmazonRootCA1.pem","./1eefc3a87b11be43f1ee29b87cc5cc85

# Se inicia con la conexión
myMQTTClient.connect()
print("Client Connected")

# se inicia con la insercion de los dispositivos

msg = '{"PK":"DEVICE","SK":"0","Name":"ESP32"}';

print (msg)
topic = "esp32/pub"
myMQTTClient.publish(topic,msg, 0)
time.sleep(1)

# Ciclo para realizar insercion de dispositivos
for i in range(4):
    msg = '{"PK":"DEVICE","SK":"'+str(i+1)+'","Name":"SIMULADOR_IOT#'+str(i+1)+'"}';
        print (msg)
    topic = "esp32/pub"
    myMQTTClient.publish(topic,msg, 0)
    time.sleep(1)

# Ciclo para realizar la inserción de la series de tiempo
# Clco  para realizar la insercion de series de Saturación de Oxigeno y Frecuencia cardiaca
while 1:

    # datetime object containing current date and time
    tz = pytz.timezone('UTC')
    now = datetime.now(tz)
    fecha = now.isoformat().replace("+00:00", "Z")

    msg=  '{"PK":"TIMESTAMP#'+str(random.randint(1, 4))+'","SK":"'+str(fecha)+'","HeartBeat":'-
    topic = "esp32/pub"
    print(msg)
    myMQTTClient.publish(topic,msg, 0)
    print("Message Sent")
    time.sleep(1)

# sentencia para realizar la desconexion de los dispositivos
myMQTTClient.disconnect()
print("Client Disconnected")
```

Source: Own.

4.2. Validation of the patient controls module

At the end of the first execution, the Doctor's control board was validated and it was found that the heart rate oscillated between 70 - 77 beats per minute and the oxygen saturation between 101 - 107, as can be seen in the indicators all remained in green color, which represents a normal state of health, Figure 8.

At the end of the second run, the Doctor's control board was validated and the following visual was shown: The heart rate was recorded with an average of 105 beats per minute and the oxygen saturation with an average of 88, as can be seen, the indicators related to heart rate were in red and the oxygen saturation in orange, which corresponds to a moderate state of health for oxygen saturation and critical for heart rate, Figure 9.

Figure 8. Dashboard for the first run Normal health status.

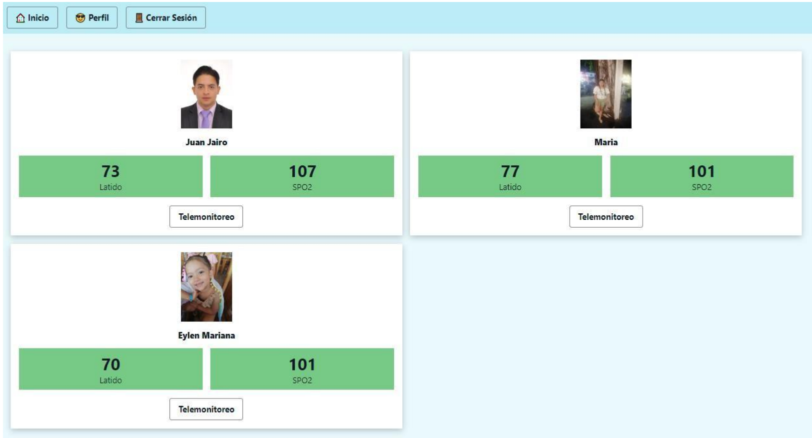


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Figure 9. Dashboard for the first execution Moderate health status.

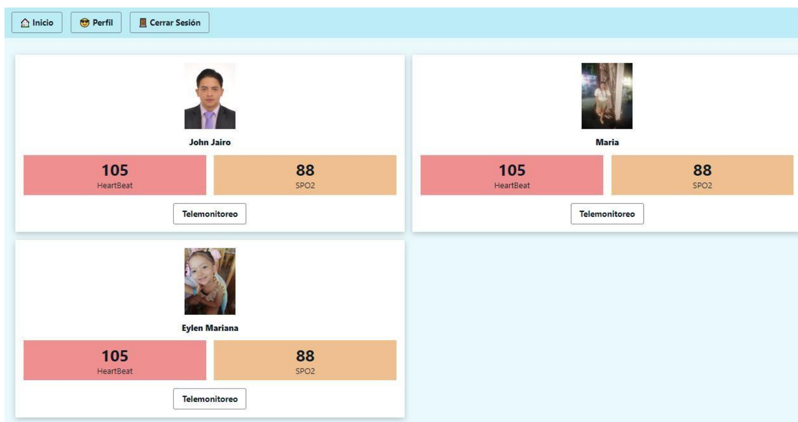

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Figure 10. Dashboard for the first execution Critical health state.

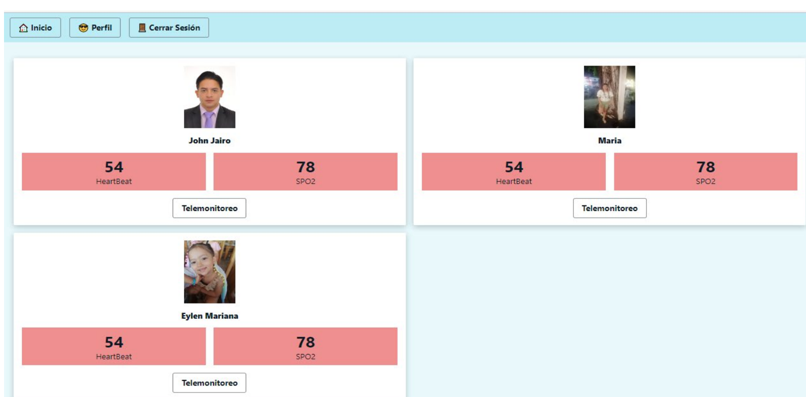

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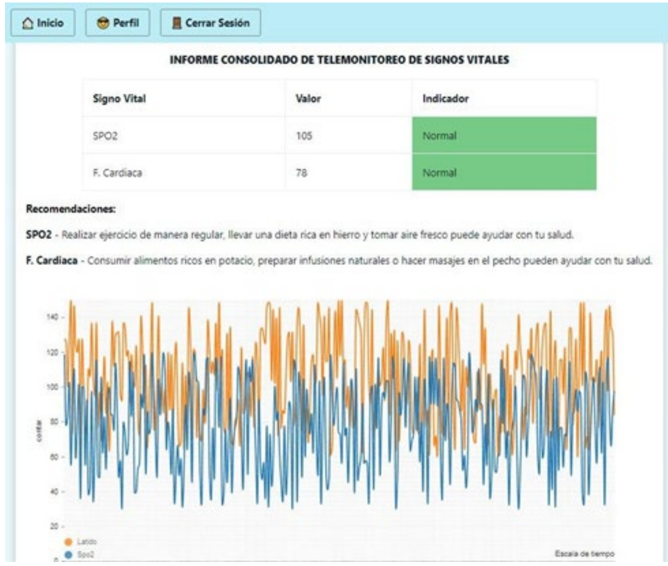
Figure 11. Automatic recommendations module for first run.



Source: Own.

At the end of the third run, the Doctor's control board was validated and the following visual was shown: The heart rate was recorded with an average of 54 beats per minute and the oxygen saturation with an average of 78, as can be seen in the related indicators, the heart rate remained in red and the oxygen saturation in red, which corresponds to a critical state of health, Figure 10.

This functionality allows the user with "Doctor" role a visual of the three patients assigned for care, under this module you can carry out a follow-up according to the level of criticality identified by the system, this is based on the established color palette (Critical=Red, Moderate=Orange, Normal=Green), With this visual the attending physician can assign an order of care based on priority according to his criteria, the assigned patients are automatically listed and are identified with their profile picture, name and two indicators with the average of the last recordings (heartbeat and oxygen saturation).

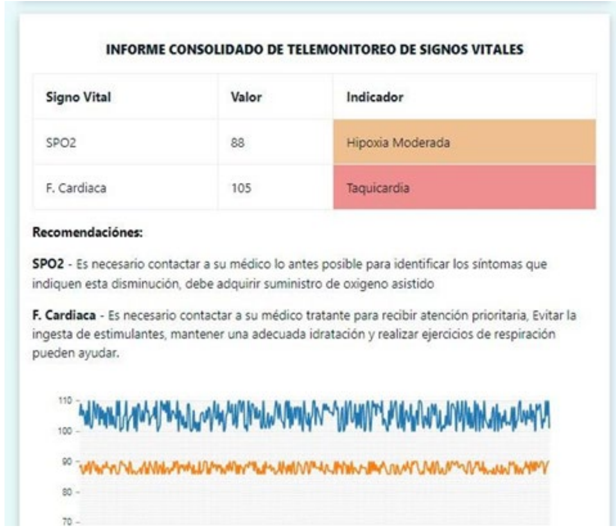
4.2.1. Validation of automatic recommendations module

When validating the report generated by the automatic recommendations module after the first execution, the normal health status indicators are shown and recommendations are provided according to the patient's health status, see Figure 11.

When validating the report generated by the automatic recommendations module after the second run, the indicators of moderate health status for oxygen saturation and critical health status for heart rate are shown, and recommendations are given according to the health status of each patient, see Figure 12.

When validating the report generated by the automatic recommendations module after the third run, the critical health status indicators for oxygen saturation and critical for heart rate are shown and recommendations are given according to the health status of each patient, see Figure 13.

Figure 12. Automatic recommendations module for the second run.



Source: Own.

Figure 13. Module of automatic recommendations for the third run.

Source: Own.

5. Conclusions

The literature review facilitated the development of the design of the proposed solution, taking into account the emerging portable technologies that have the potential and capacity to monitor the physiological vital signs of patients remotely. Wearable sensors are appropriate technologies that facilitate continuous monitoring and control of patient conditions. The proposed design is then contemplated with technical capabilities for sensor synchronization, data ingestion, data processing and information visualization in a cloud-based design. By applying the systematic approach the studies showed various techniques and proved to be on par with current cloud computing techniques in order to explore the implementation of medical diagnostic applications using the cloud as infrastructure.

The model of the proposed solution is completely agnostic to the selected cloud technology, others such as Azure, Google Cloud can be used. Therefore, the proposed design is highly scalable which gives a great advantage at the time of executing updates and evolutions on the telemonitoring solution based on a technological standard offered by the cloud.

The selected AWS technology, in addition to being cutting-edge, offers added value to the solution design and to the business due to the large amount of functionalities and services offered, allowing the renewal of telemonitoring information systems in the cloud, allowing companies to be competitive, agile and efficient; however, it is important to verify the objective and functionality of these, in order to align and standardize these resources, for the definition and innovation at a functional level to support the required transformation plans.

The proposed prototype allowed validating the operation of the solution model, achieving a telemonitoring of vital signs in real time to identify anomalies in the reading of oxygen saturation and heart rate, which allowed the documentation of the model, contributing to continuous improvement and allowing the innovation and evolution of the model defined as a vital input for making the right decisions at the organizational, financial and technological levels, which contribute to business growth.

The dimensions that were defined and structured allow to know the relationship that exists between the different elements involved in telemonitoring solutions at the process level, allowing a better use of the technological resources that support the business processes. From the above, it is possible to obtain a business and IT relationship model, concluding a global vision that allows standardization and homogeneity in the implementation processes.

The definition of the solution design provides mechanisms to improve the capabilities of telemedicine software companies, allowing for a process of continuous improvement and the possibility of rethinking premises to evaluate different investment and implementation scenarios, in order to make the right decisions.

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