INSTITUTO
UNIVERSITÁRIO
DE LISBOA

Wearable devices for Health Remote Monitor System

Tiago José Pardal Caixeiro

Master in Telecommunications and Computer Engineering

Supervisor:
Carlos Eduardo Dias Coutinho, Assistant Professor, ISCTE-IUL

Co-supervisor:
Daniel Dantas Calé, Invited Assistant Professor, ISCTE-IUL

October, 2022

TECHNOLOGY
AND ARCHITECTURE

Wearable devices for Health Remote Monitor System

Tiago José Pardal Caixeiro

Master in Telecommunications and Computer Engineering

Supervisor:
Carlos Eduardo Dias Coutinho, Assistant Professor, ISCTE-IUL

Co-supervisor:
Daniel Dantas Calé, Invited Assistant Professor, ISCTE-IUL

October, 2022

Acknowledgments

First and foremost, I would like to thank my parents, my sister, and the rest of my family for always believing in me and telling me that I would be able to finish the thesis, even when I thought I couldn't.

I'd also like to thank all of my college friends, my ”Octajericos,” who always tried to help me and believed in me and my abilities, as well as ”Casa Carlos,” who represent my home friends and colleagues who always supported me and put up with all of my stresses every day at home, making me laugh when I was down.

Finally, I'd like to thank my supervisors, Carlos Coutinho and Daniel Calé, for making their time available to me, offering thoughts and suggestions, assisting me in organizing ideas, and being able to turn and describe all of my practical work into writing, allowing me to complete this thesis.

Thank you to everyone I mentioned for their encouragement and trust; without them, it would have been very difficult for me to complete this chapter of my life.

Resumo

É possível observar como as tecnologias de comunicação e informação avançaram a um ritmo bastante acelerado nos dias de hoje. A introdução e aparecimento da tecnologia ”wearable” representa um aspeto que contribui para este progresso e tem o potencial de ser uma solução inovadora para os desafios dos cuidados de saúde, uma vez que pode ser utilizada para a prevenção e manutenção de doenças, tais como a monitorização física, bem como para a gestão de pacientes.

Para abordar alguns dos desafios dos cuidados de saúde, esta tese de investigação propõe uma metodologia de investigação, questões de investigação, e hipóteses para o desenvolvimento de um sistema inteligente de monitorização da saúde com alertas e monitorização contínua utilizando wearable devices capazes de recolher dados biométricos de seres humanos.

O conceito foi então provado pelo desenvolvimento de um protótipo utilizando wearable devices conectados a um microcontrolador, que transmite os seus dados através do Protocolo MQTT a um painel de instrumentos alimentado por o Node-RED que lida com a monitorização de métricas de saúde e onde toda a monitorização executada, e os alarmes gerados, podem ser visualizados em tempo real e depois entregues numa base de dados MongoDB para posterior análise e visualização.

Para demonstrar a eficácia deste protótipo, este foi implementado no mundo real onde foram adquiridos vários resultados através da utilização de dois utilizadores distintos. Os resultados foram bastante favoráveis e conclusivos, demonstrando que o protótipo criado foi satisfatório no fornecimento de dados para apoiar as hipóteses e questões de investigação desenvolvidas.

Palavras-chave : IoT, Cuidados de saúde, Sistemas inteligentes de monitorização, Dispositivos de uso, Monitorização de dados, Recolha e transferência de dados, Alertas

Abstract

It is feasible to see how communication and information technology have advanced at a rapid pace in today's world. The introduction and emergence of wearable technology is one aspect that contributes to this advancement and has the potential to be an innovative solution to healthcare challenges, since it may be used for illness prevention and maintenance, such as physical monitoring, as well as patient management.

To address some of the healthcare challenges, this research thesis provides a research methodology, research questions, and hypotheses for constructing an health remote monitoring system with alerts and continuous monitoring employing wearable devices capable of collecting biometric data on human health.

The concept was then proven by the development of a prototype using wearable devices connected to a microcontroller, which transmits its data via MQTT Protocol to a Node-RED powered dashboard that handles health metrics monitoring and where all monitoring performed, and alarms generated can be viewed in real-time. All this data is delivered to a MongoDB database for further analysis and visualization.

To demonstrate the effectiveness and capabilities of this prototype, it was used in the real world and the results were acquired from two distinct users. The results were very favorable and conclusive, demonstrating that the created prototype was satisfactory in providing data to support the developed hypotheses and research questions.

Keywords : IoT, Healthcare, Health remote monitoring systems, Wearable devices, Data monitoring, Collect and Transfer data, Alerts

Glossary

AI - Artificial Intelligence

AMQP - Advanced Message Queuing Protocol

ANS - Autonomic Nervous System

API - Application Programming Interface

BPM - Beats Per Minute

CoAP - Constrained Application Protocol

CRF - conditional random field

CVD - Cardiovascular Disease

DSR - Design Science Research

ECG - Electrocardiogram

EDA - Electrodermal Activity

EEG - Electroencephalography

E-health - Electronic Health

GPS - Global Positioning System

GSM - Global System for Mobile communication

GSR - Galvanic Skin Response

HR - Heart Rate

HTTP - Hypertext Transfer Protocol

IBM - International Business Machines

ICT - Information and Communications Technology

IoT - Internet of Things

IP - Internet Protocol address

IR-LED - Infrared Light Emitting Diode

JSON - JavaScript Object Notation

MAC - Media Access Control

MQTT - Message Queuing Telemetry Transport

M2M - Machine-To-Machine

M2S - Machine-To-Server

NIH - National Institutes of Health

OS - Operating System

PPG - Photoplethysmography

PRISMA - Preferred Reporting Items for Systematic Reviews and Meta-Analysis

QoS - Quality Of Services

S2S - Server-To-Server

USN - Ubiquitous Sensor Networks

URI - Universal Resource Identifier

URL - Uniform Resource Locator

WBSN - Wireless Body Sensor Network

WWBAN - Wearable Wireless Body Area Network

Contents

List of Figures

List of Tables

CHAPTER 1

Introduction

This document presents the result of my research in the field of Internet of Things (IoT) and Medicine conducted between September 2021 and October 2022 at ISCTE-IUL. This document covers themes such as Wearable Technology, E-health and monitoring systems.

1.1. Motivation

When it comes to the elderly population there are certain difficulties in terms of their healthcare because elderly individuals are frailer and have a weakened immune system, making them more susceptible to diseases. As a result, they require more care to maintain their health making it is necessary to find ways to improve their quality of life, such as encouraging the practice of physical exercise, regular medical monitoring and also physical and emotional support. They also confront several challenges because of their physical conditions, including transportation to medical facilities such as clinics and hospitals, as well as their safety on the streets[1]. Another concern is that, due to their nature and capacities, the elderly may have more difficulty knowing or remembering how to operate specific health devices or technologies capable of monitoring or ensuring their health. In addition to the elderly, we should also include and consider individuals with certain diseases, especially chronic diseases, or physical difficulties, making them as fragile as the elderly and more than those who do not have these aspects.

In today's world, it's possible to see how the ICT (Information and Communications Technology) have progressed at an accelerated pace, due to the presence of various technological advances such as AI (Artificial Intelligence), cloud computing, wearable technology and so on. Artificial intelligence allows certain electronic devices to simulate human intelligence and behavior, from performing certain functions such as playing games, or even driving a car in an automated way. Aside from that, AI is critical in healthcare since it allows for the mining of medical records, the design of treatment programs, the development of pharmaceuticals faster than any present doctor, and the diagnosis of cancerous and noncancerous tissue samples [2]. Cloud computing is a technology that uses the Internet to store and manage data on remote servers, which can then be accessed over the Internet. It is also particularly essential in healthcare because it allows for the storing and visualization of any health-related information about an individual. Another technological advancement, as previously discussed, is the emergence of wearable technology [3].

This technology has the potential to be an innovative solution to healthcare challenges since it may be utilized for illness prevention and maintenance, such as physical monitoring, as well as patient management and disease management [4]. It makes use of wearable devices [5] that can monitor the health of specific individuals in a more convenient, quick, and secure manner[6], these may contain similar technological functionalities, however, they may be located in different parts of the body, constituting the Head-mounted wearable, which are more related to aspects of control and perception, Body-worn devices, which can be divided into on-body (smart clothes, posture correction devices) and in-body (implants, smart tattoos) and, finally, Wrist-worn and handheld wearables, which are among the best known and widely used for healthcare purposes. These devices are small and simple to use, allowing for the collection of health data in real time and immediate transmission to doctors [7], this means that they can be used to collect biometric data such as heart rate, temperature, activity, and so on. Figure 1 shows how the global market for this kind of technology, wearable technology,in the healthcare sector has climbed tremendously [8].

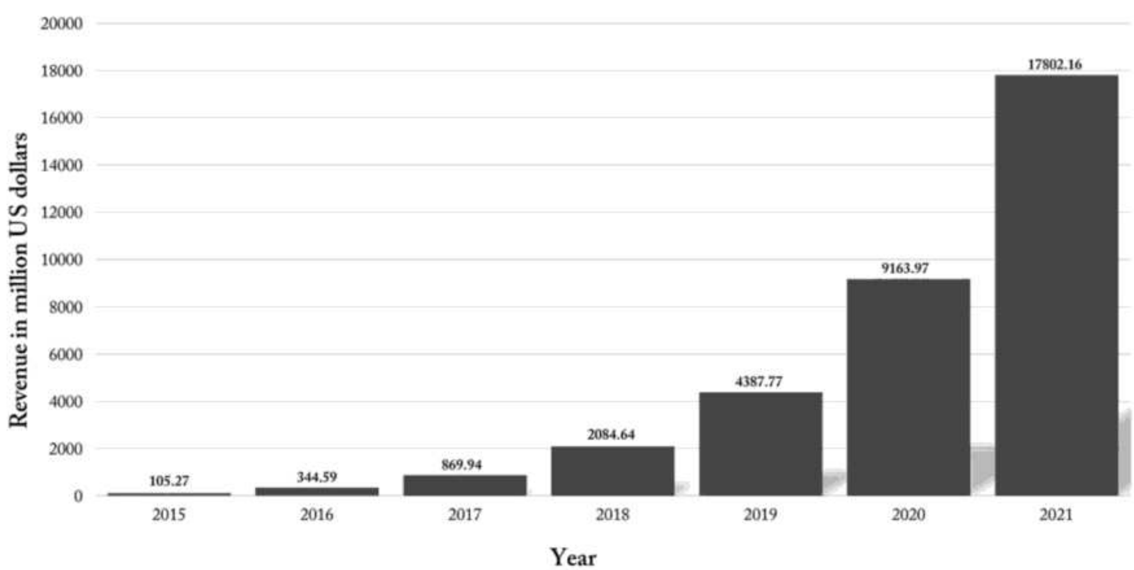


Figure 1. *Commercial grown of the Wearable Technology in the health care sector between 2015-2021 by [8]*

Due to the problems mentioned above regarding the older population and/or those with chronic difficulties, it is necessary to develop some kind of health monitoring system capable of overcoming these inconveniences, in which the health of certain individuals can be monitored, promoting the ways mentioned above to ensure their quality of life , something that is possible to accomplish due to the appearance and development of the wearable technology mentioned above.

1.2. Context

Healthcare Monitoring Systems are associated with communication and information technologies, particularly with the Internet of Things (IoT) and electronic health (E-health). IoT devices and technologies are widely recognized as critical enablers for a range of new applications, including remote health monitoring and play a critical role in making these applications more accessible and affordable to everyone [9]. E-health, according to Eysenbach [10], is a field that depends essentially on the junction of medical informatics, public health and business referring to health services and information supplied or enhanced through the Internet and similar technologies and it is also used to assist in the development of these applications. There have been certain studies that used these terms in different contexts, such as R. Miramontes, R. Aquino, *et al.* [11], a study that used a platform to monitor cardiovascular and respiratory variables, called ”PlaIMoS”. This platform consists of several wearable sensors, a network infrastructure to allow the transmission of data with security mechanisms, a server to analyze all collected data and applications to allow real-time measurements.

Through this platform were reported six parameters, such as, temperature, electrocardiogram, heart rate, blood oxygen, respiration data and fall data. Their goal of future work was defined as increasing the number of monitored and reported parameters.

A. Yunusova, J. Lai, *et al.* [12] examined the mental health of emerging adults as measured by a mental health app. This study’s major purpose was to employ event mining to anticipate changes in mental health. To do so, they recruited participants who had to download the ”Personicle” app, and using wearable sensors, they were able to monitor the contextual aspects of the participants’ daily affect changes, such as sleep, physiology, and activity. This study was authorized by an institutional review board and was adjusted to account for the stress caused by the Covid-19 pandemic. Finally, their research showed the value of adopting customized methodologies to investigate the interrelationships between stress, social interactions, technology, and mental health.

This thesis connects all the previous ideas (IoT, e-health, monitoring systems, wearable sensors), in other words, it shows how to use smart wearable devices to improve the everyday lives of people receiving long-term care, as well as a new methodology for collecting biometric data and integrating it into an health remote monitoring system with alerts and continuous monitoring. In addition to these ideas, this thesis and its project seek to contribute so that its users can access follow-up and medical support without having to travel to hospitals, allowing them to remain in the comfort and safety of their homes and carrying on with their daily lives unlike many other monitoring systems [9], [13]–[19], explained in more detail in chapter 2 sections 2.3 and 2.4, that, despite being very good and effective, some of them do not allow for the comfort of home because they are mostly used in hospitals.

1.3. Research questions

There are a few research questions that need to be answered with this dissertation. These questions are primarily concerned with the development of an health remote system for monitoring biometric data via wearable devices, as well as determining the benefits and drawbacks of using this system and these devices.

- How can the tracking of personal health contribute to improve the quality of life of the target person?
- How to efficiently automate the transmission of personal health data?
- Can we reduce the number of alerts sent to healthcare professionals without jeopardising the patient support?

The first question is more closely related to the reality of determining if the use of wearable devices is a viable method of ensuring a person's safety, and whether it is possible to do so in a timely and efficient manner. The remaining questions are related to the fact that by using wearable devices, it is possible to create an health remote monitoring system with alerts that is both efficient and beneficial to specific individuals and in constant contact with healthcare professionals, where no unnecessary alarms are generated, but only when something serious happens.

1.4. Objectives

The main goal of this dissertation is to develop an health remote monitoring system with alerts and continuous monitoring using wearable devices capable of collecting biometric data relating to human health, and to apply this system not only in a home environment so that people can be in the comfort of their homes while still monitoring their health, but also in their day-to-day lives, as described in section 1.1. Through this system it is possible to, not only, track health and efficiently automate data transmission, but it also has the ability of alerting health professionals.

To achieve this and to answer the previously mentioned research questions, some **hypotheses** must be addressed and completed:

(1) It's necessary to use a device capable of establishing a wireless connection and a wearable device capable of tracking a person's health;
(2) Extract data from the wearable device;
(3) Send the data to a server where it can be monitored using some type of protocol or/and a platform;
(4) Monitoring all collected data within the server so alerts can be generated and the data visualized;
(5) Saving all monitored data using a data base;

Primarily, to be able to answer the first research question, it is then necessary to first perform the hypotheses 1 and 2. Then, to efficiently automate the transmission of personal health data, which is related to the second research question, is necessary to perform hypothesis 3. Lastly, to be able to reduce the number of alerts sent to healthcare professionals without jeopardising the patient support and visualize the patient's health, hypotheses 4 and 5 need to be done.

1.5. Research Methodology

This dissertation is related to a method known as Design Science Research (DSR). This method focuses on the implementation and development of artifacts with the primary purpose of increasing their functional performance and developing knowledge that can subsequently be used by professionals to produce solutions to challenges they face [20]. To develop the artifacts and to create solutions, this method is split in seven guidelines, which can be seen in Figure 2.

When it comes to problem identification and motivation, and objectives of a solution, these guidelines have previously been addressed in earlier sections such as 1.1, 1.2, and 1.4, respectively. Regarding design and development are the process by which an artifact is formed and developed, which in this dissertation, consists in the development of an health remote monitor system with alerts

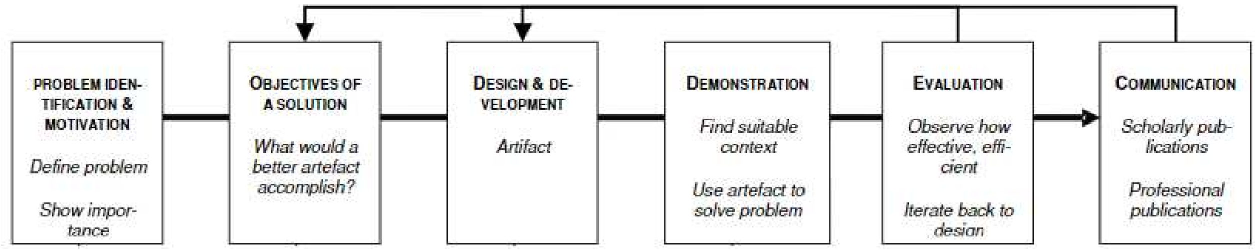


Figure 2. *DSR Methodology by [21]*

using wearable devices capable of monitoring an individual's health. This guideline is applied in Chapter 3 where an explanation of the design/architecture of the developed artifact can be found, which consists in explaining the different components and their functions, section 3.2, as well as its development, section 3.3, where it is explained what programs were used and how they work in order to create a well-functioning artifact.

The demonstration consists in putting this artifact to the test and see if it's a solution to the existing problems, referred in the guideline "problem identification and motivation", and determining its reliability, effectiveness and efficiency. The evaluation It is the guideline for determining whether the artifact created is efficient and effective. These two final guidelines, "Demonstration" and "Evaluation" are applied in chapters 4 and 5, where chapter 4 will demonstrate and discuss the artifact's results, and chapter 5 will conclude and evaluate the artifact's efficiency using the results obtained and discussed in order to answer the research questions mentioned previously in section 1.3 with the means to see if represents a good solution.

Communication is the guideline that addresses the problem and its significance, which means, publishing this research in an international conference or journal.

1.6. Dissertation structure

This section will show how the dissertation is divided, with a brief description for each chapter.

Chapter 1 addresses the motivation section, the context section, the objectives, the research questions and lastly, the dissertation's research methodology.

Chapter 2 covers the State of the Art, which consists in Research Approach, types of wearable devices, data processing used in remote health monitoring systems and wearable technologies to prevent and detect diseases.

Chapter 3 presents the architecture and development designed to create the proposed solution.

Chapter 4 discusses, describes and evaluates the proposed solution's results.

Chapter 5 addresses the main conclusions, limitations as well as suggestions and ideas for future work.

CHAPTER 2

State of the Art

The term ”State of the Art” refers to a research study that aims to discover and comprehend the present level of knowledge on a specific issue that is being examined or explored [22]. This chapter is divided into four parts, such as, research approach, types of wearable devices, data processing used in remote health monitoring systems and wearable technologies to prevent and detect diseases

The research approach addresses the databases, queries, reference management application to store all the articles and methodology used to discover and choose the articles/studies that were used in the State of the Art.

Section 2.2 discusses the different types of wearable devices that are available today as well as the many types of different groups to which they belong.

Both sections 2.3 and 2.4 will address the various data processing types and techniques used in remote healthcare monitoring systems, like how data is collected and transferred, as well as the various types of sensors employed, and the different methods used in the field of healthcare to prevent and detect diseases using wearables. Finally, an analysis was performed on the various articles that have similar thoughts and projects to this dissertation's project.

2.1. Research Approach

It was important to initially search knowledge bases for publications or studies relating to this dissertation. Scopus and Google Scholar were used as the knowledge bases.

For the Scopus knowledge base the following query was used:

(’wearable AND devices’ OR ’wearable AND technology’ OR ’health AND remote AND monitor AND system’ OR ’sensors’ OR ’iot’)

This query resulted in 460 articles, which was too many, so it was necessary to minimize the number.

Therefore, some limitations(year, areas, access, etc.) had to be imposed creating the following query:

('wearable AND devices' OR 'wearable AND technology' OR ' AND health AND remote AND monitor AND system AND ' OR 'sensors' OR 'iot') AND (LIMIT-TO (OA , "all")) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016)) AND (LIMIT-TO (SUBJAREA , "comp") OR LIMIT-TO (SUBJAREA , "engi") OR LIMIT-TO (SUBJAREA , "medi"))

From this new query 38 results were obtained. The Google Scholar knowledge base was used to search for anything more precise, that is, if it was essential to find an article with more specific information about a particular issue.

The merging of these two databases generated 70 papers and then subjected to a methodology very similar to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) flow methodology [23], which will be detailed as follows:

In the first step, all duplicates were removed from the 70 papers, and then the titles and abstracts were analyzed.

In the second step, for organization purposes, three groups were created in the Mendeley platform, "DIFFERENT TYPES OF WEARABLES", "GOOD FOR RELATED WORK" and "GOOD FOR DISEASES" with the first group containing all papers with good content to be used in the section 2.2 "Types of Wearable Devices", the second group for the section 2.3 "Data Processing used in remote health monitoring systems", and the third group containing all papers with good content to be used in the section 2.4 "Wearables technologies to prevent and detect diseases". The combination of the previous steps resulted in 34 papers, which were used in the Sections 2.2, 2.3 and 2.4.

2.2. Types of Wearable Devices

According to A. Ometov, V. Shubina, *et al.* [3], to classify the various types of wearable devices that exist, various factors must be considered, as devices, despite having similar functionalities, can have vastly different formats, such as different technological levels, different locations in the human body, and so on. In terms of the location of the wearable device in the human body, it's possible to define them in the following groups:

- Head-mounted wearables,which are fundamentally based on control and perception aspects. This category includes all types of visual accessories such as relaxation masks, eyeglasses, entertainment systems such as virtual reality, and audio devices such as personal assistants, headphones, and bass systems.

- Body-worn devices, that have a variety of functions and may be categorized into numerous groups, such as on-body (EEG (Electroencephalography) and ECG (Electrocardiogram) monitors, safety devices, various smart clothes, posture correcting devices, etc), in-body(implantables, smart tattoos, etc) and near-body and sport(smart bands, supplementary activity tracking sensors, etc);

- Wrist-worn and handheld wearables, which are among the most well-known and widely used, owing to their small size and ease of use, some examples, smartwatches, wrist bands, gesture control devices and so on.

Besides classification based on human body location, these devices may also be classified based on energy consumption. The amount of energy consumed can vary significantly since certain devices are more complex than others. These devices can be classified low, medium, or high power.

Wearable devices classified as ***low-power*** consist essentially of low power components, thus limiting their capabilities. These devices allow the collection of data and sensibility and need to work for long periods of time. This kind of low-power devices could be an advantage for areas, like healthcare [24]. J. Dieffenderfer, H. Goodell, *et al.* [25], had the goal that by using low-power devices, such as wristband, chest patch and a handheld spirometer, could understand the impact of increased ozone levels and other pollutants on chronic asthma conditions. S. Mahmud and H. Wan [26] uses a ring sensor with a small battery to continuous measure four autonomic nervous system (ANS) activities like, Electrodermal Activity (EDA), heart rate, skin temperature and locomotion.

Medium-power wearables are wearables with slightly higher capacities than low-end wearables and often have small screens. Aside from that, these devices could be composed of several sensors with direct or indirect internet connectivity options. Examples of this types of devices are smartwatches, fitness trackers, and other devices for activity or gesture recognition applications for personal, business, and industrial use. M. Xu, F. Qian, *et al.* [27] developed a deep learning framework called ”DeepWear” for wearable devices to increase performance and reduce energy consumption. This framework does not require an internet connection and was implemented in an Android OS (Operating System) application.

High-power wearables require a large amount of energy since they require high data rates and are capable of doing intensive computing tasks such as real-time video or image processing, machine Learning and so on. There are some studies that used this types of wearables such as, wearable computers with live 3d human actor capture combine with embodied mixed reality [28] and a unified code offloading system for wearable computing [29].

2.3. Data Processing used in remote health monitoring systems

Data from wearable devices is analyzed and gathered in vast volumes, depending on the unique product [3]. Nowadays, there are multiple sorts of wearable devices that employ various types of sensors, therefore there are several specific ways, depending on the sensor used, to gather and analyze data[30], however deep down they are always a little similar and share a bit of the same ideas [3].

M. Vahabi, H. Fotouhi, *et al.* [9] evaluated the use of Shimmer sensors to monitor the ECG signal and the movement of a human. These sensors are usually used to monitor several aspects of human health, such as temperature, heart activity, movement, and so on and are part of a small platform suitable for wearable applications [31] who allow information to be gathered via Bluetooth with a Master node. As a result, in this study the whole process of gathering and transferring data was done using only the shimmer sensors, a Raspberry Pi B+ (Master node) and a local database.

As can be verified in Figure 3, these sensors were configured using the Consensys software, which is compatible with Microsoft’s operating system and all the collected data was processed using Raspbian (the Linux operating system provided with the Raspberry Pi), which had a pre-installed Python version. In more detail, a Python script with open-source code was used to establish communication between the shimmer sensors and the raspberry pi, allowing all sensor data to be sent to and stored on the raspberry pi local database .

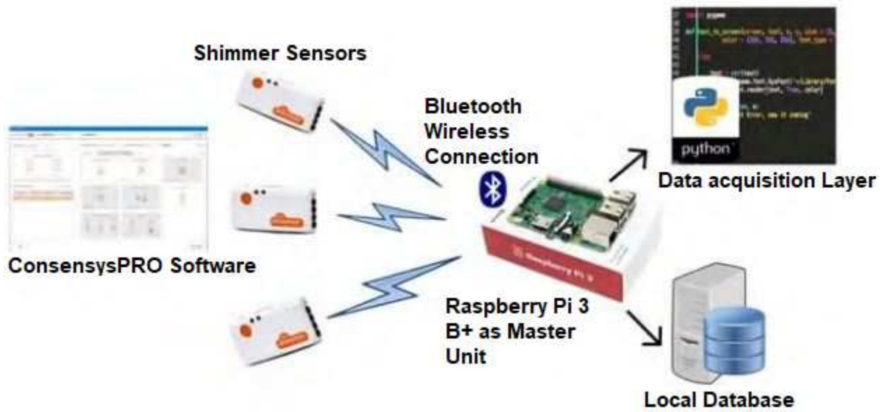


Figure 3. *Remote health monitoring system architecture proposed by [9]*

Like this study, there are other studies, such as [13] [14] [15] [16] [17], that employed different types of devices and approaches to achieve the similar goal of developing a healthcare remote system.

Instead of using shimmer sensors and a raspberry pi, [13] used an IoT platform and low-cost smart wristwatch that contains an ESP32 microcontroller and three sensors for heart rate, blood pressure and body temperature purposes. Their goal was to develop a low-cost Wireless Body Sensor Network (WBSN) for monitoring patients' vital signs in hospitals, therefore they created a smart device (wristwatch mentioned before) and designed an intelligent medical monitoring system. The smart device was inspired by wireless sensor nodes (sensing units that measure vital signs before being processed by a microcontroller) which were made up of wireless body sensors coupled to an ESP32-microcontroller (compact and portable wireless module that send data through WiFi). The data was transmitted as a star network from the ESP32, which served as a sensor node to the master ESP32+WiFi Microcontroller gathering and displaying the data on a PC or mobile phone, see figure 4 and could also be seen in the wristband of the patient. In the design of an intelligent medical monitoring system, each patient's vital signs were relayed wirelessly through a healthcare portal to a database center where healthcare professionals could observe the results, see figure 5.

The Things Board, an open-source IoT platform that enables quick development, management and scalability of IoT projects [32], was chosen by the authors to classify data structures, connect devices, maintain data security, transmit notifications and show the patients' vital signs. However, there is a little issue with this platform in that if one component, such as MQTT (Message Queuing

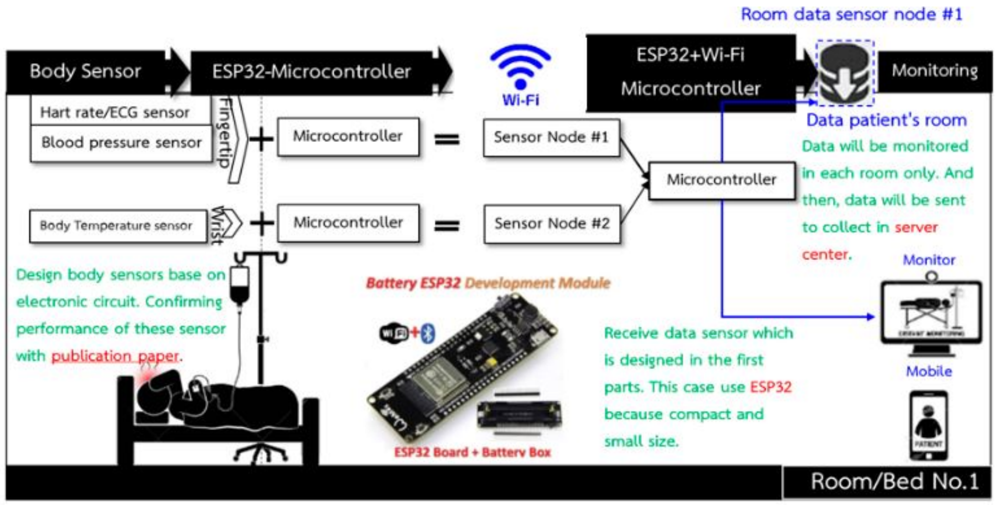


Figure 4. *Structure of body sensor nodes and the communication pathway by [13]*

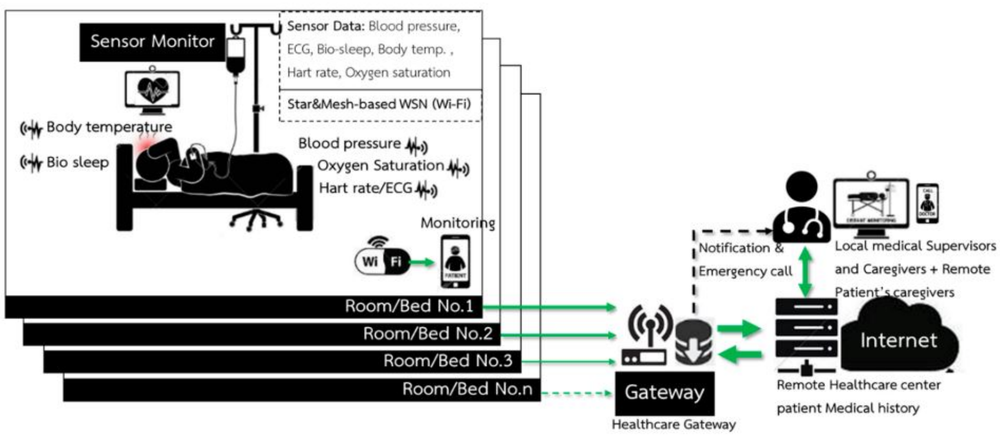


Figure 5. *Design of an intelligent medical monitoring system by [13]*

Telemetry Transport), is overloaded with messages, it may affect other components as well, jeopardizing the system's integrity. This could become a major issue, because the system we propose to design in this thesis is constantly receiving messages about an individual's health in real time.

The main goal of [14] was to create a Wearable Wireless Body Area Network (WWBAN) to monitor the health of elderly and disabled people using a pulse oximeter, heart rate, temperature, hydration, glucose level, and fall detection sensors, Arduino microcontroller, LCD display, and GSM (Global System for Mobile communication) modem. As a result, to collect, analyze and process all the data from the sensors, they were connected to the Arduino and displayed on the LCD. If the determined sensor values went below or above the normal range, an SMS alert would be sent to a healthcare professional via a GSM modem over the GSM network. The Things Speak platform was utilized to store the patient data, allowing healthcare professionals to access it.

F. Ullah, A. Iqbal, *et al.* [15] had a similar concept to [14], but instead of elders and disabled people, the authors built a framework for physical activities and health monitoring for pregnant women. Their framework consisted of only three sensors, a three-axis accelerometer, a three-axis gyroscope, and a temperature sensor, as well as a Raspberry Pi, same to [9], and a mobile phone, Figure 6.

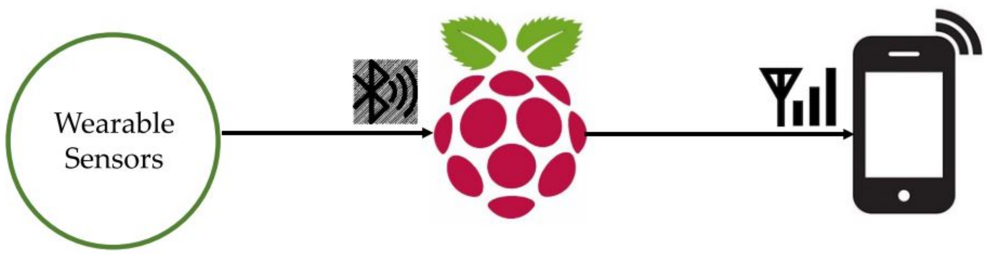


Figure 6. *Framework Architecture by [15]*

The goal was to recognize a pregnant woman's physical activity and sent monitoring messages to a health supervisor. As a result, a single wearable sensor module containing the three sensors mentioned above was employed, which was mounted at the wrist and connected to the raspberry pi through Bluetooth using Python-based *BlueZ*. Similarly, to [14], a GSM modem was used to store the phone numbers of registered gynecologists and caregivers, who would receive a message if the maternal women did not perform as expected.

The article [16] developed a Cloud-based IoT Smart Healthcare System for Remote Patient Monitoring. Their project's concept was similar to [14], where they continuously gather patients' vital signs and alerted doctors if there were any major changes. In their project, they employed heart rate, oxygen level, and temperature sensors, as well as an Arduino microcontroller and a raspberry pi, rather than only the Arduino as [14] used.

Therefore, to track the patient's health, the sensors were connected to an Arduino Uno, which sent the data to a raspberry pi, where an LCD and a wireless Internet connection were interconnected to send data to a web server (wireless sensing node). The HTTP (Hypertext Transfer Protocol) protocol was used to establish the connection, and the patient's vital signs were updated every 15 seconds, allowing for real-time monitoring. As an IoT platform, the Things Speak websites were used, same as [14], to monitor data and control the system through the internet.

The purpose of [17] was to design and develop a wearable ubiquitous healthcare monitoring system that used the following sensors, integrated electrocardiogram (ECG), accelerometer, and oxygen saturation sensor (SpO2), as can be verify in Figure 7. This system was divided into two sections, one for wearable sensor devices and another for the server. The wearable sensor devices included a USN (Ubiquitous Sensor Networks) node (created in the lab by the authors and used to connect the sensors to the server PC), a chest belt (to measure ECG and acceleration values), and a wrist type sensor (designed to measure oxygen levels).

These sensors communicated with a base station (USN node) via IEEE 802.15.4 compatible Zigbee and were connected to the Server PC. This USN node allowed the sensors to capture and send data to a Server PC, which displayed the output waveforms of the ECG, accelerometer, and Sp02 sensor.

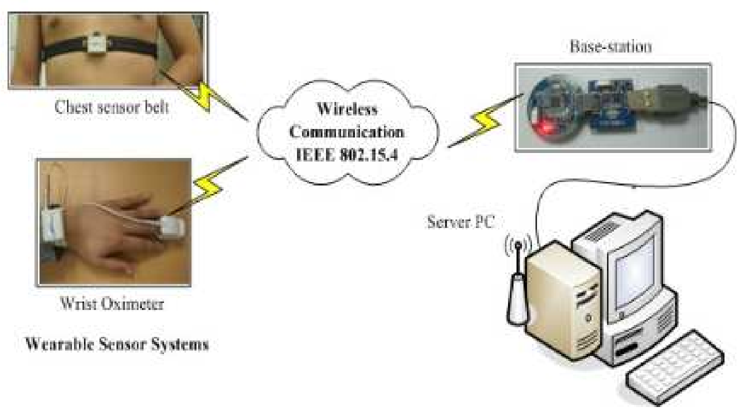


Figure 7. *System Architecture by [17]*

All the preceding articles were basically concerned with the development of a general health monitoring system, in which several vital health indicators were collected, such as, temperature, heart rate, movement, oxygen, and so on. However, there are several other studies that developed health monitoring systems but only considered one or two vital signs into account, such as activity [33] [34] [35], temperature [36] [37] [38], galvanic skin response (GSR) [39] [40] [41], oxygen levels [42] [43] [44] and so on, in order to more prominently solve certain problems.

2.4. Wearable technologies to prevent and detect diseases

In this section, several articles are listed [18] [45] [46] [19] employing certain methods to establish a health monitoring system that uses wearables, to not only prevent but also treat certain diseases.

The build-up of fatty deposits inside the arteries (atherosclerosis) and an increased risk of blood clots are linked to cardiovascular disease (CVD) [47], such as heart attack, stroke, and hypertension. For both women and men of all ethnic backgrounds, this disease is by far the biggest cause of death in the globe [48]. To try to prevent and solve some of the problems above, the article [18] established a cell phone-based wearable platform with the purpose of continuously monitoring and recording ECG values in real-time to detect and classify aberrant CVD situations at any time and place. The proposed architecture included the use of Alive Technology's cutting-edge wireless ECG and heart monitor (to acquire ECG signals in real time), a 2-lead ECG with 3-axis accelerometer capable of sending data via Bluetooth to cell phones or other wireless devices, a GPS (Global Positioning System), and an efficient ECG processing module capable of collecting the collected ECG data and dynamically extracting various ECG features for review by cardiologists. In terms of software, the following packages were used, Microsoft Visual Studio, MATLAB, and LABVIEW.

Cardiovascular illness is considered a general condition [48], and many diseases, such as heart failure, can be linked to it. Heart failure occurs when the heart does not pump enough blood for the body to function effectively [49], and in the field of wearable technology and wearable devices, there are numerous approaches to prevent and treat this disease, as discussed in the article [45]. According to this article, the most frequent way to treat this disease is to measure movement, heart rate, and blood pressure, as well as detect and monitor arrhythmia, which is an irregular heartbeat. Activity bands, smartwatches, patches, and vests are some examples of wearable devices that may be utilized at various periods in the Heart Failure ”journey” from prevention to detection of decompensation, as shown in Figure 8.

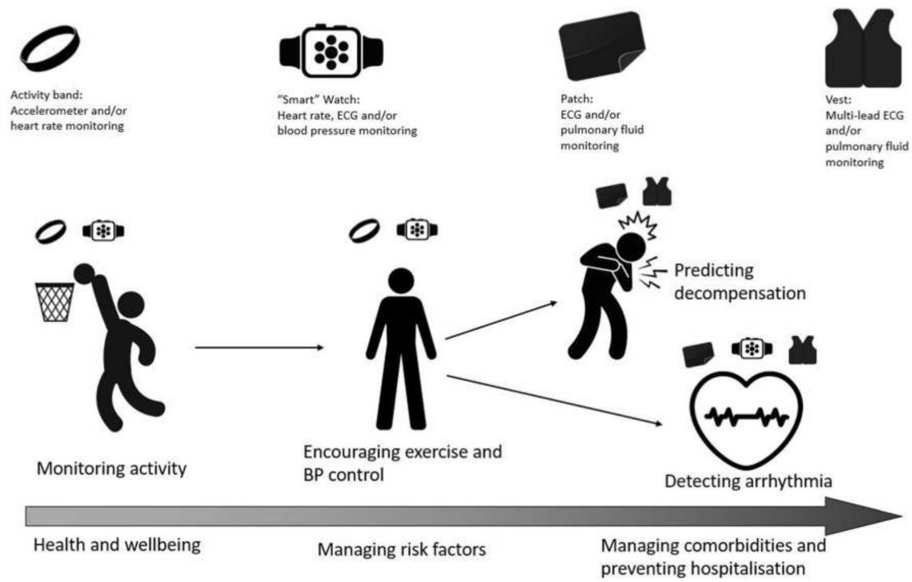


Figure 8. *Examples of wearable devices used in health and cardiovascular disease by [45]*

In addition to cardiovascular diseases, there are several chronic diseases for which objects can be used for detection and treatment, such as Parkinson's disease [46], Alzheimer's disease, bulimia and anorexia [19], diabetes [50], and so on.

Parkinson's disease is a neurological condition that causes tremors, rigidity, and difficulties walking, balancing, and coordinating physical activity [51], for which the authors of [46] conducted a review and gathered some studies like, [52] [53] [54] ... , on the potential benefits of wearable technologies for the detection and precise measurement of clinically relevant characteristics, such as motor symptoms, falls risk, freezing of gait, gait, functional mobility, and so on. The wearable technology employed in these studies to establish monitoring systems was mainly accelerometers worn on various regions of the body and paired with mobile smartphones.

The article [19] tried to create a Multimodal Wearable Sensing for Fine-Grained Activity Recognition in Healthcare for patients with Alzheimer's disease, bulimia, or anorexia. These are serious chronic diseases, with Alzheimer's disease being a brain disorder that gradually destroys memory and thinking skills [55], Bulimia being a serious potentially life-threatening eating disorder [56], and Anorexia being an eating disorder characterized by an abnormally low body weight, intense fear of gaining weight, and a distorted perception of weight [57]. The authors used accelerometer and gyroscope sensors for body locomotion, temperature and humidity sensors for ambient environment, and Bluetooth beacon location tags for location purposes to monitor these diseases. To classify the activity of the patients, using these sensors, the authors used a conditional random field (CRF), which is a class of statistical modeling method used for structured learning and prediction.

2.5. Summary of the State of the Art

Through the state of the art, it was possible to determine that there are various types of wearable devices that can be classed according to their technological level, position on the human body, power consumption, and so on and that the application of wearable technology and wearable devices is widely used not only for the creation of general-purpose monitoring systems or monitoring systems that are limited to one or two vital signs, but also for the detection and treatment of specific diseases, primarily chronic diseases. Aside from the articles mentioned, there are many more that make use of wearable technology and its many methods. However, even though many approaches exist, they don't differ significantly, because the equipment and sensors used were the same or slightly different.

It was possible to discover that the most used sensors were those that monitored temperature, oxygen, and heart rate. The equipment utilized included the Arduino, Raspberry Pi and ESP32 and the platforms most used were the Things Board and Things Speak. All the referenced studies and respective equipment, measured parameters, wireless connectivity and IoT Platforms can be found in table 1.

Despite being reviewed, the articles [45] [46] are not included in table 1 since they represent the convergence of multiple studies and knowledge to solve certain chronic diseases rather than a single study.

Ref.	Equipment/Sensors	Measured Parameters	Wireless Connectivity	IoT Platform
[9]	Shimmer Sensors, Raspberry Pi B+	ECG signal, Movement	Bluetooth	-
[13]	Wrist Band(ESP32 microcontroller, Heart rate sensor, Blood pressure sensor, Temperature Sensor)	Heart rate, Blood pressure, Body temperature	WiFi	Things Board
[14]	Pulseoximeter, Heart rate, Temperature, Hydration, Glucose level, Fall detection sensors, Arduino microcontroller, LCD display, GSM modem	Heart rate, Oxygen levels, Temperature, Hydration, Glucose, Fall detection	WiFi	Things Speak
[15]	Three-axis accelerometer Three-axis gyroscope, Temperature sensor, Raspberry Pi, GSM modem	Physical activity, Temperature	Bluetooth	-
[16]	Oxygen, Heart rate, Temperature sensors, Arduino microcontroller, Raspberry Pi	Heart rate, Oxygen levels, Temperature	WiFi	Things Speak
[17]	Chest Belt (ECG, Accelerometer), Wrist type sensor(Oxygen saturation),USN node	ECG signal, Activity, Oxygen levels	ZigBee	-
[18]	ECG and heart monitor, 2-lead ECG with 3-axis accelerometer, GPS, ECG processing module	ECG signal	Bluetooth	-
[19]	Accelerometer, Gyroscope sensors, Temperature Sensors, Humidity sensors, Bluetooth beacon location tags	Body locomotion, Ambient environment, Location	Bluetooth	-

Table 1. *Articles referenced and review in the State of the Art*

CHAPTER 3

Health Remote Monitoring System

This health remote monitoring system consists of demonstrating how it is possible to monitor biometric data in a secure and efficient manner through the use of wearable devices. For the development of this health remote monitoring system the following methodology was used :

- Identification of requirements
- System Architecture and Structure
- System development

3.1. Identification of requirements

This system consists of monitoring biometric data using wearable devices. As a result, data must be collected, transferred, monitored, and stored. In addition to the procedures outlined above, the presence of a graphical interface where users may visualize the data in a more straightforward and engaging manner is required. As a result, it is evident that specific requirements are needed to respond to the hypotheses provided in section 1.4 for the realization and development of this system, such as:

(1) To begin with, and most importantly, it's necessary to have an Internet connection and devices capable of establishing a wireless connection in order for data and information to be transmitted.

(2) It is also important to utilize a wearable device capable of gathering biometric data for monitoring a specific individual. This wearable must be able to link to other devices or platforms via bluetooth or wireless.

(3) For data transmission, a platform capable of storing the data collected by the wearable device and then transmitting it is required.

(4) The usage of an open-source server and services capable of connecting to the aforementioned platform, allowing data gathering, subsequent analysis and monitoring in real time, as well as the transmission of alerts if necessary.

(5) Create a graphical interface through this server or other platforms to visualize information about a specific individual more easily and clearly (via graphs, figures, text, alert visualization, etc.) since a lot of information and data are transferred at the same time and cannot be visualized clearly.

(6) To ensure that no data is lost, a database that can save the data for subsequent viewing or analysis is required.

The requirements 1 and 2 are directly related to hypotheses 1 and 2, since they include finding a wearable device capable of collecting biometric data as well as a device with internet connectivity that can connect to an online platform.

Regarding, requirements 3, 4 and 5 can be accomplished by using hypotheses 3 and 4 because they consist of using a platform to transfer the data, capable of connecting to an open-source server for further monitoring and visualization.

Finally, the 5 hypothesis can be explored to achieve the final requirement 6, that is, to be able to store all the data for further analysis and visualization.

3.2. System Architecture and Structure

To better understand the system architecture, that is, the various components and their corresponding functions, its structure was designed to include multiple fields, see Figure 9, or in other words, layers :

(1) ***Hardware Layer: Wearable Device and Microcontroller*** - This layer consists essentially of the different equipment used for the realization of this system. The equipment used were, a wearable device and a microcontroller. The wearable device's main function is to collect users' biometric data, while the microcontroller's main function is to extract the data collected by the wearable device. In other words, the microcontroller will act as a kind of bridge between the wearable device and the data transfer platform (explained later), where the data will be sent.

(2) ***Network Layer: Data Transfer Protocol and Platform***- The Data Transfer and platform, constitute this layer. With this protocol and platform, it is possible to establish connections with various IoT devices and store information. In this case, a connection will be established with the microcontroller and through this platform an broker is created that allows the connection of various programs and applications and the extraction of stored data.

(3) ***Data Layer: Server and DataBase***- This layer is composed of a server and a database. Server's main goal is to apply functions to analyze and monitor the biometric data present in the data transfer platform and send alerts if necessary. Database, on the other hand, has the function to safely store the analyzed and monitored data by the server, also allowing the visualization of them whenever necessary.

(4) ***Application Layer: Server Dashboard***- This layer consists of the server dashboard. This dashboard is created by the different biometric values collected, extracted and transferred by the microcontroller, more precisely by the data transfer platform. Through this dashboard it is possible to visualize the biometric data in a more appealing and easy way.

This entire architecture and structure will be made of many comparisons between various technologies by the various layers, finally determining which is the best.

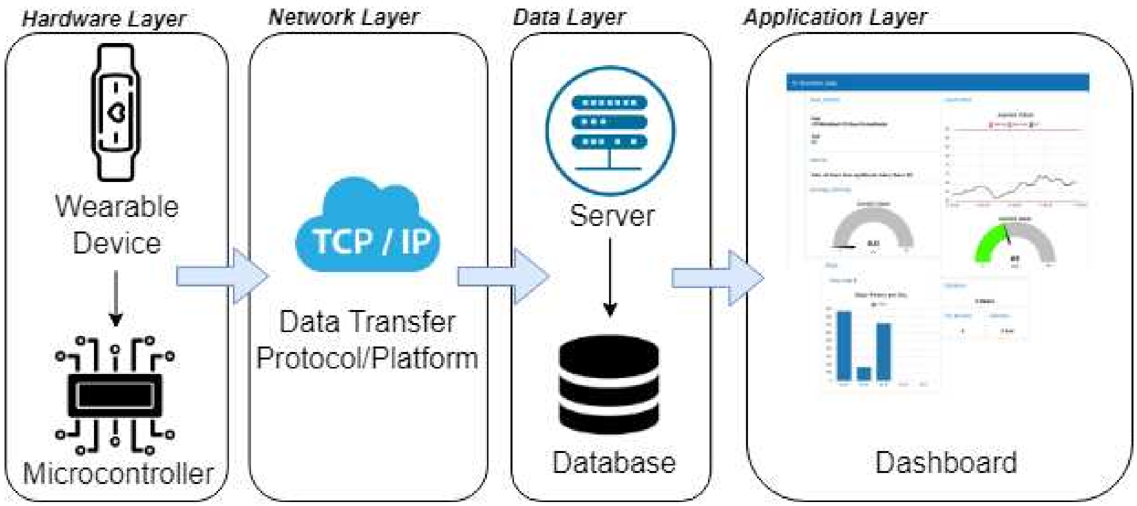


Figure 9. *System Architecture and Structure*

3.2.1. Hardware Layer: Wearable Device and Microcontroller

As noted in section 3.2 for the realization of this system there are two ends, being the equipment used, a wearable device and a microcontroller, one of the ends.

Before picking which wearable to use for the construction and purpose of this system, it is important to understand which are the best or most beneficial for collecting biometric data such as heartbeat, activity.

As previously stated in section 2.2, there are many types of wearable devices distinguished by their various locations of application throughout the human body. There are head mounted wearables, however they are not the most appropriate for the medical field because they are related to control and perception aspects and are more tied to entertainment, such as virtual reality for games or even audio devices like headphones and bass systems. Because they are unrelated to the aforementioned indicators, this form of wearable can be easily dismissed.

Body wearables such as ECG monitors, body sensors, and so on are examples of body-worn devices. Although these devices can capture a person's heart rate, their use and installation necessitate the presence of a health care provider. ECG monitors and other types of body sensors (chest, arms, waist) are often made up of multiple wires that are attached, in the case of ECG monitors, in the individual's chest area and the other sensors in their respective areas. This description makes it clear that, despite their potential to capture heartbeats, these types of wearables are not the best choice due to their difficult use, lack of mobility and portability.

Finally, it was possible to conclude that a wrist-worn wearable, more specifically a smartwatch, was chosen for the implementation of this system due to its ease of use and small size, as well as its ability to continuously collect data, ensuring the collection of the aforementioned indicators (Beats per Minute (BPM) and Activity) and providing awareness of daily habits, physical activity levels and routines [58].

Furthermore, one of the reasons for selecting this type of wearable is related to the equipment that was available for the implementation of this system as well as monetary reasons, allowing the creation of this system to be affordable to third parties which is an important goal.

As can be seen in chapter 2 section **??**, the majority of the projects described used Raspberry Pi as their chosen microcontroller rather than Arduino, which is also the favored choice for the development of this system. The Arduino is only a board with simple instructions that aren't particularly useful in this scenario, but the raspberry pi consists of a minicomputer with its own operating system that allows internet access and the installation of specific applications, libraries, and so on. Figure 10 shows both the wrist-worn wearable and the microcontroller.

(a) *Wrist-worn Device: Smartwatch*

(b) *Microcontroller: Raspberry Pi*

Figure 10. *Hardware : Equipment used in this System*

3.2.1.1. ***Wrist-worn Device: Smartwatch***

These smartwatches allow the collection of data such as oxygen levels, BPM, sleep quality monitoring, exercise values(steps, calories, distance and fat burned), stress and breathing monitoring. The BPM and exercise values will be collected and used in the development of this system. The sensor usually used by these smartwatches to collect BPM values is a BioTracker PPG sensor, PPG stands for ”Photoplethysmograph” and it’s a non-invasive technology that measures the volumetric fluctuations of blood circulation by using a light source and a photodetector at the skin’s surface [59] and can also help to diagnose cardiac arrhythmias (irregular heartbeat) because they reliably manifest cardiac and respiratory activities .

The light source, it emits light onto a type of tissue, and the photodetector measures the light reflected by this tissue. A typical light source is a green light or an infrared light emitting diode (IR-LED). In relation to the photodetector, the measurement of blood volume is mostly based on the amount of light detected on the paper .

As far as exercise values are concerned, these smartwatches occasionally use a 3-axis acceleration sensor and a 3-axis gyroscope sensor to collect them.

The main function of the 3-axis accelerometer is to measure linear accelerations relative to the three Cartesian coordinate axes, that is, to measure the velocity variations of a given point. Through this accelerometer it is also possible to detect the direction and speed of a moving object, considering the dynamic acceleration.

The 3-axis gyroscope’s main function is to measure angular velocity and angular motion relative to the three Cartesian coordinate axes of an object. They are widely used to maintain a reference direction or provide stability in navigation, stabilizers, etc.

3.2.1.2. ***Microcontroller: Raspberry Pi***

The Raspberry Pi is a low-cost, credit-card-sized computer that connects to a computer monitor or TV and operates with a regular keyboard and mouse. It functions as a computer and allows you to experiment computing and learn how to program in languages such as Scratch and Python [60]. For the realization of this system the microcontroller is running the Raspbian GNU/Linux operating system with version 11. As mentioned before, this microcontroller function as a bridge and it is possible to extract the values collected by the smartwatch using a Python-based program. It is also through this program that the connection with the data transfer platform is made, allowing the collected data to be transferred to this platform and then collected by the server.

3.2.2. Network Layer: Data Transfer Protocol and Platform

3.2.2.1. *Data Transfer Protocol*

In terms of data transfer or exchange, various protocols are available for usage in IoT environments, including for example:

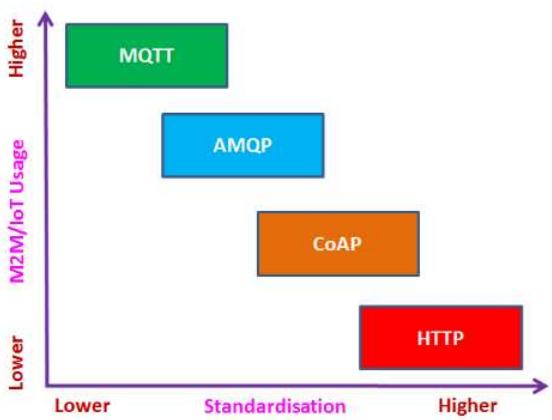
- AMQP (Advanced Message Queuing Protocol)
- MQTT (Message Queuing Telemetry Transport)
- CoAP (Constrained Application Protocol)
- HTTP (Hypertext Transfer Protocol)

AMQP is a lightweight M2M protocol that supports both request/response and publish/subscribe architecture. It works by either the publisher or consumer creating a ”exchange” with a given name that is broadcast, and then the publishers and consumers use the name of this exchange to discover each other making it possible to communicate and exchange data [61].

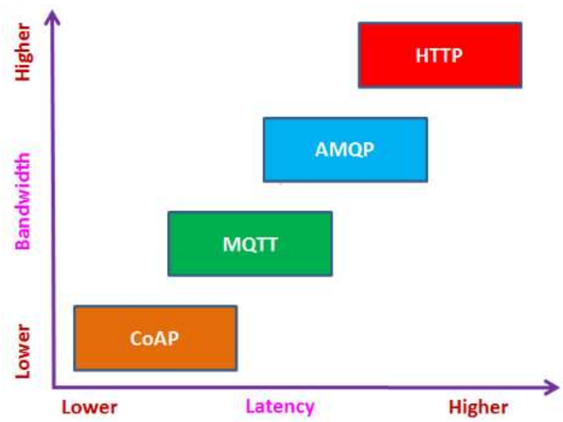
MQTT is a binary data communication protocol that runs on top of the Transport Control Protocol and allows for a variety of communication patterns in an IoT environment [62]. It refers to M2M (Machine-To-Machine) protocols that communicate using a publish/subscribe approach with topics. This is a protocol that connects networks and devices utilizing M2S (Machine-To-Server) and S2S (Server-To-Server) connections or even M2M communication patterns and routing mechanisms (one-to-many, one-to-one, many-to-many) [63].

CoAP is a lightweight M2M protocol that supports both request/response and resource/observe architectures, which is a form of publish/subscribe. CoAP was created primarily for interoperability with HTTP, which is primarily a web messaging protocol that allows request/response RESTful Web architecture. Unlike MQTT, CoAP and HTTP employ Universal Resource Identifier (URI) rather than topics. A Publisher in CoAP publishes data to the URI, while a Subscriber subscribes to a specific resource specified by the URI. When a publisher publishes new data, all subscribers are alerted of the new value as indicated by the URI. In HTTP, the server provides data via the URI and the client gets data using the same URI[61].

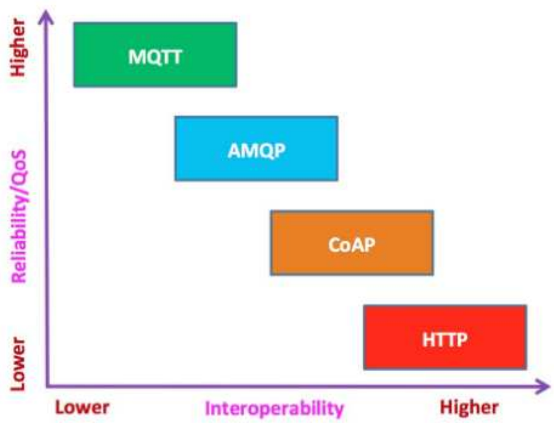
The following Figure 11 compares all the protocols mentioned previously in some important aspects, like IoT environments usage, latency, reliability, power consumption, and so on.



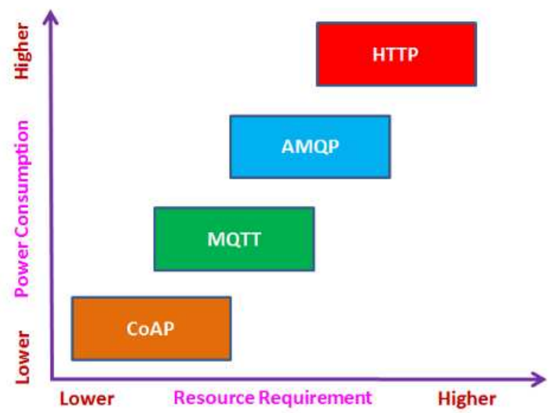
(a) *IoT Usage/Standardisation*



(b) *Bandwidth/Latency*



(c) *Reliability/Interoperability*



(d) *Power Consumption/Resource Requirement*

Figure 11. *Data transfer/Message Protocols by [61]*

When comparing the protocols mentioned previously using Figure 11, is possible to see that the ”winner” in some aspects, like IoT Usage and Reliability which provides high delivery guarantees using three types of mechanisms also known as quality of services (QoS) is always the MQTT protocol. However, the CoAP protocol is faster presenting low latency, which generates less delay, and uses less power. Although, after examining all of the aspects depicted in the figure, it is possible to conclude that the best protocol to use is MQTT, given that the system under consideration is an IoT system, and as previously stated, the protocol MQTT employs a simpler approach, employing only publish/subscribe, where clients do not require updates, reducing the resources used and making this approach ideal for use in a low-bandwidth environment [64], rather than the request/response and resource/observe approaches used by CoAP.

As the chosen one, to get a better and more specific understanding the MQTT protocol makes use of a client-server system which uses the publish/subscribe approach, see figure 12. In this system a broker distributes updates to MQTT clients, in other words, clients do not transmit messages directly to one other due to the presence of this broker, who handle the messages. Each MQTT message has a topic to which the clients can subscribe or publish. All messages published by clients are received by the broker, who then forwards the messages to all clients who have subscribed to the specified topic [62].

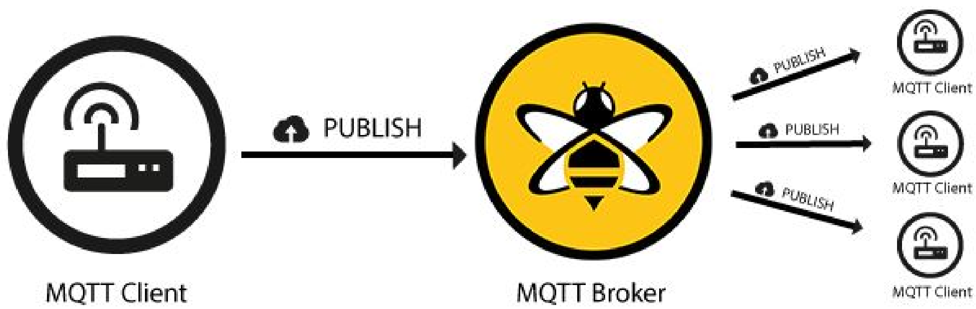


Figure 12. *MQTT Publish/Subscribe Model by [65]*

3.2.2.2. ***Data Transfer Platform***

The platform used for the use of the MQTT protocol, in other words for data transfer, was the HiveMQ cloud platform. The HiveMQ cloud platform was chosen because it is a fully managed cloud-native IoT messaging platform that makes IoT device connectivity reliable and scalable [66] and when compared to others IoT cloud platforms, such as AWS IoT and MS Azure IoT Hub, provides more features and less limitations when using the MQTT protocol, see Tables 2 and 3.

As shown in table 3, there are no message size and subscriptions per connection limitations, although this is only available in the premium edition, which needs payment. However, there is a free version of HiveMQ Cloud that allows users to create a free MQTT broker cluster, which is more than enough for the purpose of this system, and as previously stated, the goal is to develop an affordable system.

Feature	AWS IoT	MS Azure IoT Hub	HiveMQ Cloud
MQTT 5	X	X	✓
QoS 2 Support	X	X	✓
QoS 0 Support	Nonconformance to specification	✓	✓
Retained Messages	X	X	✓
Guaranteed message ordering	X	✓	✓
Direct access to messages after a successful subscription	X	✓	✓
Topic Filter	No restrictions	# and + are not supported	No restrictions
Topic namespace restrictions	No restrictions	Topic structure limited	No restrictions
Compatibility with standard MQTT client libraries (ex. Eclipse Paho)	No	Limited Use	✓

Table 2. *Platform's features using MQTT protocol by [67]*

Limitation	AWS IoT	MS Azure IoT Hub	HiveMQ Cloud
QoS 1 retry interval	1 hour	unlimited	unlimited
Publish request per second per client	100	120/second/unit 6000/second/unit at higher price level	unlimited
Subscriptions per connection	50	Limit depends on pricing	unlimited
Cloud to device message queue	unlimited	50	unlimited
Throughput	512kb/sec/connection	300MB/day	unlimited
Message Size	128kb	256kb device to cloud 64kb cloud to device	unlimited

Table 3. *Platform's limitations using MQTT protocol by [67]*

Figure 13 shows that this cluster is a distributed system that serves as a single MQTT logical corrector for MQTT connected clients [68] and has a URL (Uniform Resource Locator), a port, a capacity of 100 subscriptions per connection and a capacity of roughly 10 GB, allowing to connect to various IoT devices (Raspberry pi in this system) and store information (biometric data in this system).

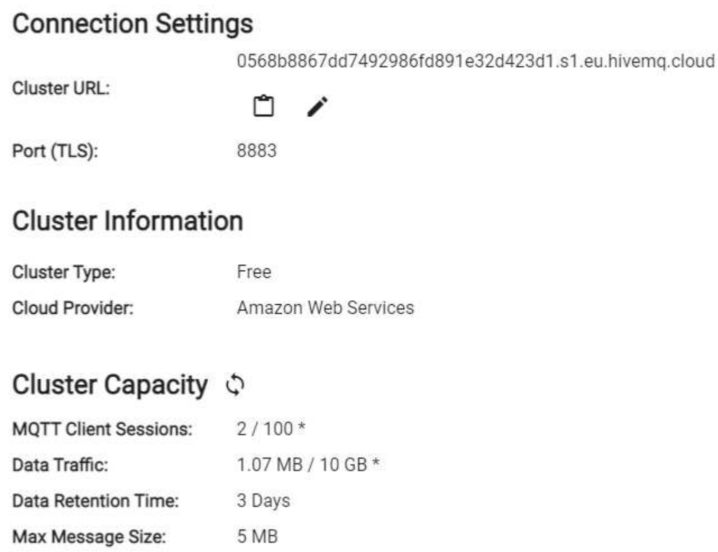


Figure 13. *Cluster Overview*

3.2.3. Data Layer: Server and DataBase

3.2.3.1. *Server: Node-RED*

The server that was chosen to monitor all the transfer data and generate alerts was the Node-RED. This server is a visual programming software created by IBM (International Business Machines) designed to connect hardware devices, APIs (Application Programming Interface) and web services as part of the Internet of Things [69]. This programming software is a free JavaScript-based tool, built on Node.js platform and has a flow editor for building JavaScript functions in a web browser, making it simple to connect flows using the palette's various nodes, these nodes can be dragged, dropped and/or wired up together, which can be seen in figure 35 that can be found in the appendix A. With Node-RED it's possible to run logic on various microcontrollers (Raspberry Pi, Arduino Uno, Arduino MKR, ...) and integrate them with cloud services, preserve historic data in databases, run more complex dashboards, and it also provides additional security choices, such as https, firewalls, and so on. One of the reasons that also helped in choosing this programming software is related to the fact that it has previously been used in various projects during my academic career, making the development of this system a simpler procedure.

The primary goal of using this software is to do the following tasks:

- Establishing a connection with a MQTT Platform;
- Gather all of the data;
- Data analysis and monitoring;
- Sending email alerts if the data does not meet the predetermined thresholds;
- Store the data in a database;

3.2.3.2. ***Database***

As previously stated, once the collected data has been thoroughly analyzed and monitored, it will be sent to a database where it will be securely stored and accessible. For that, there are two sorts of databases, Relational and NoSQL. **Oracle** is the most popular Relational database, and **MongoDB** is the most popular NoSQL database. When comparing this two databases, it is possible to see that their database language differ. MongoDB's query language consists of API calls, JavaScript, and REST (Representational State Transfer), whilst SQL is used in Oracle DataBase.

In terms of characteristics, MongoDB is a database that accepts larger data, with a maximum value size of roughly 16 MB, whereas the Oracle Database has a maximum value size of around 4 KB. Regarding features, MongoDB provides consistency, durability, and conditional atomicity and Oracle Database provides isolation, transactions, referential integrity, and revision control, which MongoDB does not offer. MongoDB is a free product, meanwhile Oracle DataBase is a licensed product [70].

A. Boicea, F. Radulescu, *et al.* [70] is a study that aimed to compare both of these databases. The authors decided to run some tests and compute the time in milliseconds it took each engine to perform some database actions (insert, update, and remove actions) and concluded that MongoDB was faster and more efficient when inserting large amounts of data than Oracle database, which was faster and more efficient when inserting small amounts of data, see Table 4 and Figure 14.

No. of records	Oracle Database	MongoDB
10	31	800
100	47	4
1000	1563	40
10000	8750	681
100000	83287	4350
1000000	882078	57871

Table 4. *Inserting times by [70]*

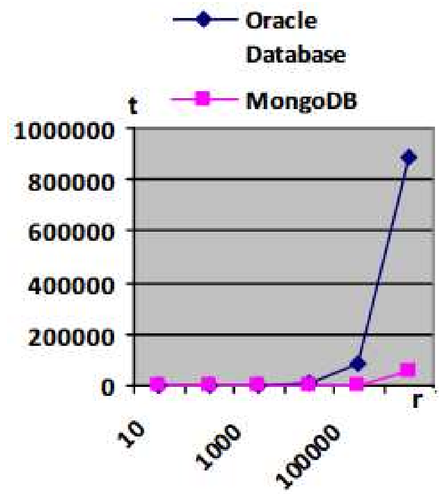


Figure 14. *Inserting times by [70]*

In terms of updating actions, MongoDB almost always had the same times regardless of the quantity of data updated, but Oracle Database times increased when updating larger volumes of data, see Table 5 and Figure 15.

No. of records	Oracle Database	MongoDB
10	453	1
100	47	1
1000	47	1
10000	94	1
100000	1343	2
1000000	27782	3

Table 5. *Updating times by [70]*

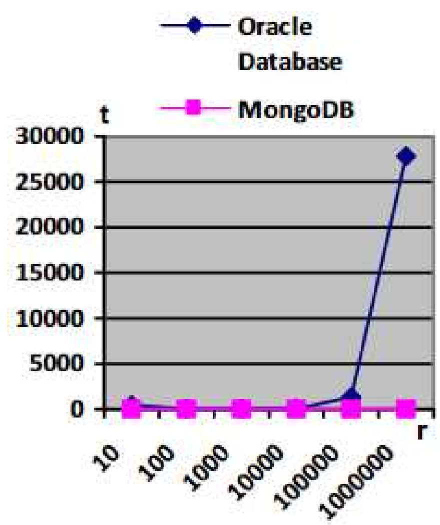


Figure 15. *Updating times by [70]*

Finally, in terms of removing actions, MongoDB spends nearly constant time deleting records, while Oracle Database increases with the quantity of records to be deleted, see Table 6 and Figure 6.

No. of records	Oracle Database	MongoDB
10	94	1
100	47	1
1000	62	1
10000	94	1
100000	1234	1
1000000	38079	1

Table 6. *Deleting times by [70]*

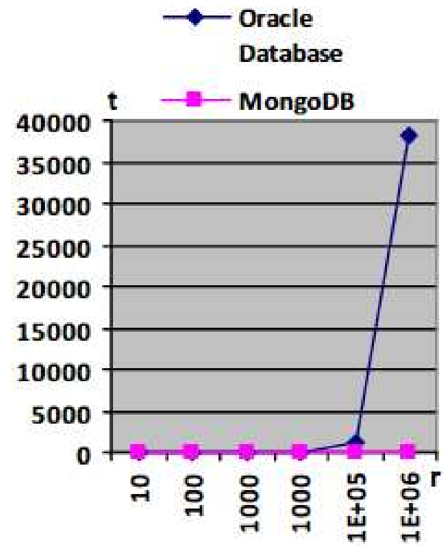


Figure 16. *Deleting times by [70]*

It was reasonable to conclude that MongoDB was the better database since it provides more flexibility throughout the development process, has built-in support for horizontal scalability, and is simple to deploy and copy databases from one server to another utilizing export/import tools. For the reasons stated above, MongoDB was chosen as the Database for this system.

3.2.4. Application Layer: Dashboard Node-RED

This layer makes it possible to see all the data that is collected and subsequently monitored. It was decided to develop this application layer since the amount of information collected about a specific individual is extremely large, making it impossible to see it in real time in an easy and straightforward manner, both for the user in question and for the health professional. This layer was created on the Node-RED server because this server allows the creation of very complex dashboards that can contain not only text, but also graphs, gauges, and even tables, and because Node-RED is the central component of this system since it where all the collected information passes through and is kept for monitoring.

3.3. System development and implementation

In this section the development of this health remote monitoring system and how it is implemented will be discussed in more detail. How to connect a smartwatch to a microcontroller, how to use a Python-based program to create a connection to a MQTT platform, how the server can use the data collected for further analysis and monitoring, the types of alerts generated during data monitoring and how health professionals can receive them, how all the monitoring data can be stored in a database, and finally, how to visualize all the monitored data and respective alerts using the node-red dashboard.

3.3.1. *Connection between smartwatch and microcontroller*

The connection between these two devices is made by using Bluetooth. The Python program inside the microcontroller allows the smartwatch to use Bluetooth to establish a connection with the microcontroller and then proceed to the information extraction process, i.e., data extraction.

However, the smartwatch, more specifically the Amazfit band 5, due to its firmware it is necessary to have a server-based pairing, and for this it is necessary to use an auth key. Only through this auth key is it possible to pair the smartwatch and collect data.

3.3.2. *Connection to the MQTT platform*

The connection to the MQTT platform was performed in Python, using a piece of code retrieved and adapted from GitHub [71].

For the realization of the proposed system, this program was modified to meet the necessary requirements. To be able to establish a connection with the MQTT platform, it is first necessary to establish certain requirements, such as the installation of Paho Python on the microcontroller and the use of an example code to allow the connection of MQTT clients with the cluster present on the MQTT platform. This example code is available on HiveMQ Cloud site and can be seen in appendix B Figure 36.

After these changes it is now possible to run the program and then connect the smartwatch to the microcontroller. To run this program, you must be in the program's directory and execute the following command, Figure 17.

```
File  Edit  Tabs  Help
pi@raspberrypi:~ $ cd Amazfit_Band
pi@raspberrypi:~/Amazfit_Band $ cd Amazfit_Band_5/
pi@raspberrypi:~/Amazfit_Band/Amazfit_Band_5 $ python3 miband4_console.py -m CD:0F:4A:83:1E:04
```

Figure 17. *Command to run the program*

This command is always the same, however the MAC (Media Access Control) address at the end of the command, in this case ”CD:0F:4A:83:1E:04”, could differ because different devices have different MAC addresses.

3.3.3. *Getting data on the Node-RED server*

Before continue with data collection and extraction in the Python program, it is important to start the Node-RED server on the microcontroller, allowing the data to be retrieved and used by the server.

As explained in subsection 3.2.2 the MQTT protocol uses a public/subscribe approach, so it is necessary for a client to subscribe to that certain topic and then use the publish method with the information it intends to send, the following Figure 18 shows the publish and subscribe methods.

```
client.publish("HR", payload=data, qos=0)
```

(a) *Publish Method*

```
client.subscribe("test/", qos=1)
```

(b) *Subscribe Method*

Figure 18. *Publish/Subscribe Methods*

When this is done it is possible to start data collection, since through these modifications the information is transferred and can later be used by the server. As mentioned earlier in subsection 3.2.3 the Node-RED server has a pallet of nodes capable of modifying the information as we prefer.

Through these nodes it was possible to create rules to monitor the received data, as will be discussed in the following section.

3.3.4. *Data monitoring methods employed*

Five monitoring methods were developed to provide a good data monitoring and implemented into the system:

(1) First of all, as in any other data monitoring system, maximum and minimum limitations for the Heart Rate value have been established. According to [72] and to the National Institutes of Health (NIH) in [73], the normal Heart Rate values over the age of 10 years old ranges

between 50/60 BPM and 90/100 BPM, choosing 55 BPM and 95 BPM as minimum and maximum values.

(2) In addition to these limits, more limits were also created taking into account the possible presence of cardiac arrhythmias. These can be classified in two ways, tachycardia and bradycardia. A tachycardia results when the heart rate value is greater than 100 BPM and a bradycardia results when the heart rate value is less than 60 BPM. When the heart rate values exceed the maximum limits and fall below the minimum limits, alerts are generated to monitor the heart rate values and verify whether everything is in order with the individual. These alerts will be discussed in greater depth later in the next subsection.

(3) Following that, it was important to understand that heart rate values can vary and reach greater levels when an individual engages in physical activity, in other words, their cardiac rate will increase, potentially surpassing the previously defined limits, resulting in the generation of ”false” alerts.

The following equation 3.1 was used for that reason and consists only in obtaining the user's average velocity.

$$\overline{v} = \frac{\Delta x}{\Delta t} = \frac{xf - xi}{tf - ti} \tag{3.1}$$

This equation is very straightforward, with Δx representing the displacement/distance traveled or steps taken by the individual, which is collected by the smartwatch used in this system, and Δt representing the time spent traveling that same displacement/distance or steps. Because the collected data is received on the server in real time, it is possible to determine how many steps the user has taken in a specific and given time. As a result, certain time intervals and step intervals can be defined, allowing for final steps, xf, with a specific final time, tf, and initial steps, xi, with a specific initial time, ti. This equation and its subsequent result, average velocity, is related with the act of running or fast pace and allows the creation of a new method to monitor the heart rate values which is then implemented in this system. But first, it was necessary to know the average velocity that a person achieves when performing the act of running, and according to L. L. Long and M. Srinivasan's research [74] the average velocity of a person when performing a walk-run mixture or fast pace is between 2 and 3 m/s, and when mostly running can vary between 3.5 and 4 m/s approximately. All of this can be seen and proved in the following Figures 19 and 20.

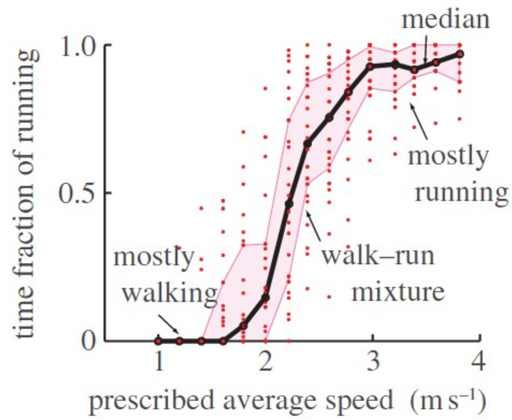


Figure 19. *Average Velocity when walking and/or running by [74]*

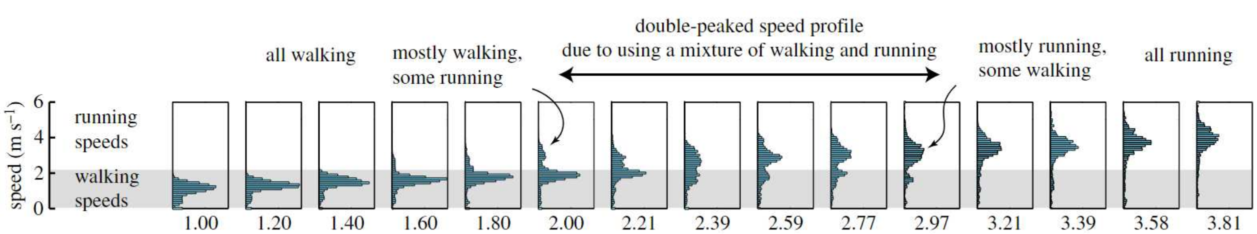


Figure 20. *Speed distributions at different prescribed average speeds by [74]*

With this information was created a threshold, where it is possible to check for physical activity whenever the user's average speed exceeds the predefined average velocity value. As a result, in this system whenever a user's heart rate, collected by the smartwatch, is above or below the previously specified maximum or minimum limits(previous monitoring methods), a check will be performed to determine whether or not the user is performing any physical activity, without generating false alarms, which will be discussed in the next subsection.

(4) However, it is also critical to remember that despite engaging in a physical activity, there is a maximum heart rate limit that, according to [75], could be defined by using the following equation 3.2.

$$BPM_{max/min} = (220 - Age) * Percentage_{max/min} \tag{3.2}$$

This equation consists of subtracting 220 by the individual's Age and then multiplying by the $Percentage_{max/min}$, which values are 0.76 (76%) to determine the maximum limit or 0.64 (64%) to determine the minimum limit (values where the heart rate should be [75]), with the maximum limit being of greater interest to the development of this system.

(5) This last method of monitoring, involves observing how the value of the heart rate changes over time, which can be rather quick. To that end, a procedure was developed that primarily involves the use of two equations.

$$\sum_{k=1}^{n} Diff\_HR_{K...n} = |HR_{K+1} - HR_K| \tag{3.3}$$

$$Average_{HR} = \frac{\sum_{k=1}^{n} Diff\_HR_{K...n}}{Number_{Diff\_HR}} \tag{3.4}$$

The first equation 3.3 consists in calculating the summation of the difference between the five received heart rate values, i.e., $HR2$ subtract by $HR1$, $HR3$ subtract by $HR2$, and so on. After obtaining this summation, it is possible to use the second equation 3.4, which consists in dividing this summation by the $Number_{Diff\_HR}$ and obtaining the average heart rate value in a time span of 5 seconds.

For example, if the value of $Average_{HR}$ is equal to 3.5, the Heart Rate value would have increased by exactly 14 values in 5 seconds, because the Heart Rate values gathered by the smartwatch are received at the Node-RED server every 1 second. It was feasible to conclude that this value would reflect a concerning increase, making it necessary to generate an alert whenever the $Average_{HR}$ value surpassed its default value.

3.3.5. *Types of alerts generated during data monitoring and receipt by healthcare professionals*

As stated in the preceding section, all data monitoring methods generate alerts, which might be of various types. However, they all share the same structure, which is divided into fields such as ”Tempo”, ”Alerta”, and ”Descricao/Valor_HR”. The ”Tempo” field indicates the day and hour the alert was generated, while the ”Alerta” field includes information such as ”Heart Rate Controlled,” ”Heart Rate High,” and ”Heart Rate Alert,” among others. Finally, the ”Descricao/Valor_HR” field only informs what kind of alert it is and what is happening to the user, as well as the heart rate value when the alert was generated.

This system has eight distinct alerts, which are, **”Heart Rate Alerta”**, **”Heart Rate Controlado”**,**”Heart Rate Nulo”**, **”Heart Rate elevado”**, **”Heart Rate baixo”**, **”Atividade fisica”**, **”Alerta Atividade fisica Heart Rate elevado”** and **”Alerta Variacao de Heart Rate”**.

The **”Heart Rate Alerta”** is generated whenever the monitoring method 1 is used, that is, when the Heart Rate is greater than or less than the maximum and minimum limits, respectively.

The **”Heart Rate Controlado”** notifies when the heart rate value is under control, that is, when it is between the maximum and minimum limits. The ”**Heart Rate Nulo”**, as the name suggests, allows to determine whether the heart rate value is null.

The **”Heart Rate elevado”** appears with the possible presence of cardiac arrhythmias, more specifically, tachycardia, while the **”Heart Rate baixo”** with bradycardia, monitoring method 2.

The **”Atividade fisica”** which alerts when, despite exceeding the maximum limits from the previous methods 1 and 2, the user finds himself performing a physical activity, monitoring method 3, however, as previously stated, there is a maximum limit when the user is attempting to perform an physical activity, which generated the **”Alerta Atividade fisica Heart Rate elevado”**, monitoring method 4.

Finally, the **”Alerta Variacao de Heart Rate”** is generated whenever there is a sudden change in the heart rate value, as shown in the monitoring method 5.

In terms of delivery, generated alerts are emailed to healthcare professionals. This is due to the presence of a node on the Node-RED server that facilitates communication with the Outlook server, see Figure 21.

Figure 21. *Email node from Node-RED*

All alerts generated during the respective day will be shown on the Node-RED Dashboard and could also be viewed in the MongoDB Database, as can been seen later in the subsections 3.3.6 and 3.3.7.

3.3.6. *Storing in a database all the monitoring data*

First of all, it is necessary to understand how the MongoDB Database is implemented and how the monitored data is received. It is possible to access data in several ways using MongoDB, and two of them were used: MongoDB Compass and MongoDB Cloud, see Figures 22 and 23.

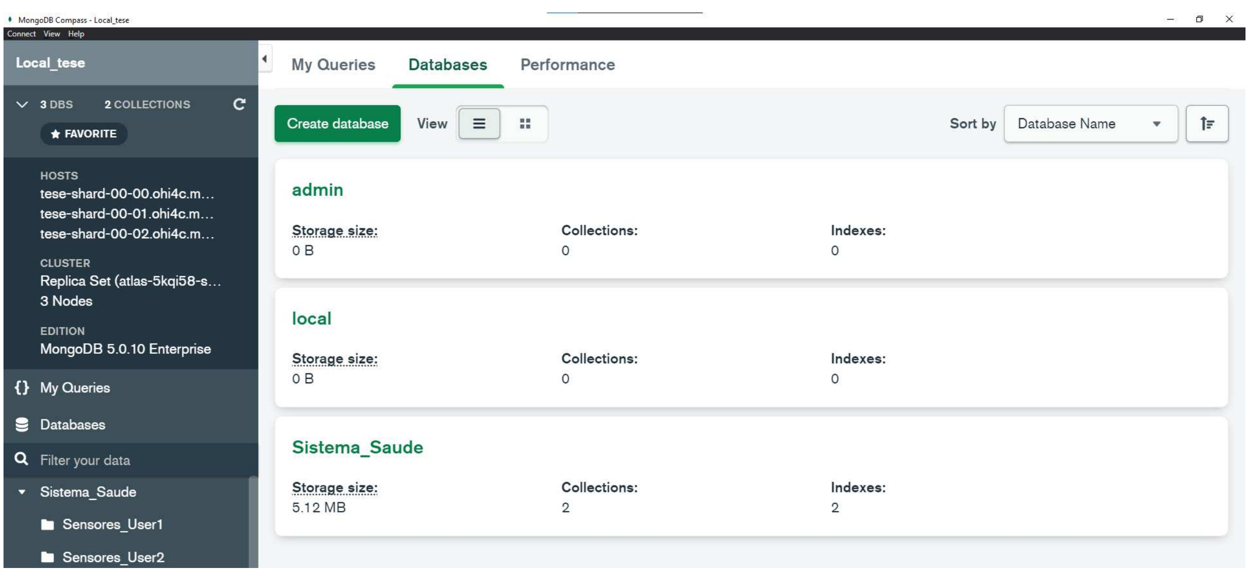


Figure 22. *MongoDB Compass*

MongoDB Compass results in a software that needs to be installed on a device to explore, modify, and view all data, whereas MongoDB Cloud is accessed through a browser, making it more convenient because it can be accessed from anywhere; however, users have the following options for connecting to the cluster: Connect with the MongoDB Shell, an application, or Visual Studio Code.

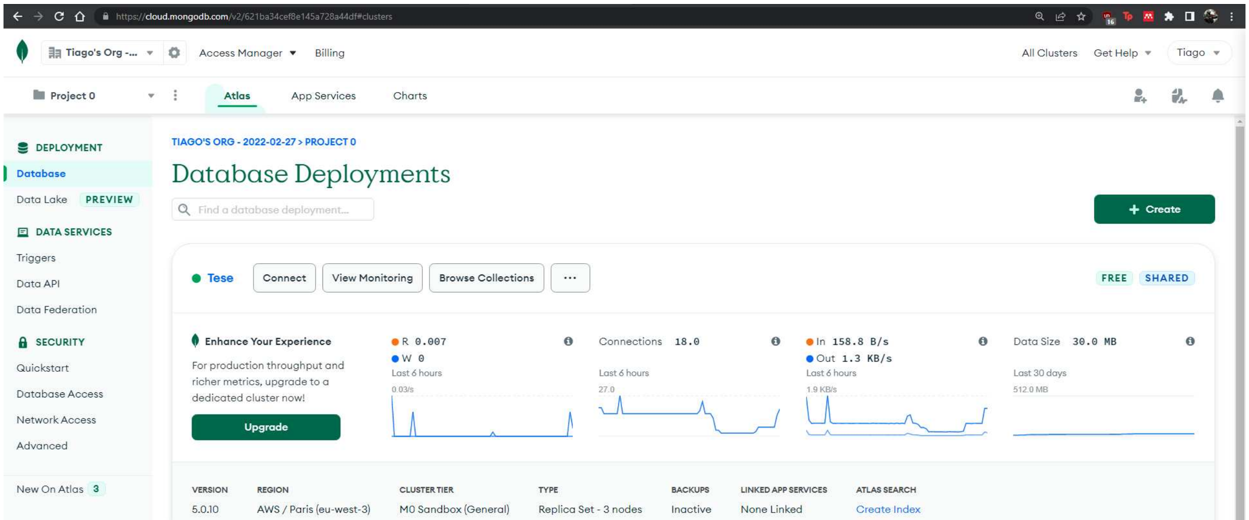


Figure 23. *MongoDB Cloud*

For the development of this system the name given to the database was "Sistema_Saude", which contains several collections. These collections are linked to different users, that is, each user has their own collection where their monitored biometric data is stored, the collections names are "Sensores_User1, Sensores_User2 , ... ", see Figure 24 .


Sistema_Saude

DATABASE SIZE: 28.53MB INDEX SIZE: 1.5MB TOTAL COLLECTIONS: 2

CREATE COLLECTION

Collection Name	Documents	Documents Size	Documents Avg	Indexes	Index Size	Index Avg
Sensores_User1	82578	28.27MB	359B	1	1.43MB	1.43MB
Sensores_User2	1078	268.85KB	256B	1	68KB	68KB

Figure 24. *MongoDB Cloud Database and respective collections*

The data is stored in JSON (JavaScript Object Notation) flexibly structured documents, which can contain a variety of structures or fields. The document's structure and information are divided as follows:

- User Details - where you can find the auth key of the smartwatch used as an id and also the user's age;
- HR (Heart Rate) - where you can find the type of value measured, in this case the heart rate, and the respective time and date of that value;

- Activity - where you can find the time of the activity which is then divided by the steps taken, calories lost, distance travelled and fat burned, using the equations developed in the subsection 3.3.4

All of this can be seen in the following figure 25.

Figure 25. *Structure of the document and its information*

In addition to the monitored data, inside the MongoDB Database the types of alerts mentioned in this section 3.3.5 are also saved in a collection called "Alertas", Figure 26.

Collection Name	Documents	Documents Size	Documents Avg	Indexes	Index Size	Index Avg
Alertas	2	349B	175B	1	36KB	36KB

Figure 26. *MongoDB Database "Alertas" Collection*

When it comes to information visualization, MongoDB can be used to apply some filters to locate any type of data in a specific field of the document's structure. One of the most used filters consists in determining the most recent value added into the database, this can be accomplished by simply writing **{ _id:-1 }** in the "Sort" field. This is frequently used since the MongoDB database organizes its data so that values added into the database appear towards the end of the collection rather than at the beginning.

Explained the entire MongoDB implementation, how it is then possible to establish a connection to it.

To establish a connection to the MongoDB Database to be able to store data is only necessary to create a cluster. Then to access this cluster simply enter the corresponding URL into MongoDB Compass, where it is necessary to enter the username and password of the user who created the cluster, all of this is explain in MongoDB site [76].

The way the monitored data is stored in the MongoDB database is very straightforward, it is only by using a node present on the Node-RED server, where all the information corresponding to the cluster is placed, Figure 27.

Figure 27. *MongoDB node from Node-RED*

3.3.7. *Visualizing all the monitored data and respective alerts using the node-red dashboard*

This dashboard is available for visualization via HTTP through the node-RED's network IP (Internet Protocol address) and includes all the fields stated in the previous subsection.

This Node-RED dashboard contains two tabs:

- ”Biometric_Data” tab;
- ”Alerts” tab

In the first tab ”Biometric_Data”, as illustrated below in Figure 28, fields such as ”User_Details”, ”Distance”, ”Fat_Burned”, ”Calories” and ”Alerts” are displayed as only text fields, however the values of the field ”Heart_Rate” are displayed in an line chart where is also possible to visualize the maximum and minim values that the heart rate could go and the current value is displayed on a gauge. The field ”Steps” are in a bar chart in which records the steps taken in the last 5 days.

It's also possible to see a gauge, whose name is ”Average_Velocity”. This gauge shows the current average velocity of the individual wearing the smartwatch which helps to see if the individual is on an activity or not, helping the monitoring of the biometric data, this will be explain in more detail later on.

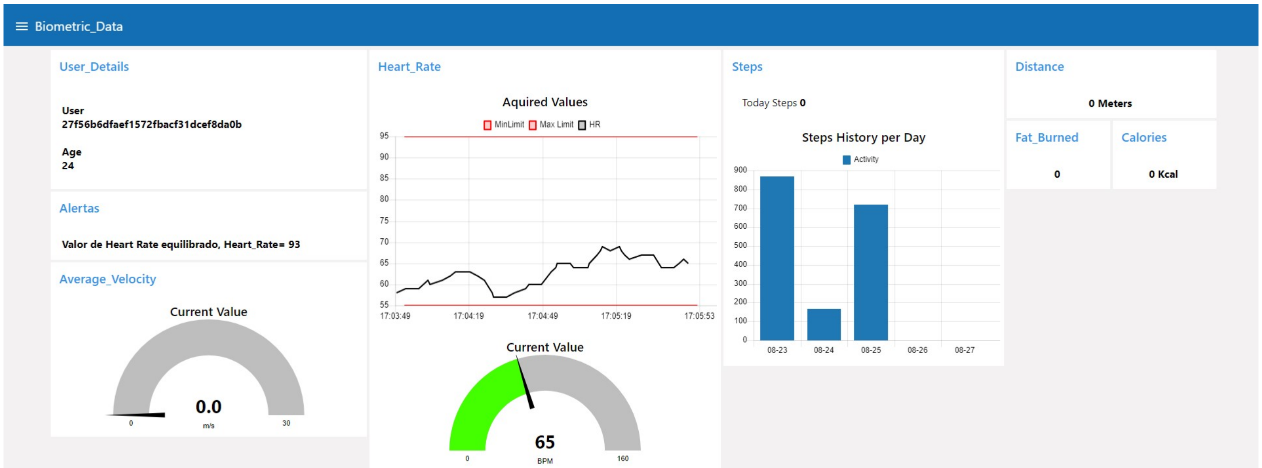


Figure 28. *Biometric_Data Dashboard*

The second tab, "Alerts," includes a table that stores all the alerts generated throughout the day, allowing to see which and how many alerts were generated, see Figure 29.

Alerts

Alertas_table

Time	Alerta	Descricao/Valor_HR
2022-08-25 16:05:59	Heart Rate Controlado	Valor de Heart Rate equilibrado, Heart_Rate= 93
2022-08-25 16:05:09	Heart Rate Alerta	Valor de Heart Rate bastante elevado, Heart_Rate= 97
2022-08-25 16:04:58	Heart Rate Controlado	Valor de Heart Rate equilibrado, Heart_Rate= 94
2022-08-25 16:04:48	Heart Rate elevado	Heart Rate elevado, possivel taquicardia, Heart_Rate= 101
2022-08-25 16:04:43	Heart Rate Alerta	Valor de Heart Rate bastante elevado, Heart_Rate= 96
2022-08-25 15:58:44	Heart Rate Controlado	Valor de Heart Rate equilibrado, Heart_Rate= 94
2022-08-25 15:58:24	Heart Rate Alerta	Valor de Heart Rate bastante elevado, Heart_Rate= 98
2022-08-25 15:45:42	Heart Rate Controlado	Valor de Heart Rate equilibrado, Heart_Rate= 92
2022-08-25 15:45:32	Heart Rate Alerta	Valor de Heart Rate bastante elevado, Heart_Rate= 96
2022-08-25 15:45:09	Atividade fisica	Encontra-se a realizar atividade fisica, Heart_Rate= 97
2022-08-25 15:36:18	Heart Rate Controlado	Valor de Heart Rate equilibrado, Heart_Rate= 82
2022-08-25 15:36:12	Alerta Variacao de Heart Rate	Variacao de Heart Rate bastante rapida, Heart_Rate= 82
2022-08-25 15:28:15	Heart Rate Controlado	Valor de Heart Rate equilibrado, Heart_Rate= 78

Figure 29. *Alerts Dashboard*

To conclude the section 3.3, the figure below illustrates a functional diagram of the system's development, 30.

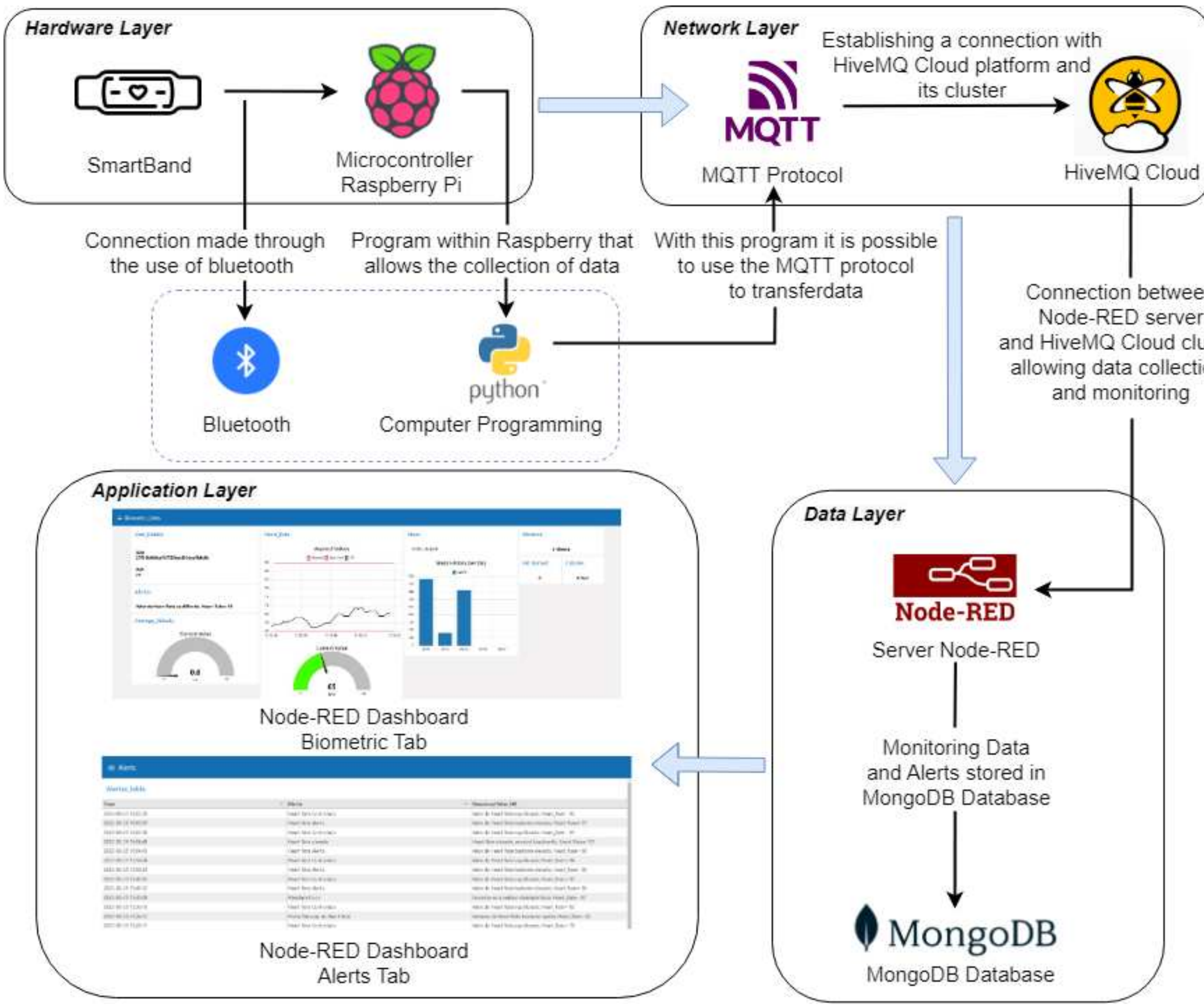


Figure 30. *Diagram of the system's development*

CHAPTER 4

Results and Discussion

This chapter will examine and discuss the results gained by employing the system built and explained in the previous chapter. These results will be related not only to the monitoring results obtained by the system, but also to the equipment and methods used to obtain better results, such as the distance or range that the smartwatch can be from the microcontroller, the methods used that then had to be changed to obtain better results, or even the exchange of methods, and so on.

4.1. The requirements for a good connection between the system's hardware

When using the hardware for the possible collection and transfer of biometric data it was necessary to verify the maximum distance that the smartwatch can be from the raspberry or, in other words, the range that the raspberry pi Bluetooth software has in order not to lose the connection, since if this happens it is impossible to collect data, which consequently prevents the monitoring of the biometric data of the respective user.

This microcontroller includes a Broadcom BCM43438 Bluetooth chipset, which enables and supports Bluetooth 4.1, [77]. The maximum distance or range of this type of Bluetooth is on average around 100 meters [78], however because this system has a connection between two devices, namely the smartwatch and the microcontroller, it was necessary to perform certain tests. Through these tests, it was feasible to determine that the maximum distance possible to retain a good connection and/or ensure that this connection is not lost is approximately a radius of 16 meters.

It is possible to conclude that the distance is a little short in comparison to the possible range mentioned earlier in Bluetooth 4.1, but it is important to remember that this connection is made through a Python-based program as mentioned in previous chapters, which due to these tests reduces Bluetooth's potential slightly. Aside from that, the presence of numerous physical obstacles, such as walls and their structure and characteristics, various sorts of objects, and so on, must be considered.

4.2. Monitoring Methods and results

Obtaining and/or visualizing the results of the monitoring methods used, can be seen in two ways.

Through the node-RED dashboard, where the results can be viewed in real time and in a clearer and more objective manner and by using the MongoDB database. To obtain the results, this system was tested firsthand by a single user, user 1. It was through this user and the information obtained from other articles and projects that the predefined values for the monitoring methods were defined. This user's age is 24 years and does not have any type of illness nor does he take any type of medication, his monitoring, more precisely his heart rate values can be visualized through the following figure 31.

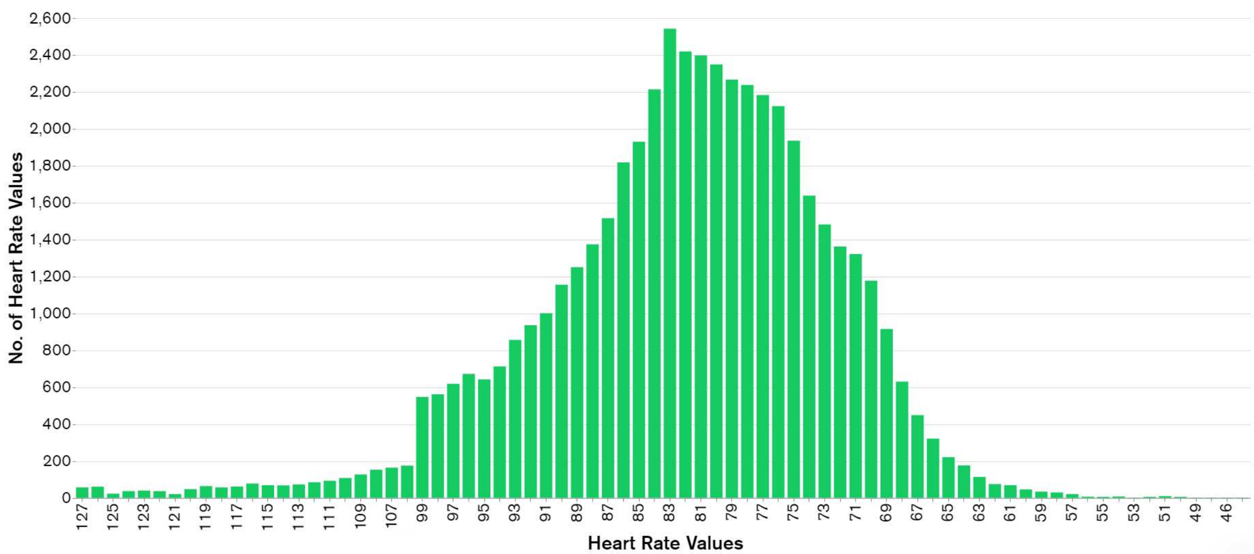


Figure 31. *user 1's heart rate values*

As shown in the preceding figure, the most registered heart rate values were between 71 and 87 BPM, which were reasonable heart rate values according to [72] [73]. However, it was possible to conclude that there were many more records of elevated values, between 89 and 99 BPM, than low values, between 65 and 51 BPM, implying that this user had a higher heart rate than a lower heart rate. Relative to extremely high values, between 105 and 127 BPM, particularly values that exceed the defined maximum values, were associated with the fact that the user was performing a physical activity or run walking, as seen below in figure 32.

```
_id: ObjectId('63078af55720060563b2e0a3')
topic: "Atividade fisica "
payload: Object
  Time: "2022-08-25 15:45:09"
  Descricao: " Encontra-se a realizar atividade fisica, Heart_Rate=  111"
qos: 0
retain: false
_msgid: "f04518695cf6cfaf"
alarm: 5
```


(a) *First Alert*


```
_id: ObjectId('63078af55720060563b2e0a7')
topic: "Atividade fisica "
payload: Object
  Time: "2022-08-25 15:48:09"
  Descricao: " Encontra-se a realizar atividade fisica, Heart_Rate=  117"
qos: 0
retain: false
_msgid: "f04518695cf6cfaf"
alarm: 5
```


(b) *Second Alert*

Figure 32. *user 1's Alert*

However, these extremely high values were also recorded when the user was not performing any physical activity, resulting in false alarms since the user's health was not in danger, concluding that this user had a slightly higher than normal heart rate.

Aside from this user, tests were also conducted with another user to provide a method of comparison, because all humans are unique, resulting in somewhat varied biometric data behaviors. The second user, user 2 is 54 years old and has high blood pressure, necessitating medication. When viewing the heart beats in the figure 33 (next page), it was possible to conclude that this user's heart rate behaves similarly to the previous one, with most of his values falling between 84 and 70 BPM. However, it was possible to see that in user 2 compared to user 1,there were many more registers of values between 65 and 50 BPM and less between 90 and 99 BPM, which was quite interesting since the number of registers of the heart rate of the user 1 is significantly higher than in user 2, due to the inability to perform tests with user 2 for a longer period.

As a result, it was possible to conclude that user 1, as previously mentioned, has a little higher heart rate and user 2 has a lower heart rate.

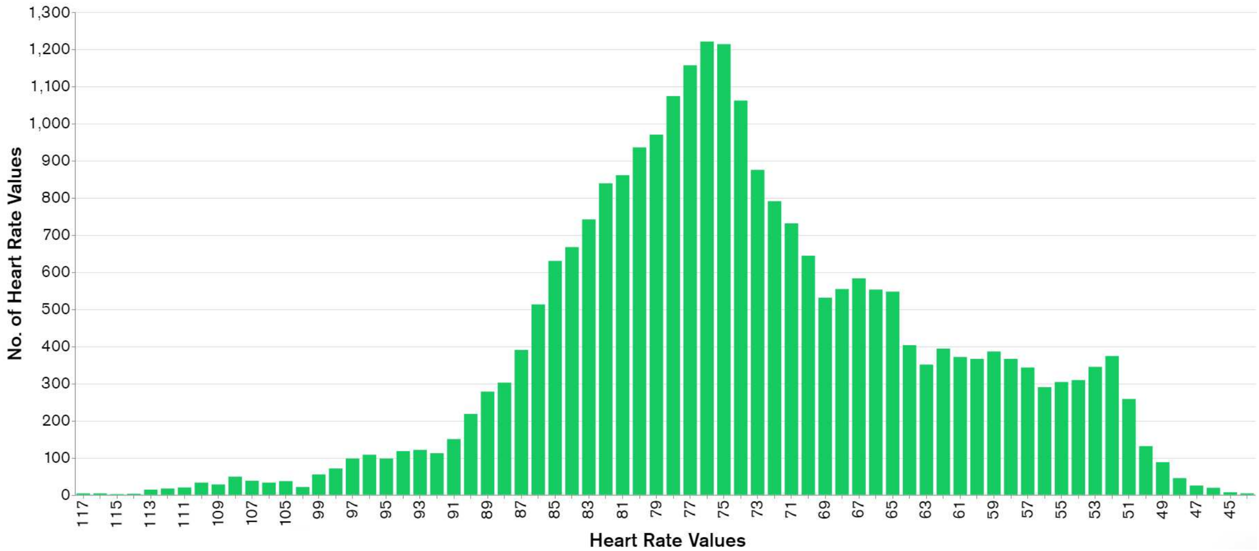


Figure 33. *user 2's heart rate values*

During the monitoring of these users, i.e. application of this health remote monitoring system, the various monitoring methods created were applied generating various alerts that can be seen in Figure 34.

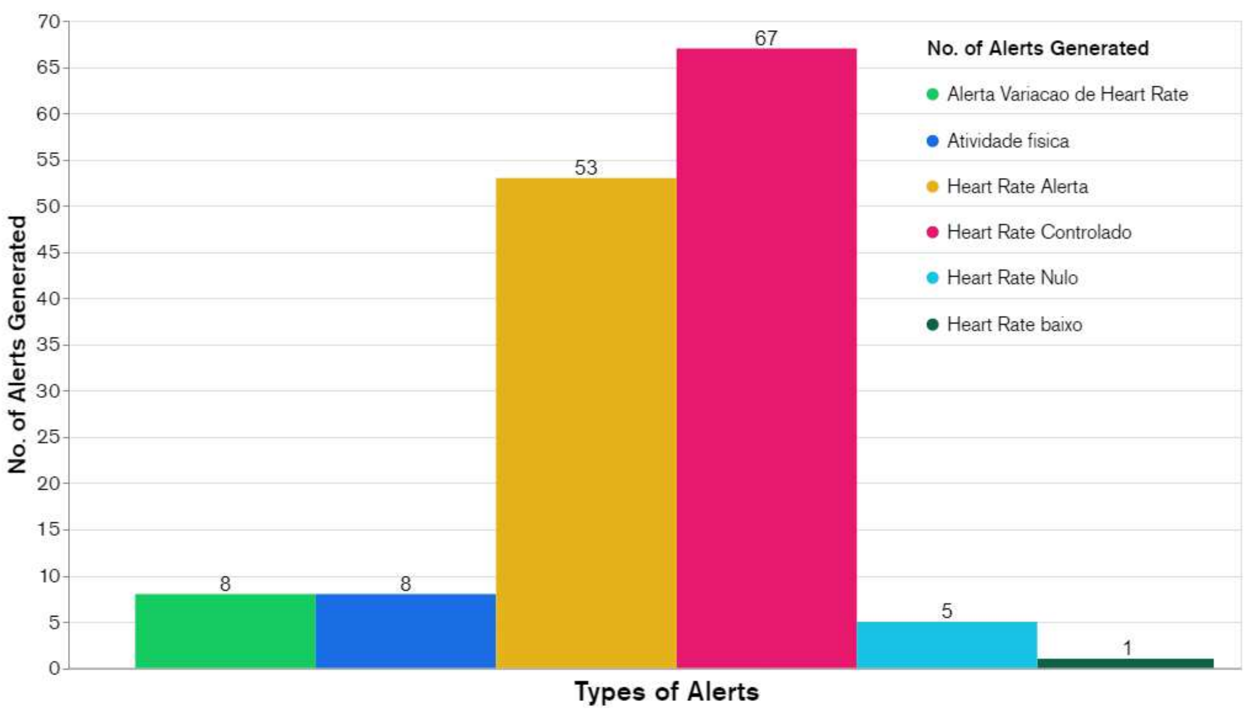


Figure 34. *Some alerts generated by both users*

It was feasible to conclude, with the results that can be found in figures 31, 33 and this alerts figure 34 that both users' monitoring was pretty good, because the most frequently created and registered alert was "Heart Rate Controlado," indicating that the heart rate values were within the limitations established in the monitoring methods.

On the other hand, it was possible to confirm the presence of the "Heart rate Alerta" alert, which indicates that the heart rate measurements were above or below the predefined limits in the monitoring methods. Through this alert, it was also possible to conclude that many times this alert was generated unnecessarily, i.e., these alerts have predefined values, and due to the tests performed on the two users, it was possible to conclude that the maximum and minimum defined values, 95 and 55 BPM respectively, were not the most adequate, despite the fact that these were the default values found in the articles [72] [73].

As previously said, the first individual had a slightly higher than usual heart rate, resulting in such unnecessary alarms because he didn't appear to have any disease, yet, his heart rate behaved in a faster manner, exceeding the maximum limit of 95 BPM. In the case of user 2, his heart rate was slower, with readings lower than the minimum limit of 55 BPM generating also unnecessary alarms. The same holds true for other monitoring methods, for example the "Alerta Variacao de Heart Rate" which requires different values for both users due to their different heart rate behaviors.

As a result, it was possible to conclude that before the limits incorporated into the monitoring methods can be defined, it is first necessary to understand the person's health history, as to the possible existence of diseases and/or taking any kind of medication, to create a more accurate monitoring system without generating so-called "false alarms."

CHAPTER 5

Conclusions and Future Work

The major goal of this dissertation, as stated in the first chapter section 1.4,is to develop an health remote monitoring system with alerts and continuous monitoring that employs wearable devices capable of collecting and transmitting biometric data about human health and allowing them to remain at home, where they are comfortable and safe, and go about their daily lives. First, it was required to grasp which equipment to use and how to connect them. Through the research that led to chapter 2, it was possible to conclude that the use of a wrist-worn wearable device (section 2.2), i.e., a smartwatch, is the most commonly used for health and IoT systems due to characteristics such as ease of use, portability, small size, ability to collect biometric data in real time, and so on, as explained in subsection 3.2.1 of chapter 3.

Once this data-collection equipment was selected, it was required to choose which other equipment to utilize whose job would be to transfer the data collected by the smartwatch to be later monitored. With chapter 2 once more, it was feasible to conclude that the most used equipment were Arduino, raspberry pi, and ESP 32, with the raspberry pi being picked for reasons already mentioned in subsection 3.2.1 and its subsection 3.2.1.2.

A detailed research was also conducted in order to determine the best software to use, which resulted in the following conclusions: regarding the program that allows data transfer, a python-based program was used inside the raspberry pi where the MQTT protocol was used and a connection to the HiveMQ Cloud platform was established, regarding the server used where it is possible to monitor and visualize data and also send alerts, Node-RED server was chosen, and finally regarding the database where all monitored data and generated alerts are stored for further analysis and visualization, MongoDB was used. All these results were reached through multiple comparisons of various types of software and were detailed in further depth in Chapter 3 of this dissertation.

With the hardware and software determined, it is now possible to conclude whether this system can achieve the main goal and answering the research questions provided in section 1.3 of Chapter 1.

The first question is more directly related to the reality of determining whether the use of wearable devices and their ability to track personal health, hypotheses 1 and 2, is a viable method of ensuring a person's safety, and whether it is possible to do so in a timely and efficient manner that improves the target person's quality of life, hypotheses 3,4 and 5. It is possible to say that this system somehow managed to answer this first question, since it was possible to perform good monitoring, as seen in Chapter 4, "Results and Discussion" where it was possible to do and observe a real time tracking of two users in an efficient way, that is, without the need for users to go to a hospital establishment and without the physical intervention of a health professional. However, as has been said, this system can in a way, within its molds, answer this question, i.e., that it was not possible to conclude or guarantee 100% a significant improvement in the lives of users because this system only works at home in medium/short distances making it not possible to verify the normal day-to-day life of a person who, for example, needs to leave home, thereby representing some limitations that will be explained and detailed in the following section.

Regarding the second research question, this system can provide a very favorable result because it is feasible to transmit all acquired data in a very efficient and automatic manner. The way this system was designed and built, that is, the use of a python-based program, the MQTT protocol, and the Node-RED server (programs explained in chapter 3) guarantee the automation of this system and, as a result, the monitoring of the users' health, hypotheses 3 and 4 were performed; the only limitation is related to the loss of connection between the smartwatch and the raspberry pi, whether for uncontrollable reasons, for example a power outage, or for controllable reasons, that is, the distance between these two equipment being quite high, as stated in chapter 4 section 4.1 .

In response to the final research question, this system can reduce the number of alerts issued to health professionals while maintaining the essential patient support, hypotheses 4 and 5. As previously said, this system contains numerous monitoring methods, as described in Chapter 3 subsection 3.3.4, and these alerts are only sent when the monitoring methods are violated. For instance, this system has a monitoring method that includes a maximum and minimum limit, alerts will be generated only if the heart rate value is outside of these limits. This means that whenever the heart rate value is above or below the upper or lower limits, it will be only generated one alert. A second alert will be generated only if the heart rate value ”enters” another monitoring method, section 3.3. Finally, it is possible to conclude that the primary goal has been achieved and all research questions have been answered by performing the aforementioned hypotheses, section 1.4.

5.1. Limitations

As mentioned in the conclusion, some limitations related to the design of this system and its capabilities emerged. The most significant limitations are related to the connection between the two devices (smartwatch and raspberry pi), notably the distance required to maintain a good connection. This became a limitation because, as demonstrated in section 4.1, the distance required to maintain a good connection and allow the user's monitoring to continue was too short, approximately 16 meters. With such a distance, the system can still function properly, but only in specific houses, namely small houses. This limitation is also tied to the system's current and available equipment, which, while relatively good in monetary terms, can have certain limitations when it comes to monitoring a user's health.

Another limitation is that the raspberry pi is not a portable device; it requires an electric current to function, which means that this monitoring cannot be done outside of the home because, as previously stated, if a certain distance is exceeded, the system stops working due to the connection between the smartwatch and the raspberry pi is lost. With these limitations, it was necessary to seek a solution, which was related to the use of a smartphone on which the python-based program was then installed, linking the smartwatch to the smartphone.

This solution appeared to be ideal because everyone nowadays owns a smartphone; unfortunately, the installation of this Python-based program on Android was not permitted due to the required installation of specific dependencies that Android lacks or does not have authorization to install. Finally, another limitation of the smartwatch is that only certain types of biometric data (heart rate, steps, calories, fat burned, distance) can be extracted, biometric data like temperature, fall detection cannot be extracted with this smartwatch.

5.2. Future Work

This section primarily consists of offering future suggestions and innovations for improving this system and making it more effective and efficient for future use. On the one hand, this section is slightly related to section 5.1, since the objectives of the future work consists primarily in addressing and overcoming the limitations of this system.

One of the most critical concerns is the establishment and maintenance of the connection between the two devices, smartwatch and raspberry pi. To do this, the distance between these devices must be increased, allowing for more accurate and effective user monitoring. With this monitoring, it is possible to assess an individual's health more accurately because these individuals can move more freely in their houses and travel greater distances without worry of losing connection, which would terminate the system and thus the monitoring.

Another requirement of future work connected to this limitation consists in making the raspberry pi portable, which is possible by using an Pi Supply, figure 37, that can be found in the appendix C. This pi supply can be connected to the raspberry pi , and by having a battery, power can be provided. If this is not possible, utilize a portable and easy-to-move device instead. With this change, better monitoring would be possible because this could be done not only at home, but also outside, without having to worry about exceeding the maximum distance between the two devices. This monitoring would allow a better and more precise analysis of the user's health, since it could be done during the user's normal daily life.

Finally, as a future work, implement this system in a larger number of houses to monitor more individuals than just two, to understand the efficiency and accuracy of this system.

5.3. Final Words

To conclude, this research was conducted during the period between September 2021 and October 2022 at ISCTE-IUL. Despite the various ups and downs that occurred during this research, I thoroughly enjoyed it and felt very accomplished, since it contributes to overcoming and solving some healthcare challenges through the development of an health remote monitoring system, where its users can have access to monitoring and medical support without having to travel from hospital to hospital, allowing them to remain in the comfort and safety of their homes and proceed to their daily lives. I learned a lot, not only in the health field, where I learned about the various biometric data types and how they behave in normal and stressful situations, but also about the use and operation of various technologies, such as sensors and microcontrollers, servers, protocols, programming languages, and databases, which enabled the creation of this system. To complete this thesis, a scientific paper was written for the ISSI2022 conference ”International Symposium on Sensing and Instrumentation in the 5G and IoT Era”, which will take place in Shanghai, China on November 17 and 18, 2022.

References

[1] A. L. Fitzpatrick, N. R. Powe, L. S. Cooper, D. G. Ives, and J. A. Robbins, "Barriers to health care access among the elderly and who perceives them," *American journal of public health*, vol. 94, no. 10, pp. 1788–1794, 2004.

[2] D. B. Mesko, "10 Ways technology is changing healthcare," *The Medical Future*, 2020. [Online]. Available: https://medicalfuturist.com/ten-ways-technology-changing-healthcare/.

[3] A. Ometov, V. Shubina, L. Klus, *et al.*, "A survey on wearable technology: History, state-of-the-art and current challenges," *Computer Networks*, vol. 193, Jul. 2021, ISSN: 13891286. DOI: 10.1016/J.COMNET.2021.108074. [Online]. Available: http://creativecommons.org/licenses/by/4.0/.

[4] M. Wu and J. Luo, "Wearable technology applications in healthcare: A literature review," *Online J. Nurs. Inform*, vol. 23, no. 3, 2019.

[5] *Wearable devices for healthcare monitoring practice*, Nov. 2021. [Online]. Available: https://digitalhealth.folio3.com/blog/wearable-device-for-health-monitoring/.

[6] *Iot healthcare wearables*, Feb. 2021. [Online]. Available: https://www.telit.com/industries-solutions/healthcare/wearables/.

[7] G. V. Angelov, D. P. Nikolakov, I. N. Ruskova, E. E. Gieva, and M. L. Spasova, "Healthcare sensing and monitoring," *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, vol. 11369 LNCS, pp. 226–262, 2019. DOI: 10.1007/978-3-030-10752-9_10.

[8] R. Tong, *Wearable technology in medicine and health care*. Academic Press, 2018.

[9] M. Vahabi, H. Fotouhi, M. Björkman, and M. Lindén, "Evaluating a remote health monitoring application powered by bluetooth," *Multi Conference on Computer Science and Information*

Systems, MCCSIS 2019 - Proceedings of the International Conference on e-Health 2019, pp. 67–74, 2019. DOI: 10.33965/EH2019_201910L009.

[10] G. Eysenbach, "What is e-health?" *Res*, vol. 3, p. 20, 2 2001. DOI: 10.2196/jmir.3.2.e20. [Online]. Available: https://www.jmir.org/2001/2/e20/.

[11] R. Miramontes, R. Aquino, A. Flores, *et al.*, "Plaimos: A remote mobile healthcare platform to monitor cardiovascular and respiratory variables," *Sensors (Switzerland)*, vol. 17, 1 Jan. 2017. DOI: 10.3390/S17010176.

[12] A. Yunusova, J. Lai, A. P. Rivera, *et al.*, "Assessing the mental health of emerging adults through a mental health app: Protocol for a prospective pilot study," *JMIR Research Protocols*, vol. 10, 3 Mar. 2021. DOI: 10.2196/25775.

[13] S. Sakphrom, T. Limpiti, K. Funsian, *et al.*, "micromachines Intelligent Medical System with Low-Cost Wearable Monitoring Devices to Measure Basic Vital Signals of Admitted Patients," 2021. DOI: 10.3390/mi12080918. [Online]. Available: https://doi.org/10.3390/mi12080918.

[14] M. C. Rushambwa, M. Gezimati, and J. B. Jeeva, "Development of a wearable wireless body area network for health monitoring of the elderly and disabled," in *IOP Conference Series: Materials Science and Engineering*, vol. 263, Institute of Physics Publishing, Dec. 2017. DOI: 10.1088/1757-899X/263/5/052052.

[15] F. Ullah, A. Iqbal, S. Iqbal, *et al.*, "A framework for maternal physical activities and health monitoring using wearable sensors," *Sensors*, vol. 21, no. 15, 2021, ISSN: 14248220. DOI: 10.3390/s21154949.

[16] G. J. Lakshmi, M. Ghonge, and A. J. Obaid, "Cloud based IoT Smart Healthcare System for Remote Patient Monitoring EAI Endorsed Transactions," vol. 06, pp. 2021–2031, 2021. DOI: 10.4108/eai.15-7-2021.170296.

[17] W.-Y. Chung, Y.-D. Lee, and S.-J. Jung, *A Wireless Sensor Network Compatible Wearable U-Healthcare Monitoring System Using Integrated ECG, Accelerometer and SpO2*. 2008, ISBN: 9781424418152.

[18] Z. Jin, J. Oresko, S. Huang, and A. C. Cheng, "Hearttogo: A personalized medicine technology for cardiovascular disease prevention and detection," in *2009 IEEE/NIH Life Science Systems and Applications Workshop*, IEEE, 2009, pp. 80–83.

[19] D. De, P. Bharti, S. K. Das, and S. Chellappan, "Multimodal Wearable Sensing for Fine-Grained Activity Recognition in Healthcare; Multimodal Wearable Sensing for Fine-Grained Activity Recognition in Healthcare," Tech. Rep., 2015. DOI: 10.1109/MIC.2015.72. [Online]. Available: www.computer.org/internet/.

[20] V. Vaishnavi and B. Kuechler, "Design science research in information systems,"

[21] K. Pfeffers, T. Tuunanen, C. E. Gengler, *et al.*, "The design science research process: A model for producing and presenting information systems research," in *Proceedings of the First International Conference on Design Science Research in Information Systems and Technology (DESRIST 2006), Claremont, CA, USA*, 2006, pp. 83–106.

[22] Wikipédia, *Estado da arte — wikipédia, a enciclopédia livre*, [Online; accessed 4-jan-2022], 2020. [Online]. Available: %5Curl%7Bhttps://pt.wikipedia.org/w/index.php?title=Estado_da_arte&oldid=59953291%7D.

[23] D. Moher, A. Liberati, J. Tetzlaff, D. G. Altman, and P. Group, "Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement," [Online]. Available: www.annals.org.

[24] *Wearable technology takes advantage of low power conversion in health and wellbeing - weartech design*. [Online]. Available: https://weartechdesign.com/wearable-technology-takes-advantage-of-low-power-conversion-in-health-and-wellbeing/.

[25] J. Dieffenderfer, H. Goodell, S. Mills, *et al.*, "Low-power wearable systems for continuous monitoring of environment and health for chronic respiratory disease," *IEEE journal of biomedical and health informatics*, vol. 20, no. 5, pp. 1251–1264, 2016.

[26] S. Mahmud and H. Wang, "An integrated wearable sensor for unobtrusive, continuous measurement of autonomic nervous system," DOI: 10.1109/JIOT.2019.2868235. [Online]. Available: http://www.ieee.org/publications.

[27] M. Xu, F. Qian, M. Zhu, F. Huang, S. Pushp, and X. Liu, "Ieee transactions on mobile computing, vol. xx, no. xx, xxxx 201x 1 deepwear: Adaptive local offloading for on-wearable deep learning,"

[28] S. J. D. Prince, S.-W. Ohl, M. Billinghurst, *et al.*, "Interactive theatre experience in embodied + wearable mixed reality space mixed presence mixed reality system view project using augmented reality for forklift operation view project interactive theatre experience in embodied

+ wearable mixed reality space," 2002. DOI: 10.1109/ISMAR.2002.1115073. [Online]. Available: http://mixedreality.nus.edu.sg.

[29] M. Golkarifard, J. Yang, Z. Huang, A. Movaghar, S. Member, and P. Hui, "Dandelion: A unified code offloading system for wearable computing; dandelion: A unified code offloading system for wearable computing," 2019. DOI: 10.1109/TMC.2018.2841836. [Online]. Available: www.ieee.org/publications_standards/publications/rights/index.html.

[30] F. D. Arriba-Pérez, M. Caeiro-Rodríguez, J. M. Santos-Gago, and L. M. Reindl, "Collection and processing of data from wrist wearable devices in heterogeneous and multiple-user scenarios," DOI: 10.3390/s16091538. [Online]. Available: www.mdpi.com/journal/sensors.

[31] User, "Shimmer user manual revision 3p," 2017.

[32] *What is thingsboard?* [Online]. Available: https://thingsboard.io/docs/getting-started-guides/what-is-thingsboard/.

[33] G. M. Bertolotti, A. M. Cristiani, P. Colagiorgio, *et al.*, "A wearable and modular inertial unit for measuring limb movements and balance control abilities," *IEEE Sensors Journal*, vol. 16, no. 3, pp. 790–797, 2015.

[34] N. Alshurafa, W. Xu, J. J. Liu, M.-C. Huang, C. K. Roberts, and M. Sarrafzadeh, "Designing a Robust Activity Recognition Framework for Health and Exergaming Using Wearable Sensors," *IEEE Journal of Biomedical and Health Informatics*, vol. 18, no. 5, 2014. DOI: 10.1109/JBHI.2013.2287504. [Online]. Available: http://ieeexplore.ieee.org..

[35] A. M. Cristiani, G. M. Bertolotti, E. Marenzi, and S. Ramat, "An instrumented insole for long term monitoring movement, comfort, and ergonomics," *IEEE Sensors Journal*, vol. 14, no. 5, pp. 1564–1572, 2014.

[36] H. Mansor, M. H. A. Shukor, S. S. Meskam, N. Q. A. M. Rusli, and N. S. Zamery, "Body temperature measurement for remote health monitoring system," in *2013 IEEE international conference on smart instrumentation, measurement and applications (ICSIMA)*, IEEE, 2013, pp. 1–5.

[37] P. Oğuz and G. Ertaş, "Wireless dual channel human body temperature measurement device," in *2013 International Conference on Electronics, Computer and Computation (ICECCO)*, IEEE, 2013, pp. 52–55.

[38] S. Y. Sim, W. K. Lee, H. J. Baek, and K. S. Park, "A nonintrusive temperature measuring system for estimating deep body temperature in bed," in *2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, IEEE, 2012, pp. 3460–3463.

[39] J. Kim, S. Kwon, S. Seo, and K. Park, "Highly wearable galvanic skin response sensor using flexible and conductive polymer foam," in *2014 36th annual international conference of the IEEE engineering in medicine and biology society*, IEEE, 2014, pp. 6631–6634.

[40] R. Guo, S. Li, L. He, W. Gao, H. Qi, and G. Owens, "Pervasive and unobtrusive emotion sensing for human mental health," in *2013 7th International Conference on Pervasive Computing Technologies for Healthcare and Workshops*, IEEE, 2013, pp. 436–439.

[41] G. Crifaci, L. Billeci, G. Tartarisco, *et al.*, "Ecg and gsr measure and analysis using wearable systems: Application in anorexia nervosa adolescents," in *2013 8th International Symposium on Image and Signal Processing and Analysis (ISPA)*, IEEE, 2013, pp. 499–504.

[42] W. Chen, I. Ayoola, S. B. Oetomo, and L. Feijs, "Non-invasive blood oxygen saturation monitoring for neonates using reflectance pulse oximeter," in *2010 Design, Automation & Test in Europe Conference & Exhibition (DATE 2010)*, IEEE, 2010, pp. 1530–1535.

[43] C.-Y. Huang, M.-C. Chan, C.-Y. Chen, and B.-S. Lin, "Novel wearable and wireless ring-type pulse oximeter with multi-detectors," *Sensors*, vol. 14, no. 9, pp. 17 586–17 599, 2014.

[44] Y. Mendelson, R. J. Duckworth, and G. Comtois, "A wearable reflectance pulse oximeter for remote physiological monitoring," in *2006 International Conference of the IEEE Engineering in Medicine and Biology Society*, IEEE, 2006, pp. 912–915.

[45] A. Singhal and M. R. Cowie, "The Role of Wearables in Heart Failure," DOI: `10.1007/s11897-020-00467-x`. [Online]. Available: `https://doi.org/10.1007/s11897-020-00467-x`.

[46] S. D. Din, A. Godfrey, C. Mazz, S. Lord, and L. Rochester, "Free-Living Monitoring of Parkinson's Disease: Lessons From the Field," DOI: `10.1002/mds.26718`.

[47] [Online]. Available: `https://www.nhs.uk/conditions/cardiovascular-disease/`.

[48] *Cardiovascular diseases (cvds)*. [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/cardiovascular-diseases-(cvds).

[49] *Heart failure*. [Online]. Available: https://www.nhlbi.nih.gov/health-topics/heart-failure.

[50] K. M. Ko and S. G. Kim, "Analysis technique of a wearable IoT health information on the MAPHIS," *International Journal of Engineering and Technology(UAE)*, vol. 7, no. 2, pp. 224–227, 2018. DOI: 10.14419/IJET.V7I2.33.13891.

[51] *Parkinson's disease*. [Online]. Available: https://www.nia.nih.gov/health/parkinsons-disease.

[52] H. Nero, M. Benka Wallén, E. Franzén, D. Conradsson, A. Ståhle, and M. Hagströmer, "Objectively Assessed Physical Activity and its Association with Balance, Physical Function and Dyskinesia in Parkinson's Disease," *Journal of Parkinson's Disease*, vol. 6, pp. 833–840, 2016. DOI: 10.3233/JPD-160826.

[53] J. Sringean, P. Taechalertpaisarn, C. Thanawattano, and R. Bhidayasiri, "How well do Parkinson's disease patients turn in bed? Quantitative analysis of nocturnal hypokinesia using multisite wearable inertial sensors," *Parkinsonism and Related Disorders*, vol. 23, pp. 10–16, 2016. DOI: 10.1016/j.parkreldis.2015.11.003. [Online]. Available: http://dx.doi.org/10.1016/j.parkreldis.2015.11.003.

[54] A. Weiss, T. Herman, N. Giladi, and J. M. Hausdorff, "New evidence for gait abnormalities among Parkinson's disease patients who suffer from freezing of gait: insights using a body-fixed sensor worn for 3 days," DOI: 10.1007/s00702-014-1279-y.

[55] *What is alzheimer's disease?* [Online]. Available: https://www.nia.nih.gov/health/what-alzheimers-disease.

[56] *Bulimia nervosa*, May 2018. [Online]. Available: https://www.mayoclinic.org/diseases-conditions/bulimia/symptoms-causes/syc-20353615.

[57] *Anorexia nervosa*, Feb. 2018. [Online]. Available: https://www.mayoclinic.org/diseases-conditions/anorexia-nervosa/symptoms-causes/syc-20353591.

[58] "Micro interactions and multi dimensional graphical user interfaces in the design of wrist worn wearables," *Proceedings of the Human Factors and Ergonomics Society*, vol. 2015-January, pp. 1712–1716, 2015, ISSN: 10711813. DOI: 10.1177/1541931215591370.

[59] D. Castaneda, A. Esparza, M. Ghamari, C. Soltanpur, and H. Nazeran, "A review on wearable photoplethysmography sensors and their potential future applications in health care," *International journal of biosensors & bioelectronics*, vol. 4, no. 4, p. 195, 2018.

[60] *What is a raspberry pi?* Aug. 2015. [Online]. Available: https://www.raspberrypi.org/help/what-%5C%20is-a-raspberry-pi/.

[61] N. Naik, *Choice of Effective Messaging Protocols for IoT Systems: MQTT, CoAP, AMQP and HTTP*, ISBN: 9781538634035.

[62] D. Dinculeană and X. Cheng, "Vulnerabilities and Limitations of MQTT Protocol Used between IoT Devices," 2019. DOI: 10.3390/app9050848. [Online]. Available: www.mdpi.com/journal/applsci.

[63] M. B. Yassein, M. Q. Shatnawi, S. Aljwarneh, and R. Al-Hatmi, "Internet of things: Survey and open issues of mqtt protocol," in *2017 international conference on engineering & MIS (ICEMIS)*, Ieee, 2017, pp. 1–6.

[64] M. Serozhenko, *Mqtt vs. http: Which one is the best for iot?* Mar. 2017. [Online]. Available: https://medium.com/mqtt-buddy/mqtt-vs-http-which-one-is-the-best-for-iot-c868169b3105.

[65] T. H. Team. [Online]. Available: https://www.hivemq.com/blog/mqtt-essentials-part-4-mqtt-publish-subscribe-unsubscribe/.

[66] *Hivemq cloud*. [Online]. Available: https://www.hivemq.com/docs/hivemq-cloud/introduction.html.

[67] ——, *Comparison of mqtt support by iot cloud platforms*, May 2020. [Online]. Available: https://www.hivemq.com/blog/hivemq-cloud-vs-aws-iot/.

[68] *Hivemq clusters*. [Online]. Available: https://www.hivemq.com/docs/hivemq/4.8/user-guide/cluster.html.

[69] M. Lekić and G. Gardašević, "Iot sensor integration to node-red platform," in *2018 17th International Symposium Infoteh-Jahorina (Infoteh)*, IEEE, 2018, pp. 1–5.

[70] A. Boicea, F. Radulescu, and L. I. Agapin, "Mongodb vs oracle – database comparison," 2012. DOI: 10.1109/EIDWT.2012.32.

[71] *GitHub - satcar77/miband4: Access Xiaomi MiBand 4 from Linux using Bluetooth LE*. [Online]. Available: https://github.com/satcar77/miband4 (visited on 07/01/2022).

[72] M. MacGill, "What should my heart beat be?" *Medical News Today*, pp. 1–12, 2017. [Online]. Available: medicalnewstoday.com/articles/235710.php.

[73] M. Seviiri, B. M. Lynch, A. M. Hodge, *et al.*, "Resting heart rate, temporal changes in resting heart rate, and overall and cause-specific mortality," *Heart*, vol. 104, no. 13, pp. 1076–1085, 2018, ISSN: 1468201X. DOI: 10.1136/heartjnl-2017-312251.

[74] L. L. Long and M. Srinivasan, "Walking, running, and resting under time, distance, and average speed constraints: Optimality of walk-run-rest mixtures," *Journal of the Royal Society Interface*, vol. 10, no. 81, 2013, ISSN: 17425662. DOI: 10.1098/rsif.2012.0980. [Online]. Available: http://dx.doi.org/10.1098/rsif.2012.0980http://dx.doi.org/10.1098/rsif.2012.0980orviahttp://rsif.royalsocietypublishing.org..

[75] CDC, "Target Heart Rate and Estimated Maximum Heart Rate | Physical Activity | CDC," pp. 22–23, 2021. [Online]. Available: http://www.cdc.gov/physicalactivity/basics/measuring/heartrate.htm.

[76] *The developer data platform*. [Online]. Available: https://www.mongodb.com/.

[77] *Using ble devices with a raspberry pi*. [Online]. Available: https://www.argenox.com/library/bluetooth-low-energy/using-raspberry-pi-ble/.

[78] E. Nilsson, T. Lindman, A. Fröberg, and E. Berglund, "Implementation and Evaluation of Bluetooth Low Energy as a communication technology for wireless sensor networks," [Online]. Available: https://www.bluetooth.org/DocMan/handlers/DownloadDo.

APPENDIX A

Node-RED programmable flow

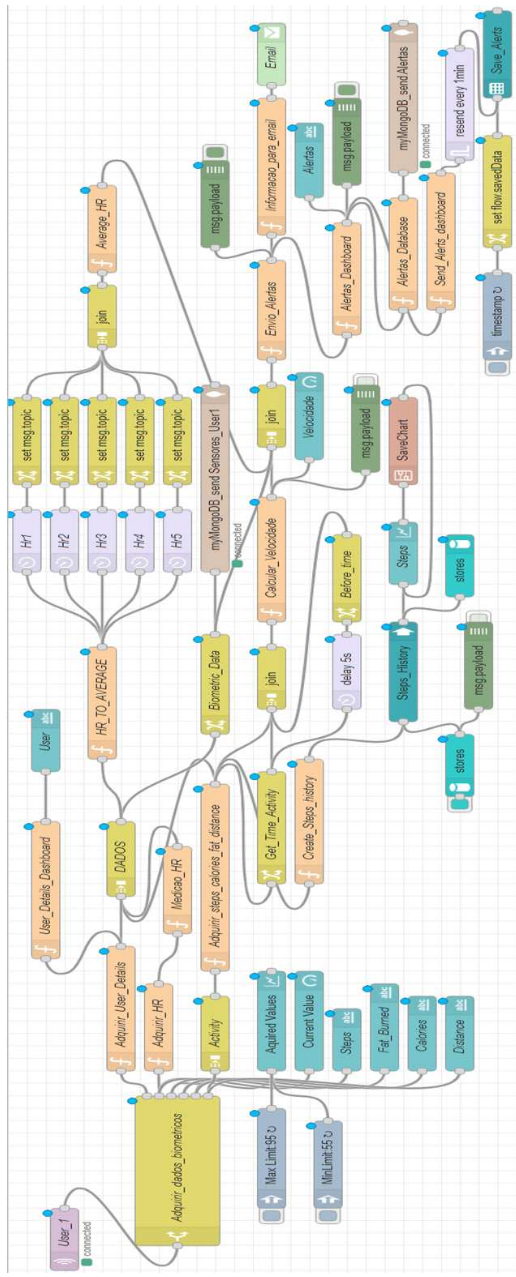


Figure 35. *Node-red programmable flow for the realization of this project*

APPENDIX B

Example code to establish connection with the MQTT platform

```
import time
import paho.mqtt.client as paho
from paho import mqtt

# setting callbacks for different events to see if it works, print the message etc.
def on_connect(client, userdata, flags, rc, properties=None):
    print("CONNACK received with code %s." % rc)

# with this callback you can see if your publish was successful
def on_publish(client, userdata, mid, properties=None):
    print("mid: " + str(mid))

# print which topic was subscribed to
def on_subscribe(client, userdata, mid, granted_qos, properties=None):
    print("Subscribed: " + str(mid) + " " + str(granted_qos))

# print message, useful for checking if it was successful
def on_message(client, userdata, msg):
    print(msg.topic + " " + str(msg.qos) + " " + str(msg.payload))

# using MQTT version 5 here, for 3.1.1: MQTTv311, 3.1: MQTTv31
# userdata is user defined data of any type, updated by user_data_set()
# client_id is the given name of the client
client = paho.Client(client_id="", userdata=None, protocol=paho.MQTTv5)
client.on_connect = on_connect

# enable TLS for secure connection
client.tls_set(tls_version=mqtt.client.ssl.PROTOCOL_TLS)
# set username and password
client.username_pw_set("tiagocaixeiro", "YOUR_PASSWORD")
# connect to HiveMQ Cloud on port 8883 (default for MQTT)
client.connect("0568b8867dd7492986fd891e32d423d1.s1.eu.hivemq.cloud", 8883)

# setting callbacks, use separate functions like above for better visibility
client.on_subscribe = on_subscribe
client.on_message = on_message
client.on_publish = on_publish
```

Figure 36. *Example code to establish connection with the MQTT platform*

APPENDIX C

Pi Supply capable to turn raspberry pi into a portable device

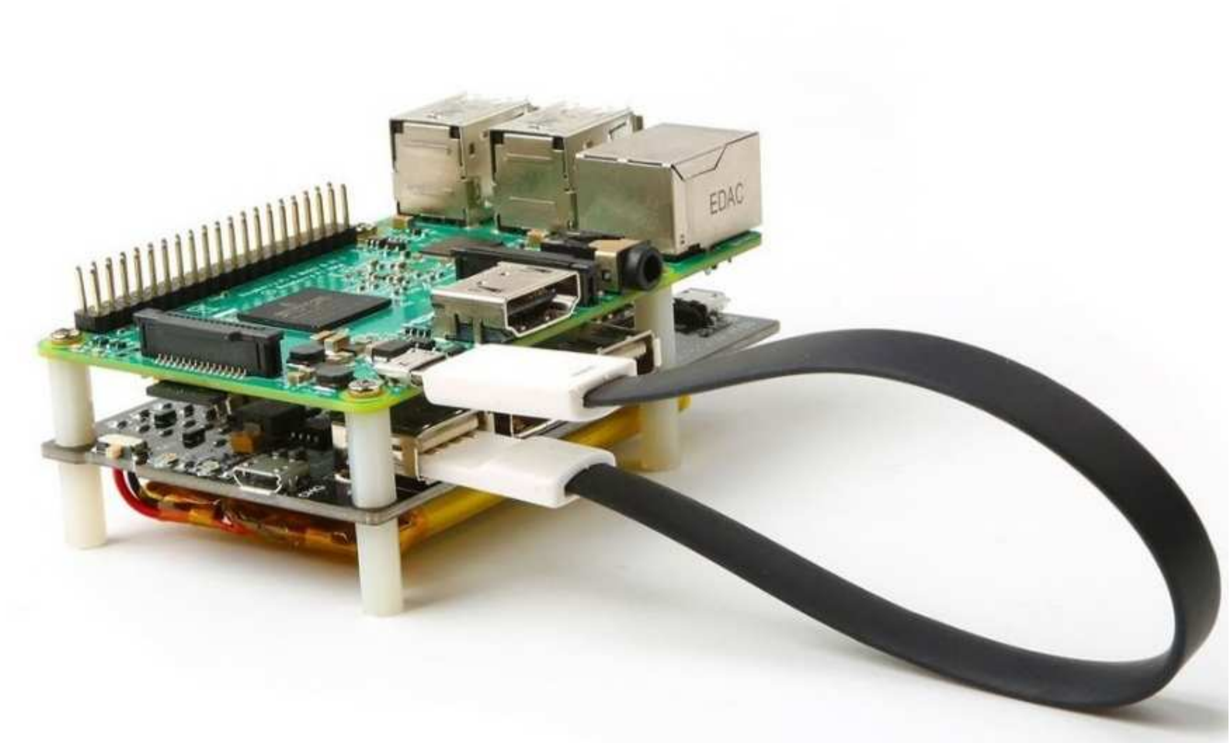


Figure 37. *Pi Supply capable to turn raspberry pi into a portable device*