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Smart System and Mobile Interface for Healthcare: Stress and Diabetes

Gonçalo Tomé Ribeiro

Master Degree in Telecommunications and Computer Engineering

Supervisor:
PhD Octavian Adrian Postolache, Associate Professor with Habilitation,
ISCTE-IUL

Co-Supervisor:
PhD Pedro Manuel Brito da Silva Girão, Full Professor,
Instituto Superior Técnico (IST)

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TECNOLOGIAS
E ARQUITETURA

Department of Information Science and Technology

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I dedicate this work to my mother, who although she is no longer with us, I know she would be very proud of her son's achievement. I also dedicate this work to my father, who, although he has lost his pillar in this life, played the role of father and mother at the same time, supporting his son unconditionally, making him the person he is today.

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Resumo

Nesta tese, foi concebido e implementado um sistema com capacidades de medição multicanal, associado à monitorização dos níveis de stress, através de um algoritmo proposto que correlaciona a frequência cardíaca, a frequência respiratória, e a resposta galvânica da pele. Foram realizados testes experimentais de validação, bem como experiências com pacientes que sofrem da diabetes. Para tal, foram realizadas medições não só de parâmetros relacionados com o stress, mas também de parâmetros como os níveis de glicose no sangue e os níveis de pressão arterial, procurando extrair correlações entre o stress e o estado da diabetes. Para além disso, a temperatura corporal foi outro parâmetro adquirido, com o objetivo de avaliar a sua importância e relação ao stress e à diabetes. O sistema multicanal proposto apresenta também tecnologia RFID para fins de autenticação, bem como acesso Wi-Fi para ligação à Internet e armazenamento dos dados adquiridos numa base de dados estruturada para o efeito, viabilizando assim o acesso remoto. Para permitir a avaliação dos níveis de stress e do progresso da diabetes, foi também desenvolvida uma aplicação móvel que permite também a visualização dos dados analisados.

Palavras-chave: *Sensores Inteligentes, Stress, Diabetes, Frequência Respiratória, Resposta Galvânica da Pele, Frequência Cardíaca, Monitorização da Glucose no Sangue, Pressão Arterial, Temperatura Corporal, Sistemas Embebidos, Aplicação Móvel.*

Abstract

In this thesis, a system with multi-channel measurement capabilities was designed and implemented, associated with the monitoring of stress levels, through a proposed algorithm that correlates heart rate, respiratory rate, and galvanic skin response. Experimental validation tests were carried out, as well as experiments with patients suffering from diabetes. To this end, measurements were made not only of stress-related parameters, but also of parameters such as blood glucose levels and blood pressure levels, seeking to extract correlations between stress and diabetes status. In addition, body temperature was another parameter acquired, in order to assess its importance and relation to stress and diabetes. The proposed multichannel system also features RFID technology for authentication purposes, as well as Wi-Fi access for internet connection and storage of the acquired data in a database structured for that purpose, thus enabling remote access. To allow the assessment of stress levels and diabetes progress, a mobile application was also developed, which also allows the visualisation of the analysed data.

Keywords: *Smart Sensors, Stress, Diabetes, Respiratory Rate, Galvanic Skin Response, Heart Rate, Blood Glucose Monitoring, Blood Pressure, Body Temperature, Embedded Systems, Mobile Application.*

Content

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List of Acronyms

AI	Artificial Intelligence
BPM	Beats Per Minute
BPM’	Breaths Per Minute
BMI	Body Mass Index
CDC	Centers for Diseases Control and Prevention
ECG	Electrocardiography
EDA	Electrodermal Activity
EEG	Electroencephalography
EMG	Electromyography
EMI	Electromagnetic Interference
GPS	Global Positioning System
GSR	Galvanic Skin Response
HRV	Heart Rate Variability
I2C	Inter Integrated Circuit
IoT	Internet of Things
LED	Light Emitting Diode
LFS	Labour Force Survey
Li-Fi	Light Fidelity
ML	Machine Learning
mHealth	Mobile Health
mg/dL	Milligrams Per Decilitre
MISO	Master In Slave Out
mmHg	Millimetres of Mercury
MOSI	Master Out Slave In
NFC	Near Field Communication
PPG	Photoplethysmography
PSS	Perceived Stress Scale
RFID	Radio Frequency Identification
RTC	Real Time Clock
SPI	Serial Peripheral Interface

SpO2	Peripheral Oxygen Saturation
SQL	Structured Query Language
VLC	Visible Light Communication
Wi-Fi	Wireless Fidelity
WSN	Wireless Sensor Network

CHAPTER 1

Introduction

In this first chapter, some fundamental topics will be presented, not only to understand the challenges inherent to smart systems and mobile interfaces in the healthcare context, but also to define future goals and solutions for existing problems.

In order to present the concepts in a structured way, promoting a better understanding of them, the **Introduction** was organised as follows: Motivation and Background, Research Questions, Objectives, Research Method, and brief explanation of the Thesis Structure.

1.1. Motivation and Background

Health is one of the most important areas of society, and the lack of investment ends up affecting not only the population in general, but also the very development of a country, affecting the most diverse sectors. Most healthcare is provided in person, requiring patients to travel to hospitals or clinics, which in many cases can cause some inconvenience. Moreover, the long waiting lines in public hospitals are a serious problem, forcing people to go to private clinics, but their high cost is also limiting.

To try to mitigate the aforementioned problems, the Internet of Things (IoT) is gaining more and more momentum, presenting a great potential to evolve or replace the methods used in conventional medicine for a new tele-medicine. In addition, the constant development of more efficient and smaller processors has strongly contributed to the migration of computing platforms to smartphones and tablets, providing excellent opportunities to explore healthcare areas making use of smart systems and mobile interfaces.

Smart systems and mobile interfaces can provide to patients high level of support, not only by performing prevention/monitoring of chronic diseases such as diabetes, cancer, cardiovascular diseases, respiratory diseases, among others, but also by improving communication with professionals for a high quality of healthcare services for a lower costs [1,2].

Smart systems applied to healthcare mainly are using sensors to acquire physiological and biological parameters in order to improve the efficiency of healthcare management [2]. The health status monitoring produce huge amount of data that means a new problem, characterized by the following questions: which of these data should be stored, how it can be stored, and where it should be stored.

The storage of large amounts of data, is usually accomplished by sending them, through wireless communications, to remote structures, such as databases and/or cloud computing platforms, with considerable capacity, not only in terms of memory, but also in terms of the diversity of tools for processing the data, preferably with minimal latency [3].

Regarding storage structures, any type of database can be chosen, however, developers must consider the purpose of their work, and in the case of healthcare, an important aspect, in addition to those mentioned above, is the speed and complexity of access, both for reading and writing the data. In this aspect, cloud computing has some advantages over traditional databases [1], however, there are currently several databases that combine cloud computing features, and these are the most advantageous for healthcare related work.

As mentioned before, an intelligent system can greatly benefit patient support, however, its strength is the monitoring and processing of the most diverse parameters, not the good interaction with users and mobility. It is true that the introduction of databases and cloud computing increases the capacity of these systems and ends up giving them a mobile character in data access, but the system itself always lacks a more user-oriented interface, as is the case of mobile interfaces and websites. Note that if one of the essential points is mobility, the use of websites ends up being redundant, and as such priority should be given to the use of mobile applications.

As for the mobile application market, it is becoming increasingly competitive, and in the context of health, this is no different. However, although there are many healthcare apps, when you want to find one that not only provides a good user experience, but also adds value and quality to the user's life, that number decreases dramatically. As such, it is important to create reliable applications that, based on medical concepts, offer certified and reliable functionalities to users.

Regarding the monitoring of chronic diseases by smart systems, different diseases require the monitoring of different parameters, and as such, it is not possible to have a single system for this purpose. However, there are common parameters in the evaluation of these diseases, such as heart rate, or even stress.

Stress is directly associated with daily experiences or situations, and negatively affects the management of chronic diseases, such as cardiovascular diseases, respiratory diseases, diabetes, among others. In this way, stress monitoring should be part of the patients' daily routine, being easily included in the period dedicated to medication, or in the case of diabetics, during the period for measuring blood glucose levels [4,5].

There are several methods proposed to estimate stress levels, such as facial expression recognition, multi-sensor systems with the option of applying fuzzy logic or more complex approaches such as classifiers based on Machine Learning (ML) algorithms, and last but not least, the use of Electrocardiography (ECG) [6-8]. However, some of these methods can be impractical to use, especially when patients want simpler, smaller systems capable of providing mobility.

When the work presented in this thesis was conceived, it was clear that the timeframe of the thesis would not allow to work on multiple chronic diseases. Thus, the current work focusses in only one research direction expressed by Diabetes as one of chronic disease that affect more than 9% from Portuguese population. This choice was not taken lightly, and the lack of healthcare for this chronic disease was considered, as was the potential to develop something that could add value to people's lives, especially when the global Covid-19 epidemic hit, and basically all diabetes medical appointments were suspended, leaving these patients without follow-up.

The number of people affected by diabetes has been increasing significantly in recent years [9], either due to poor eating habits or even due to highly stressful daily routines. As such, it is a disease that requires the patient to take more care of their health, seeking to change some eating habits and lifestyles, and it is very important to understand how food, physical activity, stress, and blood sugar levels interact with each other.

Managing diabetes is not a simple task, and as such, the use of a mobile application can help a lot to simplify this complex task, helping for instance through advice regarding diets, physical exercise, as well as providing complementary information about the disease itself [10], or even correlating stress situations with the increase or decrease of blood glucose levels. In addition, the possibility of constant monitoring and sharing data with healthcare professionals in real time, allows them to better manage the treatment of the disease.

1.2. Research Questions

In order to establish a state-of-the-art, where it is extremely important to conduct research in the literature and also experience the operation of existing products on the market, it is essential to organise the stages of this study, and in this way, the "Research Questions" are quite useful, because it is through them that the student can focus on the most appropriate contents within such a vast area. As such, the research questions established are presented below:

- How can smart systems contribute to healthcare?
- What kind of structure underpins a smart system?
- What is the best method of communication if data is to be stored remotely? How can data be stored in this way?

- Is the Cloud an added value? Can it replace or complement conventional database structures?
- What mechanisms should be implemented to promote user interest in smart healthcare systems? Are mobile interfaces beneficial in this aspect?
- How can mobile interfaces add value to a smart system? And what software can be used to implement them?
- What sensors or other types of devices can be used to monitor a person's health parameters? And how can they provide better user experience and advice?
- How does stress contribute negatively to healthcare? Are chronic diseases affected by stress, and if so, how does stress influence them?
- What is the best method and what physiological parameters can be used to monitor stress levels?
- It is known that there is a relation between stress and diabetes, but how exactly are these two related?
- How is diabetes monitoring carried out? Apart from blood glucose levels, what physiological parameters can be used to manage diabetes?
- In the current situation with the global Covid-19 epidemic, monitoring body temperature has become even more important, but does it also have any connection with stress and/or diabetes?

1.3. Objectives

The theme of the work carried out in this master's thesis focuses on the study of innovative mobile interfaces for healthcare and well-being, however, it was decided to follow a line more focused on healthcare, in particular, exploring the relation between stress and diabetes.

The first objective of this work is to develop a smart system to estimate and monitor the stress levels of an individual. The first layer of this smart system will be composed by an embedded system, which will allow the acquisition of physiological parameters by wearable sensors. These parameters must be pre-processed and sent to a database appropriate to the objectives of this work. This database must be structured in such a way as to allow access not only by the embedded system, but also by a future mobile application, capable of correlating the acquired physiological parameters, with the aim of estimating and classifying stress levels, among other relevant functionalities.

The second goal of this work is to develop a mobile application (Android, iOS, or multi-platform) to assist users in healthcare monitoring, more specifically, focused on diabetes. Note that this application can be used by any user, whether they are diabetic, someone who wants to anticipate a possible situation of diabetes, or even someone who just wants to monitor their physiological parameters. This application should provide to users health recommendations, through the provision of theoretical content, practical guides, or tips for their daily lives. Something essential to consider is that the contents provided should be easily understandable by the user with reduced healthcare literacy, which introduces the challenge of being able to convey the message to the user using a practical language, or even including animations, images, or other interactive features.

A fundamental aspect during the development of this work is to keep in mind the relation between diabetes and stress. In this condition the mobile application should also contain stress functionalities, allowing users to monitor not only their stress levels, but also the parameters acquired and associated with it. Considering that the acquisition of physiological parameters that are related to diabetes is difficult to achieve, being most of them associated with obtaining blood samples or other types of fluids (oral fluids, urine, among others), the mobile application should allow users to enter these parameters manually. Note that the physiological parameters associated with diabetes will be obtained mostly through devices prescribed by doctors (blood glucose meters, blood pressure meters, clinical analyses, medical exams, among others).

In short, the final product should be a prototype developed and tested not only in the laboratory, but also in real case scenario. Accurate results are expected, allowing well-founded conclusions to be drawn.

1.4. Research Method

The research method will follow the design and development centred approach, consisting of the following eight distinct steps:

1. **Objectives Definition** – in this step, a set of technologies, processes, tools, and methodologies inherent to smart systems and mobile interfaces applied to healthcare are studied. Furthermore, contents related to the monitoring and estimation of stress levels will also be studied, as well as aspects to be considered in the life of a diabetic. These studies are carried out with the aim of acquiring the necessary technical knowledge to survey the system specifications.

2. **Development of the System Prototype for Stress Levels Estimation** – in this step, the smart system responsible for acquiring the physiological parameters necessary for stress levels estimation will be developed. This system must have an embedded system capable of pre-processing the physiological parameters acquired by the sensors, introducing authentication, and ensuring the sending of the data to the database. In this step it will be important to choose the most appropriate database and structure it according to the objectives of this work.
3. **Testing the Prototype System for Stress Levels Estimation** – in this step, laboratory tests on the functioning of this system are conducted. This step will allow not only to confirm the correct functioning of the system, but also to correlate parameters and identify the most appropriate model for estimating stress levels. If errors or system malfunctions are detected, they should be corrected, so it will be necessary to return to step 2.
4. **Mobile Application Development** – in this step, the type of platform to be used to implement the mobile application will be defined, i.e., whether it is intended for devices with Android, iOS, or multi-platform (Android and iOS) operating systems. Once the platform has been chosen, the code required to implement all the pre-established functionalities should then be implemented, as well as the communication between the application and the database.
5. **Mobile Application Testing** – in this step, laboratory tests will be performed regarding the operation of the mobile application, as well as its communication with the database, checking if the access (writing and reading data) is performed correctly. If errors or bugs are detected, they should be corrected, so it will be necessary to return to step 4.
6. **Integration of the Work Developed in the Previous Steps** – in this step, the prototype system for stress levels estimation is integrated with the mobile application developed. Note that previously these two components have already been tested, however, in this step the real-time sending of data from the embedded system to the mobile application will be enabled, by means of the database. Finished this step, the proposed smart system is complete, being necessary to perform tests.
7. **Testing the Smart System** – in this step, the smart system will be tested in the laboratory and in real case scenarios, where the user physiological parameters are acquired through the embedded system and can display them using a mobile application. In addition, the mobile application will analyse the data and provide to the users recommendations or clarifications for healthy life. If errors, system malfunctions, bugs, or incorrect analysis of the data are detected, they should be corrected, so it will be necessary to return to step 6.

8. **Evaluation of the Smart System** – in this step, an evaluation of the proposed smart system will be carried out. To this end, it will be necessary to conduct experiments with participants, in order to obtain enough data to draw well-founded conclusions. These experiments may be shorter and performed in the laboratory, aimed at particular aspects, or extending over several days, in which the participants carry out their daily routine, however, they will be asked to acquire data at specific times of the day. An important point to note is that if the conclusions obtained are in line with the objectives defined in step 1, the project is considered finished. Otherwise, it will be necessary to analyse the problem or improvements to be made and return to the necessary research step to correct them.

1.5. Thesis Structure

This document is structured into 8 chapters, the first of which serves as an introduction. Chapter 2 presents the review of literature in order to contextualise the current reality of the area where this work is inserted, highlighting concepts, technologies, and important aspects for its realisation. Chapter 3 serves as an introduction to the work developed, i.e., a description of the system is presented, including data acquisition methods and who it is intended for. Chapter 4 presents all the work developed and related to the embedded system responsible for data acquisition, as well as important concepts considered, equipment and platforms. Chapter 5 focuses on the system's database, serving as a link between the embedded system and the mobile application developed. Chapter 6 presents the mobile application created to serve as the main user interface, being responsible for arranging in a simple and compact way the data obtained through the embedded system, as well as processing the data and generating warnings and advices for the user. Chapter 7 describes the experiments carried out with the participation of volunteers, from which the data acquired was analysed and conclusions were drawn. Finally, chapter 8 presents the conclusions drawn from this thesis, as well as possible future work. The bibliographical references of this document are also included, as well as the attachments, which include the certificate of participation in the ATEE 2021 conference and the respective paper accepted, presented, and published. In addition, an attempt was made to publish an article in the scientific journal MDPI, more precisely in the Sensors section. The article was not published, but it was not refused. The reviewers of the article pointed out that it would need Major Changes, and that they would wait for a new review, which was not yet performed at the time of the delivery of this master thesis. However, both the article and the proof of revision are also attached.

CHAPTER 2

Review of the Literature

This second chapter is dedicated to the Review of the Literature, which is fundamental to better understand the current state-of-the-art of smart systems and mobile interfaces for healthcare. Bearing in mind that this work will focus on the relation between stress and diabetes, part of this chapter will also be dedicated to exploring these two topics.

In order to present the topics in a structured way, the Review of the Literature was organised as follows: Smart Systems, Mobile Interfaces for Healthcare, Stress Assessment, Diabetes Mellitus and Other Relevant Health Parameters for Stress and Diabetes.

2.1. Smart Systems

The healthcare-related information technology market is growing, mainly due to some important factors such as rising healthcare costs, the necessity to increase quality of services, reduction of medical errors, search for new cures for diseases, among others [11].

The convergence of several information and communication technologies, including emerging smart systems, cloud computing, and advanced data detection and analysis techniques, are creating new market opportunities, not only for patients, but also for doctors, nurses, hospital services, pharmacies, among others.

In this way, the new IoT technologies allows extending the scope of medical services, not only providing a more dedicated support to patients, but also increasing the level of information processing, from data acquisition by smart sensors, which communicate with each other forming IoT networks, to the storage and analysis of them in the cloud, all in real time [12].

The development of IoT applied to healthcare presents an exponential evolution, and as such, it can be extended to wearables (wearable sensors with very low power consumption, preferably connected through wireless networks) [13], smart homes (several sensors embedded on the objects of the users' homes) [14], or even Smart Cities (sensor networks for environmental monitoring, such as air and water quality control, noise levels, among others) [12].

In addition to the above, a great advantage is the possibility of accessing data from smartphones, tablets, and computers, thus introducing the concept of mobility and versatility, in addition to the permanent contact with health professionals, without having to leave home, and the provision of assistance in cases of medical emergency.

The implementation of a smart system can be done in several ways, but usually includes a phase of data acquisition by smart sensors, connection to databases, followed by processing and storage in the cloud, thus being ready to be accessed through mobile applications or web applications. Note that the cloud is a secure platform, more reliable and efficient than the typical client-server connection, due to the fault tolerance policies supported by it. Moreover, the cloud saves memory and extra power consumption of mobile devices or the need to use memory cards [12].

It is also important to highlight that there are great expectations regarding IoT applied to healthcare, however, a better use of data should be carried out, i.e., it is essential to filter the data that really matter for healthcare, thus eliminating redundancy and provided what it is denominated smart data. In addition, the processing and treatment of these data should ensure reliability and quality of information.

2.1.1. Smart Sensors

In a society in constant technological development, where terms such as connectivity and pairing of devices are becoming increasingly important, the concept of Mobile Health (mHealth) can be explored more efficiently through the inclusion of a sensory component, capable of acquiring various data in a practical, precise, and safe way. Note that the use of sensors can be made through the use of wearable devices (ribbons, waistcoats, smart watches, suction cups, among others), implantable devices (very small size and very flexible, are deposited on the skin or underneath, highlighting the smart tattoos and microparticles injected into the blood), or even from sensors embedded in smartphones or other types of mobile devices [15].

In the specific case of healthcare, sensors can be used to monitor important parameters (heart rate, Galvanic Skin Response (GSR), Peripheral Oxygen Saturation (SpO2), body temperature, exposure to ultraviolet radiation, changes in skin colour, among others), they can also be used to diagnose and prevent/threaten potentially fatal diseases (stroke, cancer, cardiovascular diseases, hypertension, diabetes, neural disorders, chronic pain, obesity, among others) [16].

The diversity of sensors and measuring devices is considerably large. In the case of the wearable or implantable type, they can be classified as follows:

- **Smart Wristbands** – this type of device is used to monitor the physical condition and heart rate of users, allowing, through interaction with mobile applications, health recommendations to be made.

- **Smart Watches** – offer typical smartphone functions, such as counting steps, counting time, reading notifications, sending messages, making calls, among others. However, this type of device can also be useful in healthcare, it can perform heart rate monitoring, alert to some detectable hazards (e.g., atrial fibrillation), or for more specific situations, such as the investigation of chronic diseases (e.g., Parkinson's disease) [17].
- **Common Sensors** – there is a wide variety of simpler sensors, which through creative ideas can become quite interesting projects. In this category are sensors such as accelerometers, piezoelectric tapes, GSR sensors, gas sensors, among others that can be connected to the embedded computation platform to create a smart sensor.
- **Biosensors** – these are relatively new devices on the market, differing slightly from the format of Smart Watches and Smart Wristbands, being much more discreet. This type of device consists of a self-adhesive patch that is placed on the skin, monitoring the user's movements and some important parameters. Meanwhile, this category can also be divided into biomolecular sensors (high selectivity, ultra-sensitivity, and energy efficiency) and bioelectric sensors (e.g., ECG sensors to monitor heart-related parameters, electroencephalographic (EEG) sensors to monitor brain activity, and electromyographic (EMG) sensors to monitor muscle reaction) [15].

In the case of sensors embedded in systems, these can be classified as follows:

- **Environmental Sensors** – used to measure different properties of the surrounding environment, such as capturing sounds (microphone), taking pictures, or recording videos (camera), which are very useful to analyse parts of the user's body in the health field, measure light intensity (light sensor), detect the presence of nearby objects (proximity sensor), among others [18].
- **Position and Orientation Sensors** – used to determine the orientation of the mobile device in space and its location, such as measuring linear acceleration in two or three directions (accelerometer), determining orientation in relation to the Earth's magnetic field (gyroscope), enabling navigation, among others. This particular type of sensors is extremely useful for monitoring the level of physical activity and mobility of users, besides being a huge contribution to fall detection [18].

2.1.2. Wireless Communications

Communication is a very important aspect for smart systems, enabling not only communication between sensors and/or systems, but also sending data to storage infrastructures. In the case of healthcare, the use of wireless communication techniques is fundamental, thus introducing greater mobility. In the most cases, wireless communications are carried out through Radio Frequency Identification (RFID) technology, Wireless Sensor Network (WSN), Light Fidelity (Li-Fi) technology, Bluetooth, and Wireless Fidelity (Wi-Fi) access.

RFID technology uses the electromagnetic field to automatically identify and access tags attached to objects, that is, when an RFID reader approaches a tag, it generates a small electromagnetic field, from which the tag starts transmitting data to the reader. Thus, the most common use of RFID is based on low-cost passive tags, which do not require constant power from a power source, however, in more specific cases, active tags powered by a battery can be used. Note that the use of passive or active tags depends on some circumstances, for example the range, that is, if on the one hand passive tags do not have their own power source and have a range of few centimetres, on the other hand active tags have their own power through an attached battery, thus having a range up to hundreds of meters [19].

WSN technology is quite different from RFID, being similar to ad hoc networks composed of small devices/sensors that communicate with each other in order to allow monitoring and control in various situations, including healthcare applications. These devices/sensors require the coupling of a battery in order to operate autonomously, but compared to RFID technology, WSN consumes much more energy despite providing a longer range [19]. Thread and ZigBee are examples of this type of technology, but they have considerable limitations that prevent them from being used efficiently in all kinds of applications.

Li-Fi is a wireless technology that uses Visible Light Communication (VLC) systems, more precisely the use of Light Emitting Diodes (LEDs), to transmit high-speed communications, similar to what happens with Wi-Fi. Despite using VLC (light frequency ranges from 400 to 800 THz), Li-Fi can also use the ultraviolet and infrared light spectrum. Regarding LEDs, these can be switched on and off almost instantaneously, allowing data transmission using binary codes, where the LED on corresponds to the binary '1', and the LED off to the binary '0'. Thus, it is possible to encode data by varying the frequency of light. After this process, a light-sensitive device (photosensor) receives the signal and converts it back to the original data format [20,21]. Note that the data transmission can be performed by making use of sets of LEDs, where each LED transmits a single stream of data, thus increasing the frequency of data by the VLC.

Regarding Li-Fi applications, these can range from aviation (allows connectivity for passengers without introducing Electromagnetic Interference (EMI)), underwater infrastructures (communications based on radio frequencies cannot be used underwater, while communications based on light emission are much more promising), traffic (communication between cars and traffic lights would contribute to better traffic management and reduce the number of accidents), medicine (surgery rooms do not allow the use of Wi-Fi to avoid possible precautions due to radiation, and as such Li-Fi can be beneficial in the introduction of automation and robotics), among others [20].

In general, Li-Fi has several advantages, such as security in communications (communication between specific receiver and transmitter), capacity (greater bandwidth than radiofrequency), energy efficiency (use of LEDs), speed (light propagation is much faster than radiofrequency propagation), among others. However, this technology also has some disadvantages, such as limited range (emitter and receiver must be in each other's field of vision, not being able, for example, to pass through walls), limited compatibility (as it is a relatively new technology, there are not many compatible devices on the market), little use of speed (if the data transfer rate through the Internet is slow, the advantage of Li-Fi speed is not applied), among others.

Although Li-Fi and WSN are very viable and useful options in certain situations, nowadays most smart systems use Bluetooth technology and/or Wi-Fi access, and can also be combined with the use of RFID.

In the case of Bluetooth, this is used for short-distance communications, with low energy consumption, unlike Wi-Fi communications, which sometimes have considerable energy consumption. However, Bluetooth communications are less flexible than Wi-Fi communications, allowing a limited number of connected devices at the same time [22].

In the case of Wi-Fi, it is used in systems that require fast access to web servers, and as such, it is more suitable in healthcare systems where real-time monitoring of vital parameters is indispensable. In addition, they offer more security than Bluetooth communications. An aspect to be considered is the energy consumption of the systems which use this type of communication, however, there are several ways to manage it [22].

2.2. Mobile Interfaces for Healthcare

A mobile application is basically software that runs on a mobile device, exploiting the unique hardware characteristics of this type of devices. If before they had limited functions, nowadays they are much more than that, running quite complex services, such as social networks, medical support, interactive games, among others. The fact that modern smartphones and tablets are equipped with features such as Bluetooth, Near Field Communication (NFC), Global Positioning System (GPS), gyroscopic sensors, cameras, among others, allows developers to use these features to create applications for barcode reading, location-based, healthcare, among others.

An important aspect to mention is the fact that mobile applications are divided between two types, those that implement the Android operating system (developed by Google), and those that implement the iOS operating system (developed by Apple). In the case of the iOS operating system, it is only available on Apple devices, which greatly restricts users' choice to buy equipment from other brands. In contrast, the Android operating system is available on all mobile devices on the market except Apple devices, which makes it much more popular among users. In 2019 it was estimated that only 22.17% of mobile devices on the market used the iOS operating system, compared to the overwhelming majority of Android devices, which are estimated to reach 87% [23].

The mobile application market is constantly expanding and becoming increasingly competitive, and in the context of healthcare, this is no different. There are many healthcare applications, however, when it comes to finding one that not only provides a good user experience, but also adds value and quality to user's life, that number decreases dramatically. As such, it is important to create reliable applications that, based on medical concepts, offer certified and reliable functionality to patients and healthcare professionals.

The adoption of technology in healthcare, more precisely the use of mobile applications, can provide patients with a high level of support, due to the accessible way in which they perform prevention/monitoring of chronic diseases, as well as in the counselling/monitoring of various stages in the user’s life. Note that the benefits of using this type of application do not stop with patients, but also extend to doctors or other health professionals.

Although there is room for the introduction of new aspects, functionalities and tools in the mobile healthcare applications market, there is no doubt of the important contribution already made by this type of applications, of which the following benefits stand out:

- Simplified connection between patient and doctor.
- Efficient triage.
- Optimization of resources.
- Compatibility with wearables sensors.
- Extended content repository.
- Medical appointments made in a simple and easy way.
- Guarantee of taking the medication (interactive alerts for taking the medicines and order them without leaving home).
- Reduction of human errors.
- Notifications and alerts for certain situations (for example, concerning the environment around the user, more specifically, areas of higher pollution, dangerous contagion, temperature, humidity, among others).

In addition to the benefits presented, these technology have unique characteristics, such as interactivity (user monitoring by an intelligent entity of the personal assistant type), personalization (the mobile application algorithm adapts itself to the user’s data, thus creating a more personalized environment), the sense of opportunity (by being aware of the surrounding environment, the application may suggest certain actions that in other contexts might not consist of benefits), among others [24].

Another aspect to highlight is the numerous results obtained when searching for the term "health" in the mobile applications market. In a simple way, these applications can be divided into more technical applications, focused particularly on chronic diseases (obesity, diabetes, hypertension, cancer, cardiovascular diseases, respiratory diseases, among others) and more practical applications, focused on daily activities associated with well-being (pregnancy, physical exercise, weight loss, among others).

In the case of applications focused on chronic diseases, these are intended to help patients in the treatment/prevention of this type of disease in order to simplify and monitor the user's daily life, providing technical knowledge, dietary guides, suggestions for activities, medication management, consultations, direct contact with health professionals, psychological support, mental health analysis, treatment strategies, among others. This contact between application and patient should be as personalised as possible, constantly establishing an emotional and dedicated support.

2.3. Stress Assessment

Stress is something common in today's society, affecting everyone, regardless of age, environment, social status, among other aspects. The fact that it is common and that the term "stress" is widespread causes people to neglect this condition, which should be taken seriously.

According to the Labour Force Survey (LFS) in 2019/2020, about 51% of work-related illnesses were a direct consequence of stress [25]. These consequences are not only translated into the feeling of tiredness and the need for rest but can even contribute to the worsening of several chronic diseases, such as high blood pressure, cardiovascular diseases, respiratory diseases, mental illnesses, diabetes, among others.

Every person is susceptible to stress in different ways. For one person, a specific situation can lead to an increase in stress levels, but for another person, the same situation can be faced in a much calmer way. What defines a stressful situation is the way in which the person faces it. If the person is used to such situations and has the tools to solve the problem, it is unlikely to have a huge effect on the increase in stress levels. However, if it is something new to them and/or they do not have the skills to deal with the situation, it is very likely that they will experience a huge increase in stress levels [26].

When we talk about stress, its type is not specified, however, stress can manifest itself in several ways, such as [26]:

- **Environmental Stress** – related to how the human being reacts and adapts to the surrounding environment.
- **Psychological/Emotional Stress** – related to situations or experiences lived by the human being, and how his brain deals with it. This type of stress is often detected in people suffering from cancer, cardiovascular diseases, respiratory diseases, and kidney diseases, and is also responsible for a considerable percentage of suicides.
- **Biological Stress** – related to the physical response of the human body to certain stressful situations. This type of stress is very interconnected with Psychological Stress. Psychological stress affects a person's judgment and can contribute to the aggravation of mental illnesses, but biological stress is directly visible in a person's body, such as muscle strains, cramps and the aggravation of problems associated with physical condition.

Not all stress is negative and when we talk about short-term stress, it can be very beneficial (Eustress), in that it can help us to overcome everyday situations, strengthening our resistance and adaptation mechanisms, for example, increasing the competitiveness of an athlete, or even stimulating the response of our immune system. Despite the short-term benefits of stress, in the long-term, chronic stress is undoubtedly harmful to health (Distress) and is responsible for several consequences, such as [26]:

- Suppression of the immune system, which in turn increases the risk of viral infections.
- May worsen the effects felt during and after asthma attacks.
- Increased stress levels increase the risk of diabetes, especially in overweight people.
- May lead to altered acid concentration levels in the stomach, which can lead to ulcers.
- In people with sedentary lifestyles and who follow a high-fat diet, stress increases the likelihood of blockages in the arteries.
- The correlation between stress and psychiatric illnesses is somewhat controversial but according to some experts in the field, the effect of stress on psychiatric illnesses can lead to or aggravate neuroses, typically followed by depression and schizophrenia.
- Although there is no irrefutable evidence about the link between stress and cancer, recent studies indicate that there is a link between stress and the development of tumours, as the cells responsible for preventing and fighting metastases are suppressed.

In general, the human organism manifests the presence of stress in the most diverse forms, but an important aspect to consider is that the system more susceptible to stress is the nervous system, and to talk about the nervous system is to talk about the "engine" that feeds this system, that is, the brain.

The human brain not only controls the central nervous system and autonomic nervous system, but it is also responsible for controlling the whole organism, and in this way, disturbances caused in the brain will result in disturbances in other systems (immune system, muscles, organs, tissues, among others) [27]. For example, the increase in stress levels originates a response from the autonomous nervous system which triggers various hormonal reactions [28], thus leading to changes in various parameters, such as heart rate, respiratory rate, muscle tension, among others. In turn, these parameters can be monitored through various wearable sensors, such as heart rate and SpO2, monitored through Pulse Oximeter sensors.

Currently, stress is assessed through self-assessment questionnaires, such as Perceived Stress Scale (PSS) [29], or even by monitoring brain activity. Typically, the monitoring of parameters linked to brain activity is carried out in calm and controlled spaces, such as laboratories.

The creation of a system for estimating stress levels is a great challenge, and undoubtedly presents great future prospects, however, the best method for doing so is still unknown, that is, it is still not clear which parameters are most important in stress estimation, or even how this quantisation of stress levels can be carried out, since each researcher presents something different and personalised to their own work. For example, there are systems that classify stress levels into three levels, being "low", "normal" or "high" [7]. One thing is certain, most recent works explore parameters such as facial expression recognition [6], heart rate [5], respiratory rate [30], skin temperature [7], GSR [4,28], Electrodermal Activity (EDA) [28,31], ECG [30,31], EMG [28], among others, and as such, this is a starting point for future works.

For example, for facial recognition, this aims to determine a person's emotional state by comparing the facial expression captured with a database full of examples of expressions associated with a given meaning [6]. However, this facial recognition mechanism may present a high computational complexity, and by itself, it is not a reliable method for estimating stress levels. Note that even the software used in areas like psychology, does not allow estimating human emotions with 100% accuracy.

There are also proposed works that make use of the acquisition of ECG, Photoplethysmography (PPG), EMG and EDA signals, followed by their processing by ML algorithms, thus classifying stress into levels [28,31]. There are also proposals for wearable device to estimate stress through the correlation between GSR, skin temperature and PPG signals [32]. Note that in the case of PPG and EMG, it is often analysed in order to monitor respiratory rate [33,34].

An important fact to mention, is that regardless of the method proposed, and sometimes being these very similar, all the results obtained through the processing and correlation of physiological parameters present great disparities, including different accuracies, which makes even more difficult the study of stress, since there are no reference values. Furthermore, the acquisition of a big number of parameters does not make a system for the estimation of stress something infallible and ideal, that is, the important thing is to focus on the parameters that really matter and not on the quantity.

According to studies [28,35], the estimation of stress levels based on the correlation between respiratory rate, heart rate and Heart Rate Variability (HRV), provides classification results with a similar accuracy to methods which correlate EDA, EMG and HRV, the latter method being a more complex sensorial system and vulnerable to noise artefacts.

2.3.1. Related Health Parameters

A list of different methods and parameters used to estimate stress levels has already been presented, however, in general, there are certain parameters common to most of these methods, which are the heart rate, respiratory rate and GSR. Therefore, first it is important to better understand each of these parameters, to only then understand how they will influence stress levels.

In the case of the heart rate parameter, it can be obtained through devices available on the market, such as blood pressure monitors and pulse oximeters, or through smart systems that acquire data through smart sensors (ECG sensor). Heart rate parameter has a direct link to stress, in the way that when a person is stressed, his or her body releases temporarily adrenaline, causing an increase in heart rate. Apart from stress, increased heart rate can also be caused by exercise, sleep, anxiety, illness, or drug intake. Additionally, the heart rate can be classified according to Table 1 [36-38]:

Table 1 – Heart Rate Reference Values for a Normal Adult

Heart Rate [BPM]	Information	Symptoms/Consequences
< 60	Low Heart Rate (Bradycardia)	Fatigue, dizziness, confusion, feeling faint, possible infection, high blood potassium levels, active thyroid gland, risk of heart attack.
60 – 100	Normal Heart Rate	No symptoms or consequences.
> 100	High Heart Rate	Fatigue, dizziness, palpitations, chest pain, difficulty breathing, possible infection, low blood potassium levels, anaemia, very active thyroid gland, heart disease (cardiomyopathy, tachycardia, among others).

In the case of Galvanic Skin Response (GSR), it is expressed as a percentage (%) and can easily be acquired by sensors developed for the purpose, generally made up of two electrodes positioned on two consecutive fingers. The GRS is proportional to the amount of sweat produced by the human body, that is, when a person is more nervous and/or stressed, the activity of the sweat glands increases, producing more sweat, which consequently translates into an increase in the GSR. Furthermore, it can also be classified according to Table 2 [39,40]:

Table 2 – GSR Reference Values for a Normal Adult

GSR [%]	Information	Symptoms/Consequences
0 – 31	Low levels	Does not pose a problem or risk to human health.
32 – 82	Normal levels	Does not pose a problem or risk to human health.
83 – 100	High Levels	It does not pose any problem or risk to human health, however, there is a high psychological stimulation (increased emotional response) and greater sweat production.

In the case of respiration rate, this defines the number of Breaths Per Minute (BPM') and is typically measured by manually counting breaths over one minute [41]. There are also devices used in laboratories that obtain respiration rate through chemical reactions between compounds and the air expelled during breathing [42]. In addition, there are also wearable devices capable of estimating respiration rate, but they are quite expensive and difficult to purchase [43].

Another important aspect is that respiratory rate is regulated by the nervous system, i.e., it has a direct link to stress, in that during the human body's response to stress, the person breathes more quickly to rapidly deliver oxygen-rich blood throughout the body [44]. If a person has respiration impairment such as asthma or emphysema, the stress condition can make breathing even more difficult.

The normal respiratory rate as a function of age is established as follows [45]:

- **New-born:** about 44 BPM’.
- **Children:** 18-30 BPM’.
- **Pre-teens:** 20-30 BPM’.
- **Adolescents:** 18-26 BPM’.
- **Adults:** 12-20 BPM’.
- **Adults over 65:** 12-28 BPM’.
- **Elderly over 80 years:** 10-30 BPM’.
- **Athletes:** 60-70 BPM’.

Additionally, the respiratory rate for a normal adult can be classified according to Table 3 [45]:

Table 3 – Respiratory Rate Reference Values for a Normal Adult

Respiratory Rate [BPM']	Information	Symptoms/Consequences
< 12	Low Respiratory Rate (Bradypnea)	Slow breathing that can lead to Apnea or low concentration of oxygen in the blood, which leads to situations of Hypoxia.
12 - 20	Normal Respiratory Rate	No symptoms or consequences.
> 20	High Respiratory Rate (Tachypnea)	Violent physical exertions that can be indicative of lung disease, heart disease, fever, anxiety, or poison contamination.

2.3.2. Mobile Applications to Manage Stress

Regarding the market of mobile applications dedicated to stress, their number is still small. Moreover, of the mobile applications that fall into this small group, they only ask the user about his daily routine and how he feels in certain situations. There are even applications that use the smartphone camera to estimate the heart rate and activity performed by the user, although the quality and effectiveness of such applications is questionable [46,47].

Given the limitations of the market for mobile applications to monitor stress levels, opportunities arise to combine the best of both worlds, namely, on the one hand, having an efficient smart system to obtain and process physiological parameters important for stress (heart rate, respiratory rate, GSR, body temperature, among others) and, on the other hand, providing the information to a mobile interface, ensuring that users are able to monitor and obtain more accurate and reliable advices, thus helping in their quest for well-being.

2.4. Diabetes Mellitus

Diabetes Mellitus, or commonly known as Diabetes, is a chronic disease resulting from the absence of insulin, caused by the body's inability to use the sugar that circulates in the blood, causing it to accumulate (Hyperglycaemia), which can even affect other systems of the human body such as diabetic retinopathy, which can lead to blindness, kidney failure, periodontal disease, which can lead to falling teeth, loss of sensation in the extremities, which can lead to limb amputation, cardiovascular diseases, among others [48].

During the year 2020, the Centers for Diseases Control and Prevention (CDC) in the USA, published a report regarding diabetes-related statistics, of which the following are highlighted [9]:

- **People with Diabetes:**
    - Total: 34.2 million people have diabetes (9.8% of the Portugal population).
    - Diagnosed: 26.9 million people, including 26.8 million adults.
    - Undiagnosed: 7.3 million people (21.4% are undiagnosed).
- **People with Pre-Diabetes:**
    - Total: 88 million people aged 18 years or older have prediabetes (34.5% of the adult US population).
    - 65 years or older: 24.2 million people aged 65 years or older have prediabetes.

As evidenced by, currently diabetes is a widespread chronic disease which begins to be something quite common in the most developed countries, and can go up to 10 different types, from Insulin-dependent Diabetes (also known as Type 1 Diabetes), Type 2 Diabetes, Gestational Diabetes in pregnant women, diabetes as a consequence of genetic mutations, or even diabetes derived from glucagonomas and pancreatic diseases [48]. Note that from this list of different types, those affecting most patients are Type 1 Diabetes and Type 2 Diabetes.

In the specific case of Type 1 Diabetes, it is essential to use devices which can constantly monitor blood glucose levels and, if necessary, automatically inject insulin doses. However, this automatic intake of insulin can be life-threatening, and as such, this type of smart system must be capable of recognizing different physiological parameters of the patient, thus determining the exact dosage of insulin to be injected.

Of the two types of diabetes highlighted as affecting the most patients, Type 2 Diabetes is the most common, having as main risk factors obesity, sedentary lifestyle, and genetic predisposition, which through prevention and control of these factors, can be avoided [48]. Basically, this condition is due to the imbalance of glucose levels, which can increase above normal, or even decrease drastically. Another very important aspect is the fact that this type is strongly linked to autonomous nervous system sympathetic branch responses.

The activation of the sympathetic branch od autonomic nervous system not only translates into increased stress levels, but is also related to increased levels of adrenaline, noradrenaline, cortisol, and growth hormones, which consequently affect human metabolism [49]. To try to predict and counter these changes, it is important to create innovative devices that monitor important physiological parameters, such as eye movement, skin temperature, GSR, HRV, among others [49]. Besides the need to develop this type of devices, it is important to note that, for some of these physiological parameters, there is no equipment on the market yet, being mostly proposed in scientific articles.

2.4.1. Diabetes Monitoring

In diabetes monitoring, the main parameter to be acquired is the blood glucose levels, which are expressed as Milligrams Per Decilitre (mg/dL) and is one of the most important carbohydrates in biology, used by the body's cells as an energy source for metabolism. If blood glucose levels are above normal over long periods of time, a person is typically diagnosed with diabetes, always needing confirmation by clinical analysis.

When diagnosing diabetes, it is important to know whether the patient is fasting or has already eaten food, as this is something that directly influences blood glucose levels. With this in mind, blood glucose levels are classified according to Table 4 [50]:

Table 4 – Classification of Blood Glucose Levels for a Normal Person

Blood Glucose Levels in Fasting [mg/dL]	Blood Glucose Levels After Meals [mg/dL]	Blood Glucose Category
< 70	**< 70**	Low blood glucose levels associated with Hypoglycaemia.
70 - 99	**70 - 139**	Normal blood glucose levels.
100 - 125	**140 - 199**	Pre-Diabetes status.
> 125	**> 199**	Diabetes diagnosis.

After being diagnosed with diabetes, patients should take some precautions in terms of diet, physical exercise, regular diabetic consultations, and daily monitoring of blood glucose levels. Another important aspect to consider is the fact that for a person diagnosed with diabetes, blood glucose levels classified as normal no longer apply in the same way as for normal people, and as such, this distinction is made as follows [51]:

- **Normal Blood Glucose Levels in Fasting:**
    - Person without Diabetes: 70 – 99 mg/dL.
    - Person with Diabetes: 80 – 130 mg/dL.
- **Normal Blood Glucose Levels After Eating:**
    - Person without Diabetes: less than 140 mg/dL.
    - Person with Diabetes: less than 180 mg/dL.

It is also important to mention that although blood glucose level is the most common parameter in diabetes management, there are also other important parameters to monitor, such as weight, blood pressure, heart rate, stress levels, among others. As for blood glucose monitoring, it is a simple method whereby patients only have to take a small sample of blood, which is then analysed by a meter prescribed by their doctor. In the case of weight, it is easily measured using scales. Similarly, blood pressure and heart rate can be monitored using commercially available meters, and the same meter obtains both parameters. In the case of stress level monitoring, there is no equipment on the market yet, opening up opportunities for researchers to contribute.

2.4.2. Diabetes Mobile Applications

Controlling diabetes is not a simple task, involving carbohydrate counting, insulin doses, A1C, blood glucose levels, glycaemic index, blood pressure, weight, among others. In this way, the use of a mobile application can greatly help to simplify this complex task, it can help not only to follow the indicators described, but also give advice on the most appropriate diet or useful exercise, or even provide complementary information about the disease itself. In addition, the possibility of constant monitoring and sharing data with health professionals in real time, allows them to modify and better manage the monitoring and treatment of the disease.

A negative aspect in terms of diabetes mobile applications, is the fact that the manufacturers of specific equipment in the field of diabetes (blood glucose meters, insulin pumps, among others), do not introduce options in the software that allow the integration and synchronisation of these devices with smartphones, which hinders the development of smart systems with mobile interfaces capable of using these devices to increase the quality of the support given to diabetics.

Based on the research carried out in the market of mobile applications for diabetes, it is important to highlight some solid applications that provide a good user experience, such as "Beat Diabetes" [52], "BeatO" [53], "BG Monitor" [54], "Diabetes:M" [55], "Glucose Buddy Diabetes Tracker" [56], or even "Health2Sync" [57]. Through the analysis of these applications, it is possible to highlight the following functionalities:

- **Libraries of Contents** – provides users with detailed information about the disease (description of the complications resulting from the disease, important parameters, among other), recommended diet (best and worst foods, recommended fruits, vegetables to be avoided, caloric values, etc.), simple ways to increase physical activity, or even diets/recipes suggested by specialists.

- **Personalized and Real-time Follow-up by Doctors** – one of the best ways to help a patient is to provide ongoing follow-up, whether through updates on treatment strategies, tips on how to control blood glucose levels, real-time consultations, or diet and exercise plans based on the patient's medical history.
- **Glucose Levels Recording** – by recording blood glucose levels, the mobile application can analyse the data, even generating explanatory graphs. Furthermore, this data can be shared with other people (family, friends, doctors, among others).
- **Smart Monitoring** – this functionality is more aimed at Type 1 Diabetics, allowing the monitoring of blood glucose levels, food intake and physical exercise performed, in order to automatically calculate the recommended insulin dose. However, in my view, the introduction of Artificial Intelligence (AI) could help monitoring data, and by means of notifications, inform the user if the daily insulin dose has already been taken or if it is still missing.

2.5. Stress and Diabetes: Other Relevant Health Parameters

As previously mentioned, it is clear that there is a relation between diabetes and the nervous system, in the sense that the increase in stress levels causes a reaction in the human organism which translates into an increase in blood glucose levels [49]. However, this relation is not clear, and if we consider all the systems that are part of the human organism, they all react in a different way, as is the case of the nervous system (associated to stress) and the digestive system (commonly associated to diabetes).

In order to understand a little better, the parameters that can influence both stress and diabetes, and considering that in this chapter parameters such as heart rate, respiratory rate and GSR have already been discussed, two parameters that can have a considerable influence on both stress and diabetes are discussed below, namely body temperature and blood pressure.

2.5.1. Body Temperature

Body temperature is typically expressed in degrees Celsius (ºC), however it can also be expressed in degrees Fahrenheit (ºF), this last case being applied only to countries like the USA, some parts of Canada, Cayman Islands, among others. Body temperature is closely associated with fever, in that an increase of at least 1ºC above the person's usual temperature can already be considered fever [58]. To acquire body temperature, it is common to use thermometers, which can be obtained in pharmacies, electronic shops, medical posts, supermarkets, among other places. Note that in smart systems, body and environmental temperature can be obtained using temperature sensors, infrared temperature sensors, thermography, among other methods.

Typically, the normal body temperature is between 36ºC and 37ºC, however, a person can present small oscillations in body temperature in relation to another person, and as such, it is important to know the habitual body temperature of the person, to then be able to determine if the body temperature is above the usual or not [58]. It should be noted that temperature oscillation may depend on age, activity performed, daytime, part of the body where the temperature is measured, among other aspects. It is important to note that in addition to normal body temperature, environment temperature should also be considered, since on hot days, it is normal for body temperature to be slightly above normal, without this meaning fever or any other type of associated disease.

As mentioned previously, the part of the body where the temperature is measured is important, and as such, the following options should be considered [58]:

- **Rectal** – the acquisition of temperature in this part of the body is ideal for children under the age of 3. It is not exactly practical to perform, however, the values obtained are quite precise. Temperature is considered to be above normal when it is equal or superior to 38ºC.
- **Axillary** – the axilla is the most common part of the body to measure the temperature and may be used by people of all ages. It is the most practical method, however, it is not as precise or fast as the rectal acquisition. Temperature is considered to be above normal when it is equal to or above 37,6ºC.
- **Tympanic** – acquiring the temperature at the eardrum is the method that should be performed in people over 3 years of age (very reliable), however, for people under this age, it is not justified. This method is quicker and more hygienic, which is why it is more often used at hospital level. Temperature is considered to be above normal when it is equal to or above 37,8ºC.
- **Oral** – temperature acquisition in the mouth can be performed on people of all ages, however, children under 5 years old may have difficulty holding the thermometer still, especially as the acquisition takes about 3 minutes. This method is more accurate than measuring the temperature in the axilla, however it is less practical, and attention should be paid to eating hot food before measuring. The temperature is considered to be above normal when it is 37.6ºC or more.

Regarding the relation between body temperature and stress, there have not yet been enough studies carried out to understand how this relation is established and what repercussions it may have [59]. Basically, it is known that stress can be associated to body temperature, however, this relation is not always verified, depending on the person, that is, there are people where this relation is not verified, and there are people where this relation is verified, and within this second group, there are people in which the increase in stress levels is associated to the increase in body temperature, and other people where the increase in stress levels is associated to the decrease in body temperature [60].

In addition to the above, the relation between stress and body temperature may be associated with different types of diseases, be they infectious, chronic, virological, among others. One of these cases is Psychogenic Fever, being a psychosomatic condition related to stress, which manifests itself in a high body temperature. It is caused by exposure to emotional events or chronic stress, and currently the number of individuals affected by it is unknown due to poor medical diagnosis, which may indicate other types of illnesses, or even because not much is known yet about the relation between body temperature and stress. One thing is certain, these patients show symptoms of high temperature induced stress symptoms, to be added to symptoms of psychiatric illnesses that the patient may still have [59].

The reason for mentioning psychogenic fever is that it is mainly caused by stress, i.e., exposure to stressful situations causes an increase in body temperature, among other effects. The way to treat or manage psychogenic fever is to control stress levels. However, generally applied to this disease or other types of diseases, it is not clear how the relation between stress and body temperature can be established, and as such, conducting future studies would be a great asset.

Regarding the relation between body temperature and diabetes, fluctuations in body temperature should be taken seriously, as even a change of a few degrees can be catastrophic for the human body, as enzymes slow down, electrolytes get too low, and hormones don't work as well [61].

The heat we produce in our body is the result of countless chemical reactions that occur in each cell. This heat production is usually matched by equal heat dissipation, ensuring that body temperature stays within a narrow range, because the skin acts as a thermoregulator, allowing heat to dissipate. However, blood glucose levels can disrupt this process, and in the case of diabetics, who have levels above normal, body temperature regulation can be impaired, requiring further monitoring [62].

It is important to consider that if a diabetic performs physical exercise, their body temperature will increase, which also happens in healthy people, however, it is in the phase of temperature decrease that the differences appear, to the extent that the body of a diabetic may present deficiency in temperature regulation, and as such, the body may not be able to cool down so efficiently [62,63]. Another aspect to be considered is that all people have blood glucose levels, in the case of diabetics these are above normal or there is a greater lack of control, however, all people are susceptible to small fluctuations in glucose levels [64].

Bearing in mind that in any person, glucose levels can affect the regulation of body temperature, the ingestion of high-carbohydrate foods should be avoided, especially before bedtime. These carbohydrates will lead to an increase in blood glucose levels, which in turn will lead to an increase in body temperature, which will make it difficult to fall asleep, or will degrade the quality of sleep [65]. It is also important to mention that a bad night will affect the routine of the following day, in other words, a person will be more stressed, tired, lack of concentration and impatient, which will affect the performance of the most diverse tasks.

2.5.2. Blood Pressure

Blood Pressure is expressed in Millimetres of Mercury (mmHg), and is the pressure exerted by the blood as it travels through the circulatory system. This pressure is normally above atmospheric pressure, which prevents circulatory system from collapsing. In addition, blood pressure is measured in two stages, where in the first stage, the cardiac cycle begins, in other words, the heart relaxes, stops pumping and starts receiving blood. At this stage blood pressure is minimal, and the term used to define it is Diastolic Blood Pressure. In the second stage, the heart contracts, and pumps blood into the arteries. At this stage the blood pressure is maximum, and the term used to define it is Systolic Blood Pressure [66].

To monitor blood pressure, the typical blood pressure monitors available on the market are used, which can be obtained in medical centers, pharmacies, electronic shops, among others. These monitors are divided into wrist monitors and upper arm monitors. If wrist monitors invest more on mobility and reduced size, in terms of precision, they are not as efficient as upper arm monitors, and this is due to the fact that the wrist area is narrower, not containing so many arteries and of greater thickness. In addition, these monitors measure the pressure exerted on the cardiac muscle, and as such, they must be at the same level as the heart [67].

Regarding the blood pressure values, these are classified according to Table 5 [68]:

Table 5 – Classification of Blood Pressure Levels for a Normal Person

Systolic Blood Pressure [mmHg]	Diastolic Blood Pressure [mmHg]	Blood Pressure Category
< 120	**< 80**	If these systolic and diastolic values have occurred, then the blood pressure is considered normal.
120 – 129	**< 80**	If these systolic and diastolic values have occurred, then the blood pressure is considered elevated.
130 – 139	**80 – 89**	If these systolic or diastolic values have occurred, then the blood pressure is considered high, and we are facing the first stage of hypertension.
> 140	**> 90**	If these systolic or diastolic values have occurred, then the blood pressure is considered high, and we are facing the second stage of hypertension.
> 180	**> 120**	If these systolic and/or diastolic values have occurred, then the blood pressure is considered critical, and we are facing the last and more dangerous stage of hypertension.

Although blood pressure is related to heart rate, which in turn is related to stress, it is not clear that there is a direct relation between blood pressure and stress. The same was verified for blood pressure and blood glucose levels. In the literature review conducted in this thesis, it was not possible to confirm these correlations, which still raises further questions, and as such, would be an interesting point to explore.

CHAPTER 3

System Description

This chapter is an introduction to the system proposed in this thesis, which has three important structures, namely the embedded system (multichannel system for obtaining physiological parameters, such as heart rate, respiratory rate, GSR and body temperature), the database (Firebase), and the mobile application (analysis and display of the data obtained, both through the application itself, and also through the embedded system). These three structures will be explained in more detail in the next chapters of this document.

Regarding the system itself, this allows users to monitor the physiological parameters mentioned above, i.e., by using the embedded system, each user can view in real time these parameters, which in case the conditions are met, will be stored locally or remotely (if there is internet connection, through mobile data or Wi-Fi access, the data obtained will be stored remotely, however, if there is no internet connection and the system has available the SD memory card, the data will be stored locally). Note that whenever there is internet connection, the system will check if there are data in the SD memory card to send to the database, thus moving from a local storage to a remote storage. Another important aspect of this embedded system is the guarantee of confidentiality and authenticity, through the introduction of RFID technology, i.e., each user will have its own RFID tag, with a unique identifier number, which will be associated with each data obtained.

Regarding the database, the Google’s Firebase was chosen, that is a simplified non-relational structure. This database is structured in the form of a tree, where each node is a JSON file, which stores a set of tags associated with a particular piece of data. This type of database was chosen to facilitate communication between the embedded system and the database, as well as between the database and the mobile application.

Regarding the development of the mobile application, the Android platform was chosen, enabling greater user coverage. The application is extremely important because this is where the algorithm for estimating stress levels is implemented, based on the parameters obtained through the embedded system. In addition, this application also allows other parameters to be entered, such as blood pressure and blood glucose levels. Note that these last two parameters are obtained through the most varied monitors available on the market, which will be discussed in more detail in the following subchapter. Although users have to enter data on blood pressure and blood glucose levels, due to the lack of compatibility between these monitors and the mobile application developed, it ends up ensuring greater convenience for the user, to the extent that he/she doesn't need to change his/her usual equipment, trying to find one compatible with the mobile application.

Besides the registration of parameters and assessment of stress levels, the mobile application assesses each parameter individually, giving its opinion to the user and recommending counteractions. The application also provides informative content related to each parameter, diabetes, and stress. It is also possible to visualise the evolution of the user's parameters through graphs, as well as providing data access to health professionals registered in the system.

Figure 1 below represents the architecture of the system proposed in this thesis, in which the three structures mentioned above are represented. It is important to highlight that the embedded system is intended for users, while the mobile application can be used by patients/users and health professionals (such as doctors). In order to simplify the communication implemented in this system, and trying to exclude technology that could raise problems, it was chosen only Wi-Fi communications. In terms of data flows, the communication between the embedded system and the database is unidirectional, with the origin being the embedded system and the destination the database. On the other hand, the communication between database and mobile application is bidirectional.

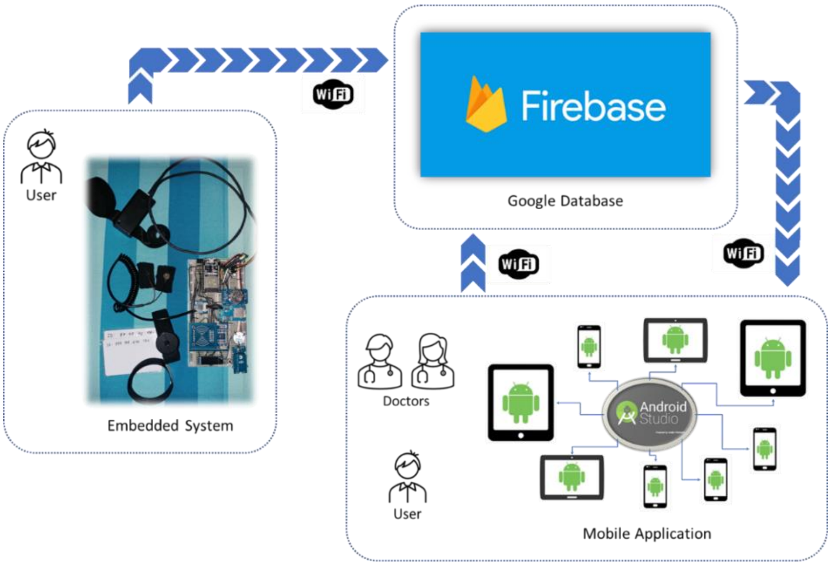


Figure 1 – Architecture of the Proposed System

3.1. Users and Data Acquisition

The system developed is intended for diabetics and the health professionals who accompany them, however, anyone who wants to monitor their stress levels can use the system, although the component related to diabetes does not apply, because although all people have blood glucose levels, only diabetics have a lack of control of these levels, which exceed the limits pre-established as normal.

For the purposes of classifying users, patients are considered to be any person, diabetic or not, who wishes to use the system. On the other hand, health professionals can be doctors or nurses who follow the patients' clinical history. It should be noted that nurses were included and classified in the same group as doctors, because typically for each diabetic who has a family doctor, a family nurse is assigned, who is responsible for performing the so-called diabetic consultations, where the evolution of blood glucose levels is questioned, the patients' weight and height are measured, in order to determine the Body Mass Index (BMI), the sensitivity of the patients' extremities is analysed, mainly through the toes sensitivity, among other parameters.

In case the type of users of the system are patients, the stress level estimation is only achieved through the proposed embedded system, which is responsible for acquiring data regarding heart rate, respiratory rate, GSR, and body temperature, which are communicated in real time to the database, depending on the availability of the Wi-Fi connection. If no Wi-Fi connection is available, the data will be stored in the memory card, thus ensuring that no data is discarded. Patients must also use the mobile application, which, among several important functions presented in more detail in chapter 6 of this document, allows them to visualise the evolution of the health status parameters obtained by the embedded system and the respective estimation of stress levels. In addition, users can also register, through the mobile application, their blood glucose and blood pressure levels, obtained through their own meters. It should be noted that most of the parameters acquired through the embedded system, with the exception of GSR, can be obtained through any meter that the patient has for the purpose, and introduced in the system through the mobile application, however, for stress levels estimation, these 4 parameters must be acquired simultaneously, which mainly suggests the use of the proposed embedded system. It is also important to mention that this system was developed considering the use of the embedded system together with the mobile application, and as such, each patient must have its own RFID tag, in order to authenticate the data coming from the embedded system.

In the case of health professionals, the embedded system component is not considered, and they must use only the mobile application in order to monitor the parameters related to their patients. For confidentiality and privacy purposes, each health professional may introduce one or more patients to his/her list, and he/she must know the number of the patient's RFID tag. Note that health professionals can also be patients and considering that the same mobile application is used for both types of users, it separates each type, i.e., it is not possible to access the application at the same time as a patient and as a health professional. In addition, access to the mobile application is performed through access credentials, where in the case of health professionals, these are introduced into the system by health management, and not by themselves, while in the case of patients, the access credentials are basically composed of email and password, chosen, and introduced by the patients themselves.

CHAPTER 4

Embedded System

In order to clearly expose all the work carried out in the development of the embedded system, this chapter first presents a general overview of the system, and then focuses on important parts of it, such as the hardware and software.

4.1. System Overview

The developed embedded system in this thesis is actually a multichannel system composed of several sensors and modules which allow acquiring, storing, processing, and sending data. This system is one of the most important components of the overall system developed, focusing on the acquisition of fundamental data for the estimation of stress levels, besides allowing the analysis of each data individually. Note that the embedded system does not implement the stress levels estimation algorithm, which is implemented in the mobile application, however, it operates to acquire heart rate, respiratory rate, GSR and body temperature, which involves several complex processes.

The system acquires and allows the user to visualize in real time the 4 mentioned parameters mentioned. To avoid overloading the database, the system perform the averages for each parameter in a 10 second interval, saving these calculated values in a SD memory card or sending them directly to the database. In this way, subsequent data analysis is performed considering these parameter averages, which mitigates to some extent any disturbances or noise artefacts.

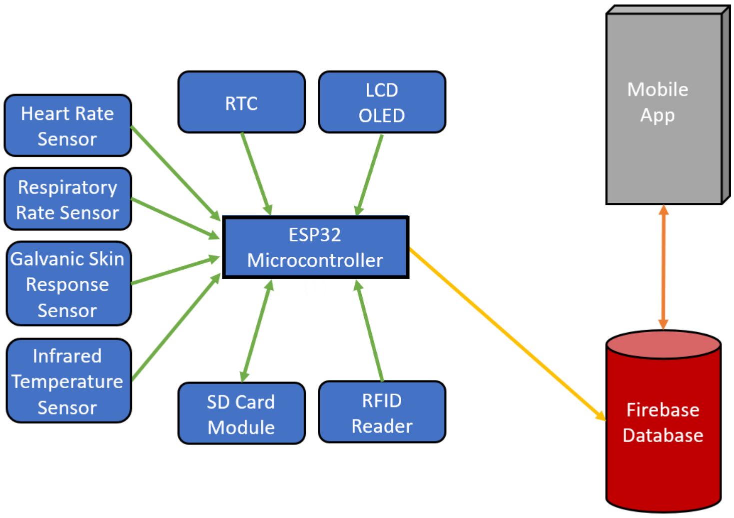


Figure 2 – System Architecture focused on the Embedded System. Highlighted in blue are the components of the embedded system, more precisely, the computing platform core (ESP32 microcontroller and modules), and the multichannel sensing unit (sensors). Highlighted in red is the database, having been chosen Google's Firebase. Highlighted in grey is the user interface, more precisely, the mobile application developed. Note that both the database and the mobile application will be addressed in the following chapters of this document.

In terms of user interaction, the embedded system requires the use of an RFID tag, in order to authenticate the user's data, and after the presentation of these tag, the system then starts its processes. In this system a simple user interface was also implemented, which presents several messages related to state changes, options for the user, operations performed, and disposition of the data obtained in real time, as can be seen in Figure 5 below. In this figure it is possible to observe the interactions between the system and the user, more precisely, the type of messages that will be generated by the state and type of system operations. Note that in red is the normal flow of the system, however, there are particular situations, as for example represented in blue, where the Real Time Clock (RTC) is not available, but there is SD memory card and Wi-Fi connection, which requires checking the existence of old data to send to the database. Represented in green, is the transition originated when the user presses the push button responsible for changing user.

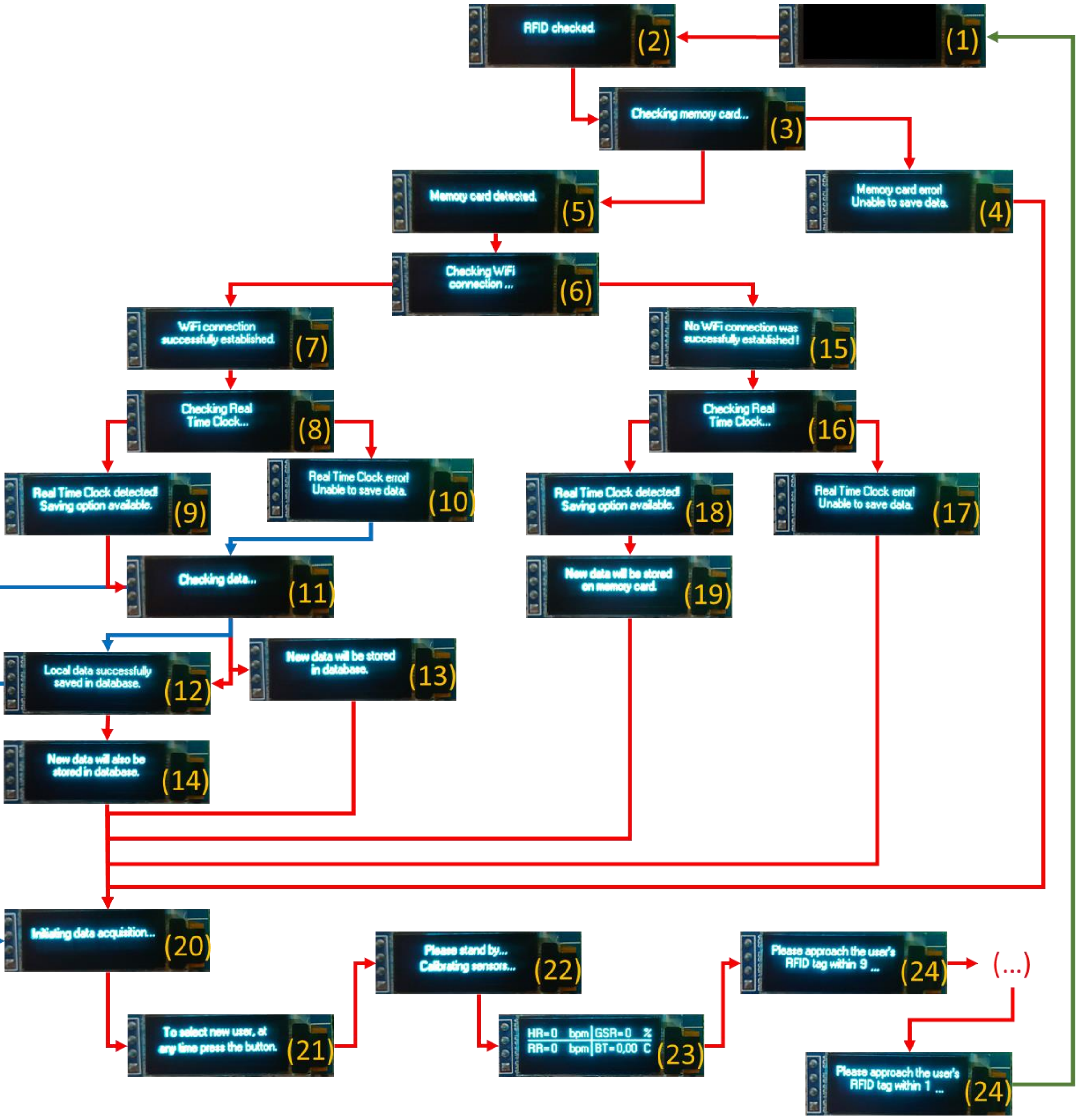


Figure 3 - Flow of the Embedded System User Interface

The type of messages displayed to users via the OLED LCD screen and shown in Figure 5 are numbered from 1 to 24, translating into the following states:

1) **Screen off** – the system only starts its processes after the user approaches its RFID tag.
2) **"RFID checked."** – the system recognises the RFID tag and starts its processes, starting by checking the existence of the SD memory card.
3) **"Checking memory card..."** – checking the existence of the SD memory card, responsible for storing the configuration file of the Wi-Fi access credentials and for storing the data obtained during the acquisition process, in case a Wi-Fi connection is not established. Please note that the file corresponding to the Wi-Fi access credentials will be explained in more detail in **subchapter 4.1.4** (SD Memory Card), presented later in this chapter.
4) **"Memory card error!"** – an SD memory card could not be detected or has problems, and therefore the system cannot establish a Wi-Fi connection or save data, and therefore the system proceeds directly to the data acquisition process (state 20).
5) **"Memory card detected."** – upon being able to detect a SD memory card, the system will check the Wi-Fi connection.
6) **"Checking WIFI connection..."** – the system will access the Wi-Fi access configuration file, in order to check if it is possible to successfully establish a connection with any of the connections registered in the file.
7) **"WIFI connection successfully established."** – success in establishing Wi-Fi connection, followed by checking for the existence of a Real Time Clock (RTC) at state 8.
8) **"Checking Real Time Clock..."** – it is necessary to check the existence of an RTC, in order to obtain a timestamp to associate with data acquisition. Note that this timestamp is made up of the year, month, day, hour, minute and second.
9) **"Real Time Clock Detected."** – when an RTC is detected, the option to save the data is enabled, and contrary to state 18, the data will be remotely saved in the database.
10) **"Real Time Clock Error!"** – when there is no RTC or an error in it, the system cannot save new data, however, given that to reach this state there was a SD memory card and Wi-Fi connection, it is possible that there is old data that needs to be sent to the database (state 11).

11) **"Checking data..."** – the system checks if there is old data on the SD memory card, and if so, sends it to the database, then deletes the file as the data has been moved to a remote storage. Note that if the RTC is not available and there is no old data to send to the database, the system will jump to state 20. If the RTC is not available, but there is old data to send to the database, the system goes to state 12 and then jumps to state 20. If the RTC is available and there is old data, it is sent to the database, followed by state 12, then state 14. If the RTC is available, but there is no old data to send to the database, then state 13 follows.
12) **"Local data successfully saved in database."** – is only to inform the user that there was old data on the SD memory card, and it was stored remotely in the database.
13) **"New data will be stored in database."** – there being no old data to send to the database, and the system having registered the successful establishment of a Wi-Fi connection, it informs the user that the new data to be acquired will be stored in database, proceeding to state 20.
14) **"New data will also be stored in database."** – originating from state 12, means that there were old data that were moved to the database, and as such, the system informs the user that new data to be acquired will also be stored in the database, proceeding to state 20.
15) **"No WIFI connection."** – in state 6 the possibility of establishing a Wi-Fi connection was checked, however when the process failed, the system advanced to state 15, which informs the user of these state, and then follows to state 16.
16) **"Checking Real Time Clock..."** – similarly to what occurs in state 8, here the existence of an RTC is verified. Note that to reach state 16 means that it was not possible to establish a Wi-Fi connection, and as such the data cannot be sent to the database for the moment.
17) **"Real Time Clock Error!"** – as in state 10, there is no RTC available, and therefore no new data can be saved, and as there is no Wi-Fi connection, it is also not possible to send existing old data to the database. In this way, the system jumps to the data acquisition process (state 20).
18) **"Real Time Clock Detected."** – similarly to state 9, the system informs the user that a RTC has been successfully detected, which then makes it possible to store new data on the SD memory card.
19) **"New data will be stored on memory card."** – given that there is no Wi-Fi connection but the RTC is available, the system informs the user that new data acquired in the future will be stored on the SD memory card.

20) **"Initiating data acquisition..."** – in this state the system starts the process of acquiring new data, informing the user of these state. Note that until reaching this state, the system has made several checks, and if there is no memory card or RTC, the system cannot save new data, which does not mean that the user cannot monitor its parameters, i.e., even if it is not possible to save data, the system always allows the user to monitor his/her heart rate, respiratory rate, GSR and body temperature, although in this way the purpose of the system is somewhat lost. If the user wishes, they can always record these parameters and enter them directly into the mobile application, although this is not very practical.
21) **"To select new user."** – the system informs that for monitor the parameters of a new user, the Push Button must be pressed, thus allowing to introduce a new RFID tag.
22) **"Calibrating sensors..."** – in this state the system calibrates the available sensors, and in the particular case of the temperature sensor, it acquires the ambient temperature, so that it can then acquire more accurately the user's body temperature.
23) **Data acquired in real-time** – in this state the user may visualise the parameters being acquired in real-time. It is also important to mention that during data acquisition, the embedded system will periodically check if it is possible to establish a Wi-Fi connection (if it is not already connected), or if the Wi-Fi connection has been terminated (if it is connected and the connection is terminated for some reason).
24) **Counter until the introduction of a new user** – this state is originated by the user pressing the Push Button, causing the system to finish acquiring data for the current user and to prepare for the introduction of a new user. The system then informs the current user that the new user must approach its own RFID tag within a specific time, which is a 10 second countdown. Finished this countdown, the system returns to state 1, waiting for the presentation of a viable RFID tag.

Regarding the development of the embedded system prototype, it underwent changes as the work progressed. In an initial phase, this system was based on a Breadboard, from which it was possible to gradually add components, in order to guarantee synchronism and smooth operation between them. If for some time the system required two microcontrollers to meet its needs, as the work evolved, several optimisations were carried out, of which the reduction in the number of microcontrollers stands out, i.e., the proposed prototype presents a single microcontroller capable of dealing with the complex functionalities of the system.

Figure 4 shows the first complete developed version of the embedded system, and besides the breadboard with the modules and sensors (in the case of the GSR sensor it includes the electrodes for the fingers, and in the case of the respiratory rate sensor it includes the module to be placed on the chest), it is also represented a fundamental component for the operation of the system, that is, the RFID tags (white cards and tokens on wristbands).

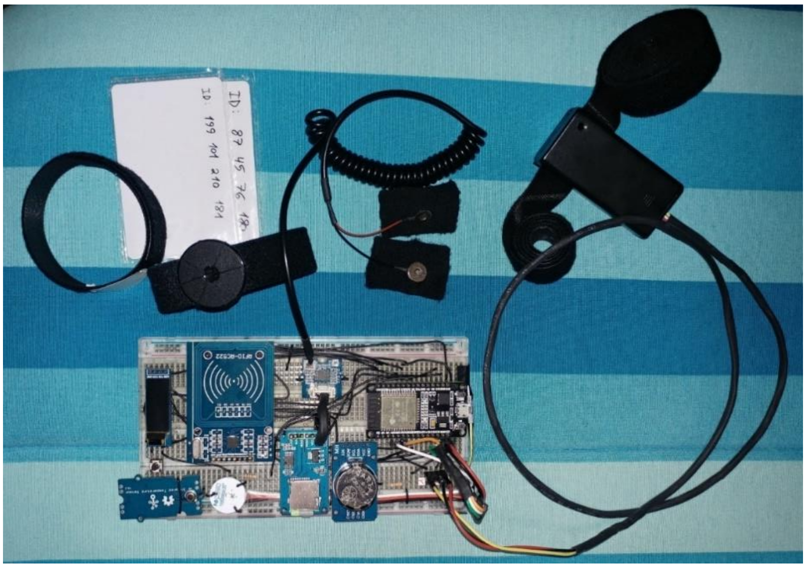


Figure 4 – Laboratory Version of the Embedded System

After the optimization of the developed embedded system, there was the need to create a more interactive and practical version, capable of being a more viable solution for users. To this end, the system migrated from its Breadboard-based version, to a more professional solution and different from the laboratory context, which resulted in the construction of a circuit based on a perforated board, as can be seen in Figure 5 below.

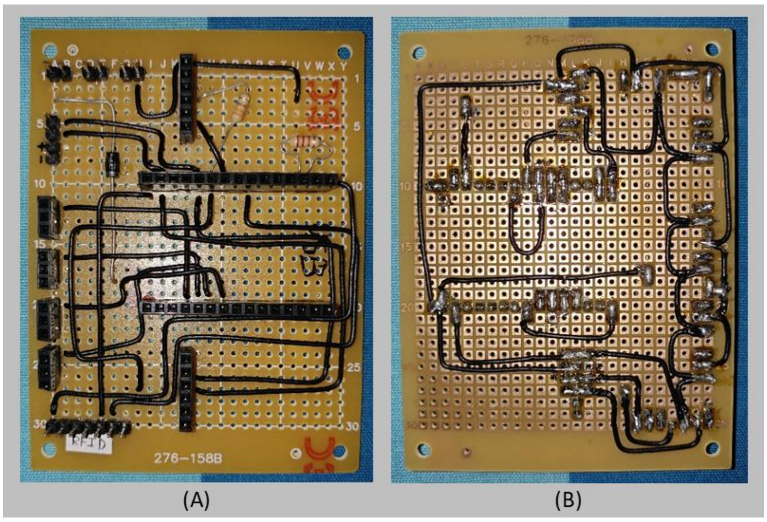


Figure 5 – Circuit implemented in the Perforated Board. Figure A represents the board seen from above, where the modules and microcontroller are fixed, as well as the headers where the sensor cables are connected. Figure B represents the board seen from below, where all the necessary soldering was performed.

The developed perforated plate is the main component of the embedded system, however, from the user's point of view there is a need to present something in a more beautiful and presentable format, and for that, the services of the Fabrication Laboratory (VFABLAB) of ISCTE were required, in particular, of the Architect João Sousa, who built the mould of the hand and pressed wood box that constitute the final prototype of the embedded system.

Figure 6 shows all the components of the embedded system. Highlighted in purple is the box and the hand mould where the perforated plate was mounted, as well as all the sensors, screen (responsible for informing the user of all the system states) and RFID tag reader (responsible for user authentication). Highlighted in red is the respiratory rate sensor, as well as the cable that allows connecting it to the rest of the system. Highlighted in yellow are the RFID tags, which are composed by cards and wristbands based on tokens. Highlighted in blue are the memory card, responsible for storing the data in case there is no Wi-Fi connection, and the Wi-Fi access credentials. Highlighted in green is the power cable, where the connection to the system is made via USB Type-C, while the other end of the cable features a normal USB plug.

Figure 6 – Embedded System Final Prototype

In Figure 7 it is possible to see the arrangement of sensors and modules, as well as the perforated board with some components and connections to the sensors and display. An important aspect to note is the fact that attention was paid to the fixing of the cables, thus allowing the box to be opened without damaging the connections or the system components.

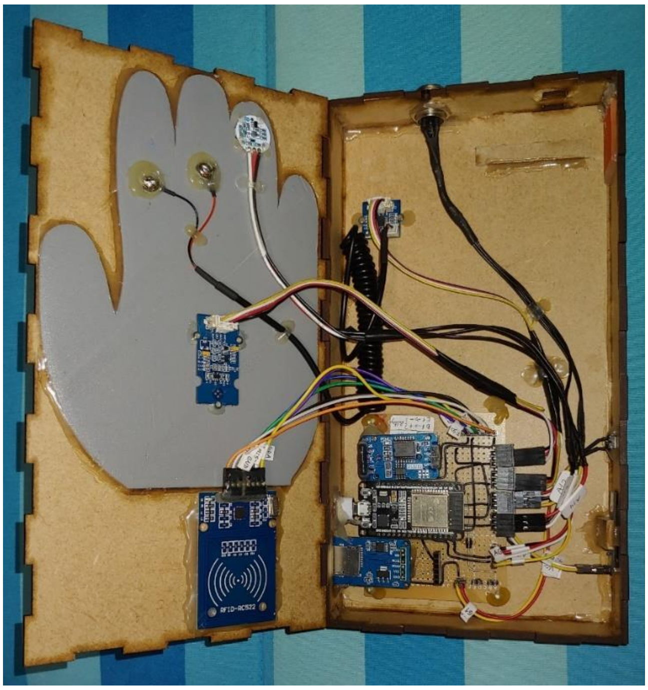


Figure 7 – Internal view of the Embedded System Final Prototype

Despite the care taken regarding the internal arrangement and fixing of the components, from the users' point of view, only the externally visible components are important, and as such, all these components have been clearly identified, which can be seen in the following Figure 8. This figure shows some important aspects of the final prototype, namely highlighted in red is the information screen of the system states, highlighted in yellow is the button to select a new user, highlighted in green is the USB Type-C connector for the system power supply, highlighted in purple is the SD memory card input, and highlighted in orange is the 3-pin connector to connect the respiratory rate sensor.

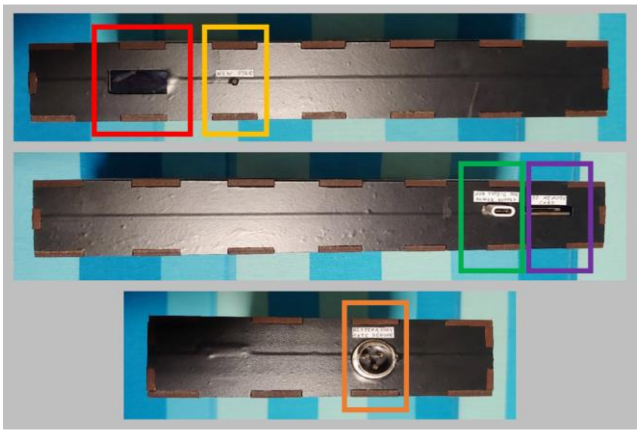


Figure 8 – External Side View of the Embedded System Final Prototype

4.2. Hardware

This subchapter specifies all the hardware components of the embedded system, as well as discussing important processes carried out during its development, such as the search for the most suitable heart rate sensor, the development of the respiratory rate sensor, the creation of RFID wearable tags, and the study about the system energy consumption and sizing of an internal battery.

As mentioned earlier, the embedded system involves several processes, some of them complex, which required the use of the following materials:

- **Heart Rate Sensor (Velleman WPSE340)** – plug-and-play sensor capable of real-time heart rate acquisition. This sensor works based on an analogue signal, not requiring any communication protocol, such as Inter Integrated Circuit (I2C) and Serial Peripheral Interface (SPI). In addition, it features a 16mm diameter, 3mm thickness, working voltage ranging from 3 to 5 volts, working current of 4mA (when voltage is 5 volts), and has 3 connections with cable lengths of 18cm. The 3 connections are for power (red cable), ground (black cable), and analog signal output (white cable) [69].

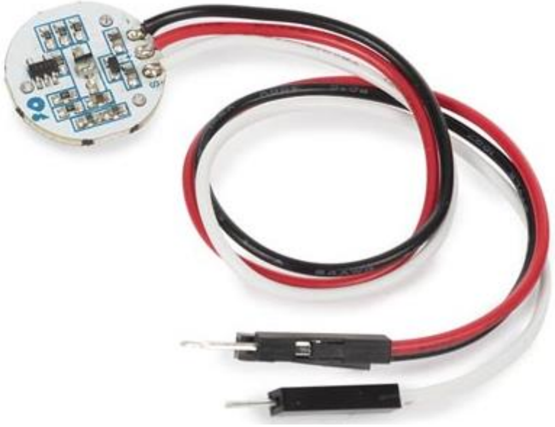


Figure 9 – Velleman WPSE230 sensor

- **Grove-GSR Sensor** – this sensor allows monitoring skin conductivity based on two electrodes connected to two fingers of one hand. The emotional changes that a person experiences cause changes to the amount of sweat produced by sweat glands, which varies the skin conductivity, i.e., the more stressed a person is, the greater the production of sweat, which in turn will contribute to the increase of the skin conductivity. Although this sensor can use the I2C communication protocol (4 cables), its typical operation involves only analog signals (3 cables). Its operation is quite simple and does not require too complex configurations, however, it must be calibrated manually, by means of the small screw embedded in the sensor module (potentiometer). Regarding the characteristics of the sensor, it has a working voltage that varies between 3.3 and 5 volts, dimensions of 2cm x 2cm, and has 4 connections with cable lengths of 20cm. Of the 4 connections only 3 are used, which relate to power supply (red cable), ground (black cable), and analog signal output (yellow cable).

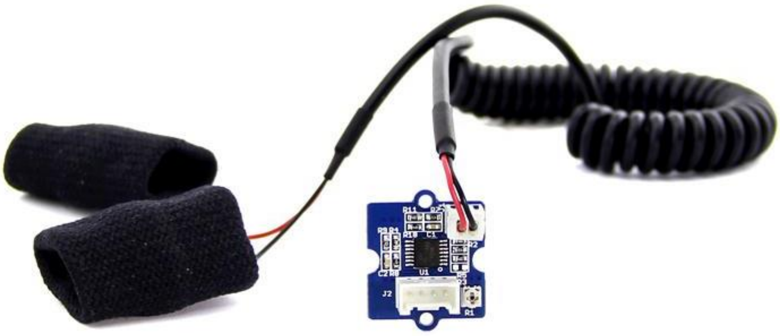


Figure 10 – GSR sensor

- **Respiratory Rate Sensor** – this sensor is a prototype developed in the laboratory and will be discussed in more detail in subchapter 4.2.2 of this document.

- **Infrared Temperature Sensor (Grove OTP-538U)** – this sensor allows non-contact temperature monitoring. The sensor is composed of 116 thermocouple elements in series in a floating micromembrane with an active diameter of 545µm and with a blackened surface to absorb the incident thermal infrared radiation, which induces a voltage response at the output terminals [70]. A particularity of this sensor, is that it does not require any communication protocol, working based on analogical signals, however, it allows to simultaneously measure the temperature of something in particular (object or person), and the surrounding temperature. This sensor can be used as a body thermometer, motion sensor, switch, distance meter, among other uses. As characteristics it presents a working voltage between 3 and 5 volts, power consumption less than 0.6mW, measurable temperature range between -10ºC and +100ºC, accuracy of +/- 2ºC, range of 9cm, and dimensions of 2cm x 4cm [70].

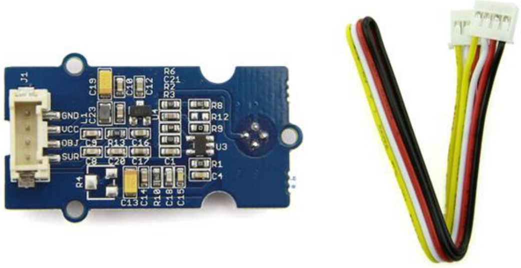


Figure 11 – Grove OTP-538U Sensor

- **RTC module (DS3231)** – this high precision real time clock module has a 32Kbit EEPROM memory unit, a 10bit temperature sensor with a resolution of 0.25ºC, a crystal oscillator with temperature compensation and the crystal itself [71]. In terms of usefulness in the proposed system, the DS3231 is extremely important in obtaining the timestamp associated with each acquired data. This module allows to acquire accurately the real time up to the second (year, month, day, day of the week, hours, minutes, and seconds), as well as to store this parameter thanks to the incorporation of a CR2032 battery. In addition, the DS3231 has two time of day alarms, digital output of the temperature sensor, and communication via I2C, with configurable address. An added value of this module is the operation in low power consumption, which thus increases the battery backup runtime [71].

Figure 12 – DS3231 RTC Module

- **RFID Reader Module (RC522)** – this module allows wireless communication at a frequency of 13.56MHz (classified as High Frequency) with RFID tags for the purpose of authentication of system users. This identifier number for authentication is associated to each data acquired by the system, as well as the timestamp obtained by the RTC Module. The acquisition of this module brought included proximity MIFARE cards, however, tokens embedded in wristbands were also used to facilitate user interaction. In terms of features, the RC522 only needs a 3.3 volts power supply, and has normal operating mode (power consumption between 13mA and 26mA), stand-by mode (power consumption between 10mA and 13mA), and sleep mode (peak current less than 30mA). This module communicates with the microcontroller through the SPI communication protocol, presenting a 10Mbit/s transfer rate. In terms of physical characteristics, it presents a dimension of 8.5cm x 5.5cm x 1cm, and a weight of 21g [72].

Figure 13 – RC522 RFID Module

- **MicroSD Card Reader Module** – this module allows reading and writing MicroSD memory cards, being compatible with a wide variety of microcontrollers. It communicates via SPI protocol and has a voltage regulator, thus allowing working with microcontrollers that provide a working voltage of 5 volts or 3.3 volts [73]. In the case of the proposed system, this module reads two types of file, being the first one related to the Wi-Fi network access credentials, which must be authenticated by the users. The second type of file concerns the storage of the user’s physiological parameters acquired by the system if no Wi-Fi connection is available to store the data remotely in the database. In this way, if a viable MicroSD card is presented, the system never loses data, even though a Wi-Fi connection may not be available. An interesting aspect of using this module and its memory card is that the system, before starting any data acquisition, checks whether there is data on the memory card to send to the database.

Figure 14 – MicroSD Memory Card Read/Write Module

- **ESP32 Microcontroller (NodeMcu Wi-Fi CP2102)** – due to the system's needs in enabling Wi-Fi and Bluetooth communications, as well as the computational weight required, there was a need to choose a microcontroller capable of handling these requirements, and as such, in terms of cost-benefits, the ESP32 microcontroller NodeMcu Wi-Fi CP2102 was chosen. Being the heart of the embedded system, the ESP32 processes the reading of RFID cards, checks the existence of memory cards, checks the RTC, tries to establish a Wi-Fi connection, reads and writes files on the SD memory card, processes the data acquired by the sensors, and also implements processing algorithms that allow to analyse, for example, the ECG waveform obtained by the heart rate sensor, allowing to detect the positioning of the finger, and to obtain the cardiac variability and respective heart rate. In the case of body temperature, the microcontroller performs an auto-calibration in order to eliminate all thermal noise from the surrounding environment, allowing to accurately detect the users' body temperature. Another important aspect is the fact that the system can generate a large amount of data in a single second, and in order not to overload the system with sending data in real-time to the database, or storing them in the SD memory card, an algorithm was implemented that calculates the averages every 10 seconds, which are then stored in the database or SD memory card.

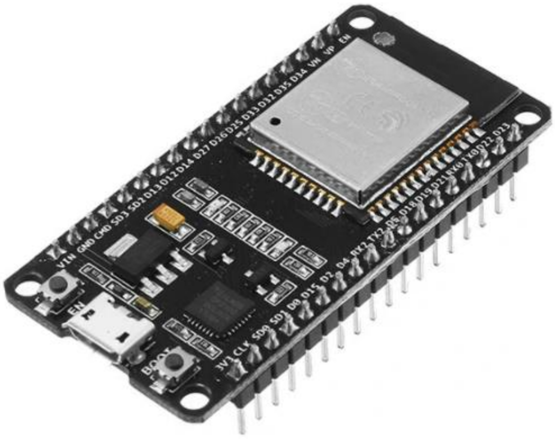


Figure 15 – ESP32 NodeMcu Microcontroller

Regarding the specifications of the ESP32 microcontroller used, the following are highlighted [74]:

- CPU: Xtensa Dual-Core 32-bit LX6
- Processor: Xtensa P2P 32-Bit LX6 Dual Core
- ROM: 448 Kbytes
- RAM: 520 Kbytes
- Flash: 4 MB
- Maximum Clock: 240 MHz
- Standard Wireless 802.11 b/g/n
- 2.4 GHz Wi-Fi connection
- Embedded antenna
- Micro-USB connector
- Wi-Fi Direct (P2P), P2P Discovery, P2P Group Owner mode and P2P Power Management
- Operating modes: STA/AP/STA+AP
- Bluetooth BLE 4.2
- 11 GPIO pins with functions PWM, I2C, SPI, among others
- Transfer rate: 110-460800bps
- Allows remote firmware upgrade
- Analogic Digital Converter (ADC)
- Distance between pins: 2.54mm
- Dimensions: 49 x 26 x 7 mm (length x width x height)

Besides the hardware components identified above, other more general components were also used, such as a SSD1306 display (0. 91'' LCD screen with 128x32 bits resolution), a 4-pin Push Button (to be pressed when a new user is to be inserted), a MicroSD memory card (in this case a card with 64Gb memory was used, however, any type of MicroSD card is compatible with the system), resistors (330Ω and 2.2KΩ), perforated board and male and female pin bars. It is also important to note the use of a Micro USB to USB Type-C adapter for powering the system. Note that the use of resistors is important for the proper functioning of the system, and this way, the 2.2 KΩ resistor is necessary for the Push Button to work, being this one interleaved between the Push Button and the Ground. The 330 Ω resistor is essential for both modules to communicate with the microcontroller according to the SPI protocol, i.e., as the RFID module has a working voltage of 3.3 volts and the memory card module 5 volts working voltage, this resistor between the SD memory card module and the MISO line serves to lower the working voltage of the latter, thus allowing both modules (slaves) to be heard by the microcontroller (master).

Regarding the arrangement of all hardware components, this was done according to Figure 16, where red colour corresponds to a voltage of 5 volts. Black colour corresponds to Ground. Green colour corresponds to Serial Data (I2C protocol), connected to the microcontroller GPIO21 pin. Blue colour connected to pin GPIO22 corresponds to Serial Clock Line (I2C protocol). Green colour connected to GSR Sensor corresponds to its Analog Input. Blue colour connected to the Respiratory Rate Sensor corresponds to its Analog Input. Orange colour connected to the RFID Reader corresponds to a voltage of 3.3 volts. Yellow colour that is connected to the Push Button, serves as Input Signal. Bright Blue colour connected to the GPIO23 pin corresponds to MOSI (Master Out Slave In, SPI protocol), allowing the modules (slaves) to listen to the microcontroller (master). Pink colour connected to pin GPIO19 corresponds to MISO (Master In Slave Out, SPI protocol), allowing the microcontroller (master) to listen to the modules (slaves). Purple colour connected to the GPIO18 pin corresponds to Serial Clock line (SPI protocol). Grey colour connected to the SD memory card module corresponds to the Chip Select functionality. Brown colour interleaved between the Ground and the Push Button resistor was necessary, because connecting this resistor to the Ground line shared by all the modules and sensors would cause an attenuation of the operating voltage and consequently their improper/erratic operation. Beige colour connected to the Thermometer corresponds to its Analog Input. Grey colour connected to Heart Rate Sensor corresponds to its Analog Input. Purple colour between pin 25 and pin EN, both of the microcontroller, enables the reset operation of the microcontroller, thus allowing a new user to be introduced to the system.

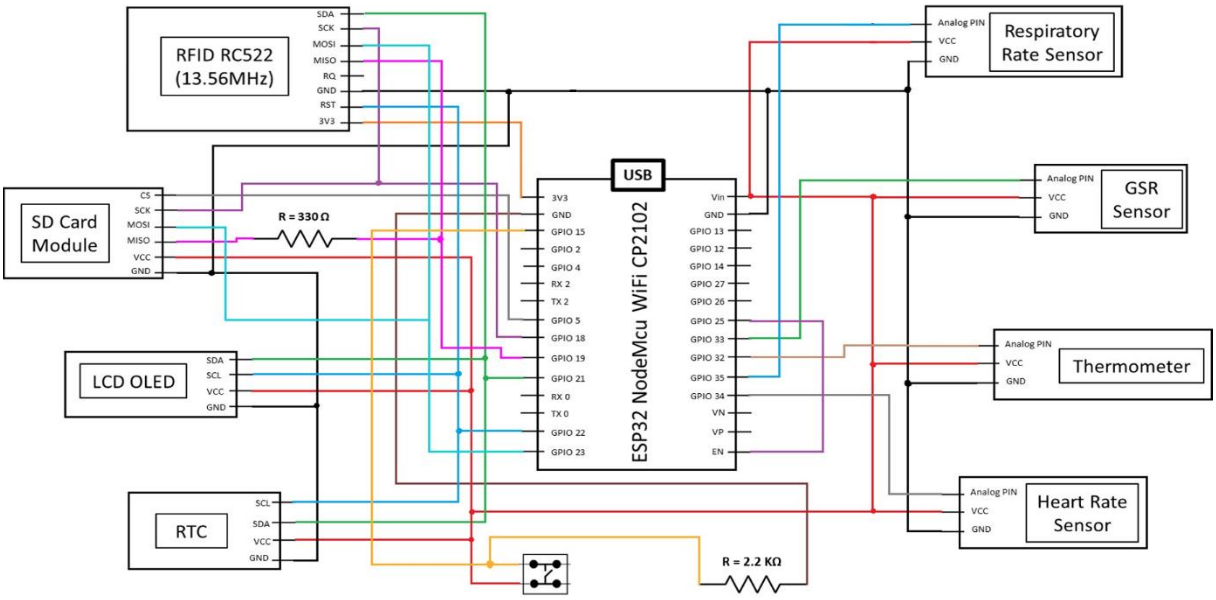


Figure 16 - Multichannel Sensing System Connection Block Diagram

4.2.1 Heart Rate Sensor

The development of a model for heart rate calculation was a process that suffered some changes during the course of this thesis, in most cases due to the sensor incompatibility with the rest of the system.

The first heart rate sensor used was the MAX30100, embedded in the M5Stack HEART module. This sensor allows obtaining both heart rate and SpO2 values, however, for the purpose of the presented system, this last parameter did not add any value, since in most situations it is used as a physiological parameter associated with respiratory diseases, which is not something explored in this work. Regarding its specifications, the MAX30100 sensor uses the I2C communication protocol, programmable sampling rate, saving LED current, advanced functionality to improve measurement performance, fast data output capability, GROVE interface, compatibility with Arduino-style microcontrollers and drilling for fixing [75].

Figure 17 – M5Stack HEART sensor

The MAX30100 sensor is very intuitive to use and facilitates its implementation in an embedded system, however, it presents some limitations in terms of libraries, making impossible the correct operation with other type of sensors that are also complex, which is the case of the proposed system. In reality what happened was that the MAX30100 took all the I2C communication to itself, which means, it had to be constantly in contact with the microcontroller, that if it divided part of its time to get values from another sensor, putting the MAX30100 on hold, it would freeze and never get values again, unless the microcontroller was reset, resetting the sensor.

Since the MAX30100 sensor is very sensitive and requires constant attention from the microcontroller, a solution was adopted to get the raw values from the sensor, i.e., the photodetector and emitter LED analogue inputs. This model converted the raw values to beats per minute values, using a developed algorithm. Regarding the libraries, the ones for obtaining the raw values allowed to restart the communication pipe, and this way the sensor would no longer freeze and would work in a reasonable way, considering that the obtained values were estimates resulting from the operation of the developed algorithm.

In the final model for the operation of this sensor, the values obtained were acceptable, although not ideal, and furthermore, the fact that the MAX30100 used the I2C protocol, made it difficult to synchronise with the other sensors, which made it necessary to abandon this sensor and start using the heart rate sensor Velleman WPSE340, previously presented in subchapter 4.2. (Hardware) of this document.

The WPSE340 sensor is actually a sensor capable of obtaining the ECG signal, making it a very viable solution for obtaining heart rate and other important parameters such as HRV. The only less good aspect of this sensor is the fact that it does not provide any library capable of displaying already worked values. Thus, all the code implementation associated with this sensor had to be done during the course of this thesis and will be addressed later in subchapter 4.3 (Software) of this document.

Briefly, 3 methods were implemented for this sensor, being one responsible for detecting the positioning of the finger on the sensor, another responsible for analysing the ECG signal and return values for heart rate, and the third method responsible for obtaining averages of 10 in 10 seconds for heart rate.

4.2.2 Respiratory Rate Sensor

In a first attempt to estimate the respiratory rate, a method was created using an integrated circuit with a high sensitivity thermistor (LM335Z) at the exit of the nostrils of the user. This way, when a person exhales, they would release hot air from their lungs, which would result in an increase in the temperature detected by the LM335Z. On the other hand, a person inhaling, would inhale the outside air with a lower temperature than the air expelled from the lungs. These temperature variations detected by the LM335Z would allow to create a model for the detection of the number of breaths, i.e., whenever the temperature decreased and then increased, the counter implemented in the microcontroller would be incremented, and as such, after 60 seconds, the system would be able to display the number of breaths per minute.

The problem with this first method, is that although the LM335Z would be quite sensitive to temperature rise, it is much more difficult to verify rapid drops in temperature, unless some mechanisms were introduced to assist the sensor cooling, but such an option would put into question the efficiency and accuracy of the data obtained.

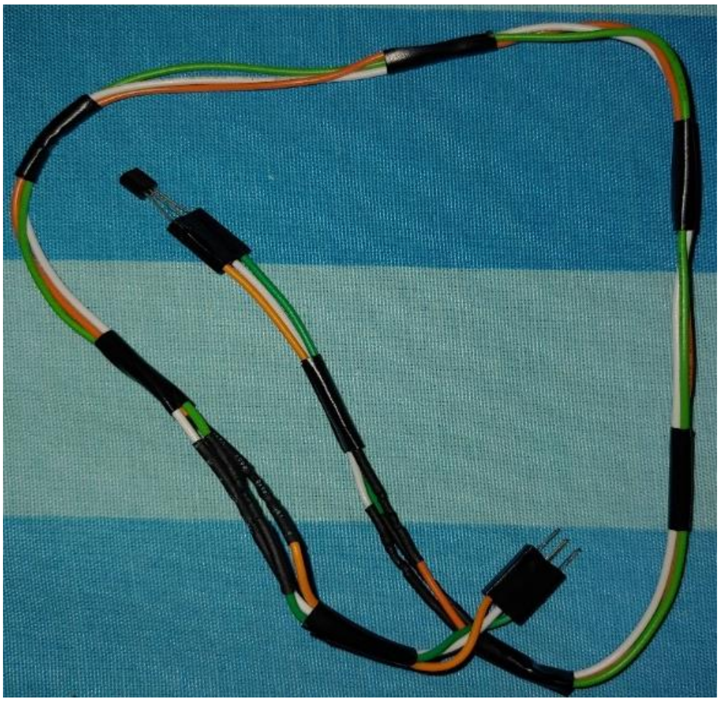


Figure 18 - First Respiratory Rate Sensor Prototype

In a second attempt to estimate the respiratory rate, a method was created which used a pressure sensor attached to an elastic strap positioned on the user's chest. In this way, whenever the user inhaled, the air would fill the lungs, which would result in an increase in the volume of the thoracic cage, thus increasing the pressure exerted on the sensor which would be positioned between the elastic strap and the user's chest. Whenever the sensor detected a certain level of pressure, it would increase the counter implemented in the microcontroller, and at the end of the 60 seconds of measurement, the value stored in the counter would correspond to the number of breaths per minute.

The problem with this second method is that human tissue is not rigid enough, i.e., even if the elastic strap was replaced by a fixed strap, it would have to be adjusted to be very tight, which would cause discomfort to the user. In addition, the user would have to use one of his/her hands to press the sensor, that is, the increase in the volume of the thoracic cage would press the sensor against the user's hand, thus obtaining readings of the force exerted.

In a third attempt to estimate the respiratory rate, a method was created using an accelerometer attached to an elastic strap positioned on the user's chest. In this way, whenever the user inhaled, the air filled the lungs, resulting in an increase in the volume of the thoracic cage, varying the three axes of the accelerometer. Of these three axes, only the measurements from one (z axis) were used, something that occurred due to the specific positioning of the accelerometer on the tape. Whenever the z axis values suffered changes, these were processed in order to estimate the movements of inspiration and expiration, thus resulting in the counting of the number of breaths.

This method was developed considering measurement intervals lasting 10 seconds, from which a differentiation of inspiration and expiration movements was performed, followed by the estimation of the same values for a 60 second interval. This estimation presented acceptable values, however, the ideal interval for obtaining such values would be 60 seconds, which theoretically would correspond to obtaining accurate and adequate values for the analysis of respiratory rate, and not something converted for the effect. Thus, this change was made in the system, which in turn began to present an unpredictable and random behaviour, consequently affecting the processing of data from the accelerometer, and not even with the implementation of filters and noise attenuation it was possible to correct, thus making the use of this method unfeasible.

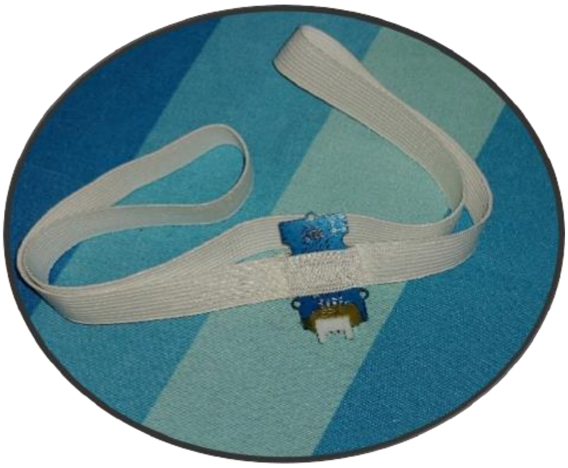


Figure 19 – Second Respiratory Rate Sensor Prototype. This prototype had a white elastic band to position the accelerometer near the user's chest, and by the accelerometer itself. Regarding the specifications of the accelerometer (MPU-9250), it also works as a gyroscope, having 9 measurement axes. The MPU-9250 has three 16-bit ADCs to digitize the magnetometer outputs, low power consumption, low cost, and high performance with a wide detection range [76].

The methods presented above were all considered in the development of a sensor to monitor the respiratory rate, however, all of them presented limitations that ended up making their use unfeasible. In this way, and based on research in scientific articles, it became clear that an efficient method could pass through the analysis of ECG and PPG signals, which would require the use of self-adhesive electrodes positioned on the individual’s skin, or a system capable of analysing the complex shape of the ECG waves obtained, for example, through a heart rate sensor.

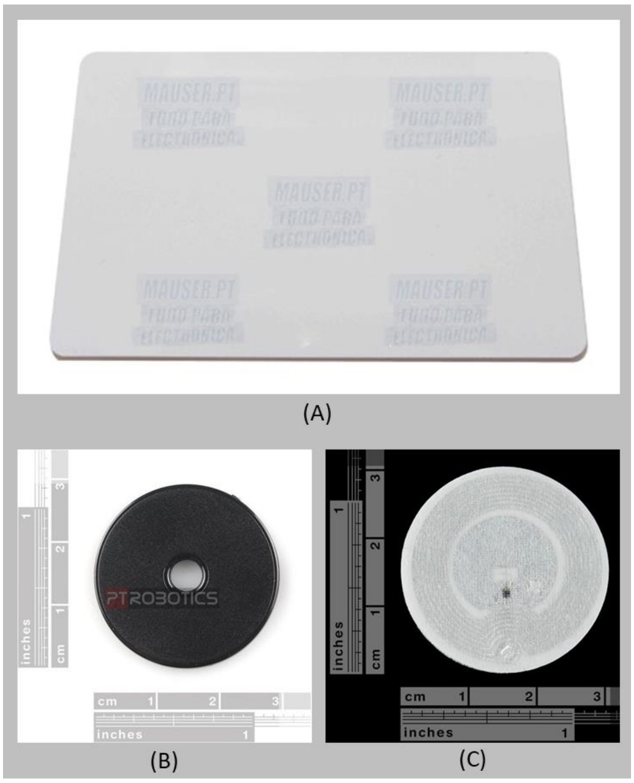
Considering the computational burden that using ECG and PPG could bring to the system, as well as the problems identified with using the previous models proposed to acquire respiratory rate, the solution adopted is a culmination of experiments, i.e., several concepts were considered, among them some present in the previously tried methods. For this solution, the components were arranged inside a small module, to which the cable establishing the communication between sensor and microcontroller is connected. This module when placed on the user's chest, is able to count the number of breaths in real-time. Note that this sensor was developed during this master thesis as an isolated project, able to be integrated in the proposed system. Due to the innovation brought by this sensor, a patent application is something to be considered, which has not yet occurred at the date of this thesis. Considering these circumstances, it was not possible to include in this document more details about the operation, components, and internal appearance of this sensor.

Figure 20 – Final Prototype of the Respiratory Rate Sensor. This prototype consists of a module that includes the use of sensors and mechanisms in order to estimate the respiratory rate in real-time. Furthermore, a Velcro strap was chosen instead of the typical elastic bands, which gives more rigidity, but more flexibility in the adjustment.

4.2.3 RFID Tags

User authentication is an important aspect of the proposed embedded system, and for its implementation, as previously mentioned, the RC522 RFID reader module was used, which operates at a frequency of 13.56 MHz (High Frequency). This detail is fundamental when it comes to RFID tags because only tags operating at the same frequency can be detected by the reader module. In the particular case of this system, only passive tags were used (no battery is required, so when they are brought close to the reader, they receive an induced current that activates them, returning a unique identification code), more specifically three types of tags, being MIFARE Proximity Cards, MIFARE 1K Tokens, and MIFARE Classic Stickers, as can be visualised in Figure 21 below.

In Figure 21, the tag represented in "A" is the example of MIFARE proximity cards, which are characterized by their weight of 6g, dimensions 54x85 mm and PVC (synthetic plastic polymer) material [77]. The tag represented in "B" is the example of Tokens, which are characterized by their storage capacity of 1Kb, and can be read or written by compatible devices [78]. The type of RFID tag "B" is mostly used to store data, however, due to its 30mm diameter and 2.25mm thickness, it becomes ideal for solutions where something small and unnoticed is required. The tag represented in "C" is the example of MIFARE Classic Stickers, and in terms of characteristics, it is quite similar to the Tokens presented in "B", also containing a data storage capacity of 1Kb, but unlike the "B" tags, these are compatible with NFC technology [79]. RFID tag type "C" is mostly used for data storage, however, due to its 30mm diameter and 0.4mm thickness, it becomes ideal for solutions where something small and unnoticeable is required, especially as this type of tag is an adhesive that is easy to place on most surfaces, including human skin.



(A)

(B)

(C)

Figure 21 – Passive RFID tags used as a Form of Authentication

In order to simplify even more the system authentication method, it was sought to acquire RFID tags in wristbands format, allowing users to go through their daily routine without the need to carry a card all the time, however, there is a great demand in the market for this kind of wearable, being impossible to acquire any. In this way, were developed homemade wearable devices with RFID tags embedded, and for that, MIFARE Tokens and MIFARE Classic Stickers were used, positioned in adjustable Velcro strips to fit the wrist of each user, as can be seen in Figure 22 below.

In Figure 22, represented in "A" are the two types of RFID wearable created, arranged on its full length, being one based on MIFARE Classic Stickers (white circular sticker), and the other based on MIFARE Tokens (black circular token). Represented in "B" is the RFID wearable based on MIFARE Classic Stickers. Represented in "C" is the wearable based on MIFARE Tokens.

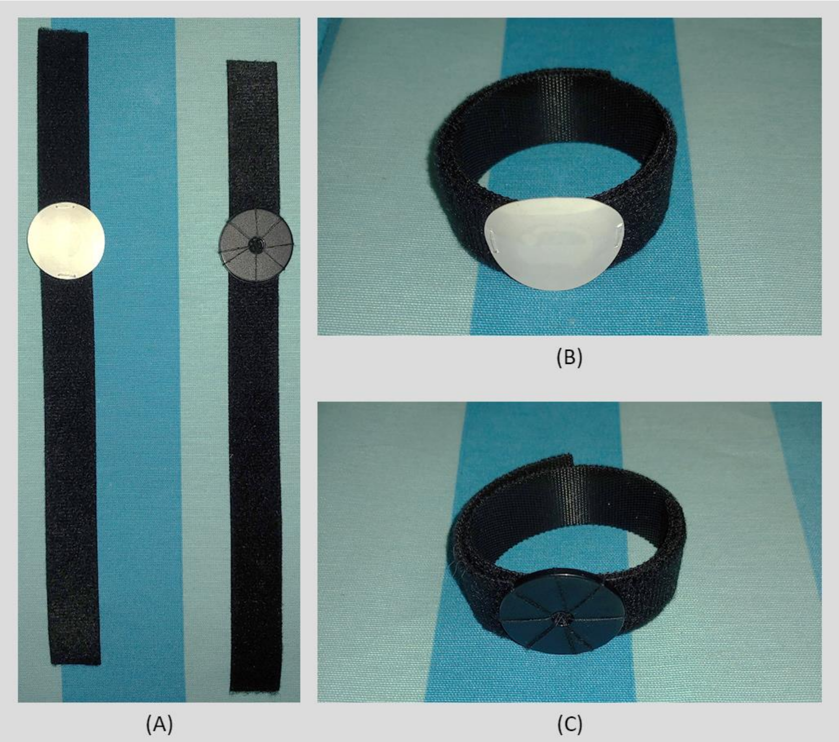


Figure 22 – RFID Wearables Built

4.2.4 Energy Consumption and Battery used

As previously mentioned, an important aspect of the proposed system is mobility, however, with this concept also comes the concept of autonomy, and as such, it was considered the incorporation of an internal battery in the system, in order to enable its correct operation without requiring external power, except for the battery charging process.

In this study regarding the system energy consumption and respective planning for the introduction of an internal battery in order to fulfil the system needs, the Chauvin Arnoux multimeter model CADI-2, presented in Figure 23, was used. Note that due to the age of the equipment, it was not possible to find its specifications, however, it is important to mention that despite the age, this equipment continues to work properly, being a very accurate equipment and presenting more reliable results than a large number of more recent multimeters.

Chauvin Arnoux multimeter was used to measure the electric consumption of the system, collecting values relative to electric voltage and current. This equipment allows the measurement of several parameters, such as continuous electrical voltage, alternating electrical voltage, electrical resistance, continuity between two points, diode value, continuous electrical current, alternating electrical current, among others. In addition to the diversity of parameters, this equipment also allows obtaining values in various scales, for example, volts and millivolts (V and mV respectively), or ohms, kiloohms and megaohms (Ω, kΩ and MΩ, respectively).

Figure 23 – Chauvin Arnoux Multimeter Model CADI-2

Regarding the study about the energy consumption of the embedded system and sizing of a battery capable of meeting its needs, it is important to determine the time that a battery would last considering the capacity of the battery itself and the electrical discharge current of the system, i.e., the duration of a battery is given by the following Equation 1.

$$\Delta t = \frac{C}{I} \tag{1}$$

The field "C" of Equation 1 concerns the battery capacity, its value being expressed in milliamperes per hour (mA.H) and made known in the battery specifications. The field "I" of Equation 1 refers to the system discharge current, its value being expressed in milliamperes (mA). These values must be obtained by equipment capable of monitoring the electric current, which is the case of oscilloscopes and multimeters. To determine the system discharge current, it is necessary to determine the input current and the output current, as represented in Figure 24 below. Note that I1 represents the electrical current entering the system, and I2 represents the electrical current at the output of the system. Through the variation between I1 and I2, it is possible to determine the system discharge current.

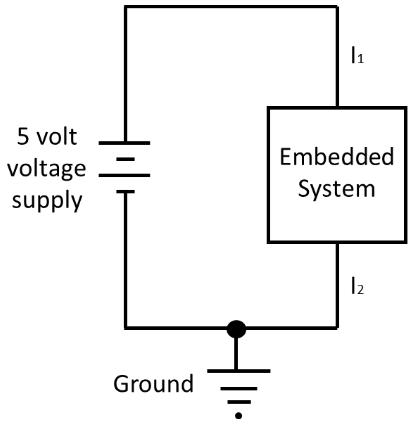


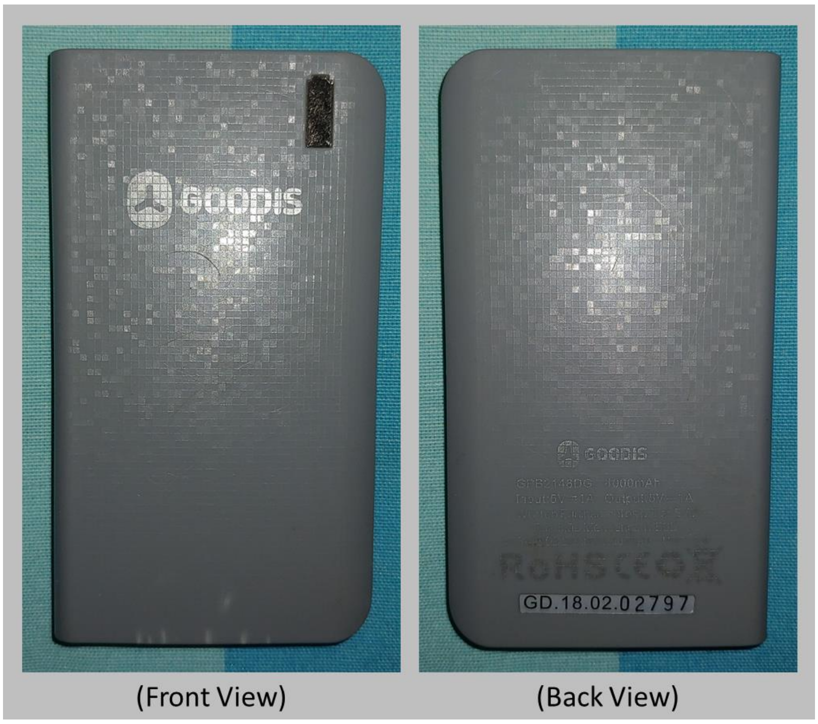
Figure 24 – Simplified Electrical Diagram of the Embedded System

Using the multimeter, it was possible to determine that the input current (I1) is 70 mA, however, the output current (I2) varies depending on the state in which the system is, i.e., there are certain operations performed by the system which result in greater energy consumption and respective increase in the discharge current, and as such, the output current varies between 15.15 mA and 17.36 mA. Thus, the discharge current of the system is given by the difference between the input current and the output current (Equation 2).

$$\mathrm{I} = \mathrm{I1} - \mathrm{I2} \tag{2}$$

Applying Equation 2, results that the maximum discharge current is 54.85 mA, while the minimum discharge current is 52.64 mA. Admitting that the battery capacity is 4000 mA.H, and the discharge current is given by Equation 2, applying Equation 1 results that the maximum battery life (maximum autonomy of the system) is approximately 3.166 days, while the minimum battery life (minimum autonomy of the system) is approximately 3.039 days. Note that the proposed system will not operate 24 hours a day, and as such, it is likely that the autonomy of the system will be greater than the values indicated.

Regarding the battery in use, it was decided to use a battery from GOODIS GPB2148DG Powerbank, as well as its integrated circuit for voltage regulation and battery charging. This Powerbank features a capacity of 4000 mA.H, 5 volts input voltage, 1 amp input current, 5 volts output voltage and 1 amp output voltage.



(Front View) (Back View)

Figure 25 - GOODIS GPB2148DG Powerbank

The first battery chosen and considering the sizing performed for a 4000 mA.H battery, was the GOODIS GP2148DG Powerbank battery. After preliminary tests, it was found that the battery of this Powerbank did not allow the correct operation of the system, because although on the outside is visible the reference to an output voltage of 5 volts, the battery itself only had a voltage of 3.7 volts. The inclusion of the voltage rectification circuit should compensate for this aspect of the voltage, however, the combination of the 3.7 volts with the output current of 1 amp, consequently affected the correct operation of the system, especially the operation of the heart rate sensor, which due to the LED emitter and the photodetector, presented a higher energy consumption that was not supported by the battery in question.

The second battery to consider was the GOODIS GPB4316GR Powerbank battery, which had a capacity of 10400 mA.H. Although the exterior of this Powerbank refers to an output voltage of 5 volts, the battery itself had 4.5 volts, which combined with an output current of 1 amp or 2 amps, allowed the correct operation of the system. The only negative aspect, and that made it impossible to use the battery in question, was the fact that the system consumption was not enough for the integrated circuit of the Powerbank to detect the presence of any device, and as such, it was constantly turning off (Powerbank mechanism with timing in order to avoid being always on if there was no device connected).

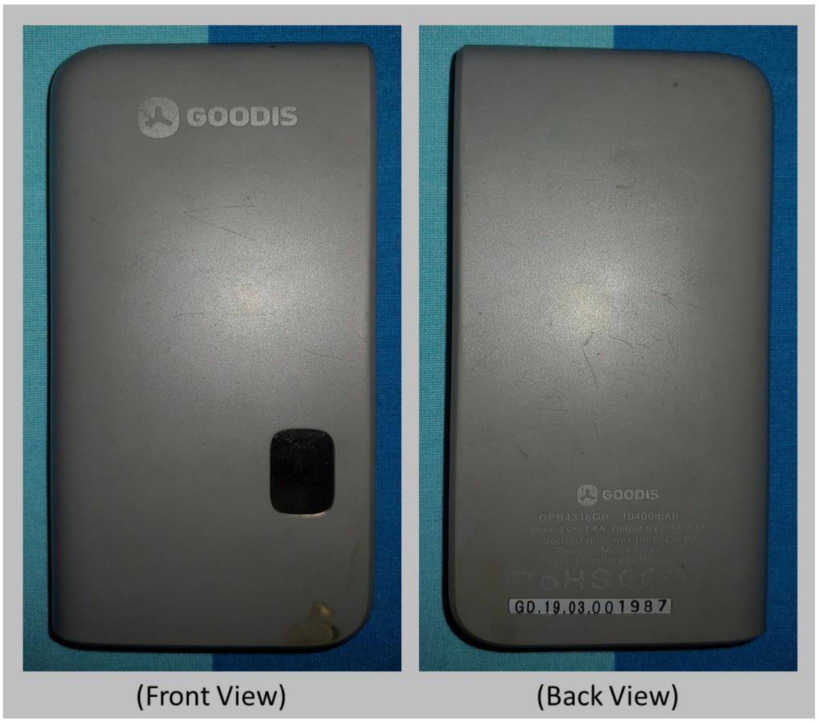


Figure 26 - GOODIS GPB4316GR Powerbank

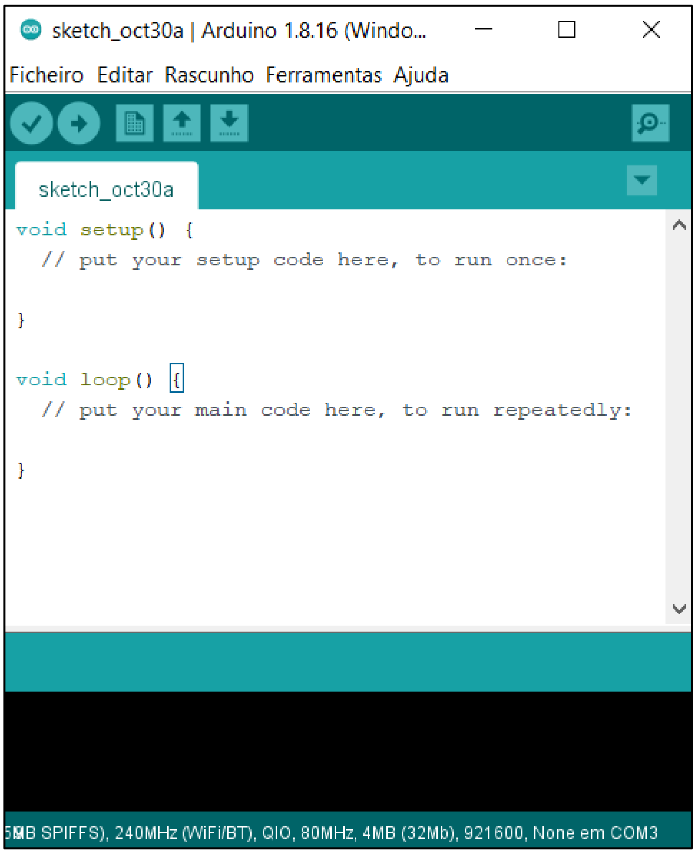
Considering all the problems encountered with the adaptation of a Powerbank as power supply source for the system, it was decided to introduce the Micro USB to USB Type-C adapter, thus making it possible to power the system externally through any energy source that features USB Type-C, which may be a Powerbank, computer, USB socket, smartphone charger, among others. Note that in the future, it would be interesting to conduct a study in order to incorporate an internal battery in the system, as well as the development of a circuit for charging and regulating the output voltage in order to properly connect the battery and the system.

4.3. Software

After connecting all the components that are part of the hardware, it is fundamental to deal with their programming, especially if the components are not plug-and-play style (as is the case in the proposed system). Another important aspect is the use of the MicroSD memory card, which requires a brief configuration regarding Wi-Fi connections. Thus, following this subchapter, the software used by the components of the embedded system will be discussed, as well as the configuration of the MicroSD memory card.

4.3.1. Components Programming

In order to programme the embedded system components, the Arduino IDE (Integrated Development Environment) platform was used, which can be easily downloaded from the Arduino website and easily installed on any computer. This platform enables code to be written using C and C++ language, which, after being compiled to detect errors, is loaded onto any Arduino-compatible board, which is the case with the ESP32 microcontroller used in the proposed embedded system.

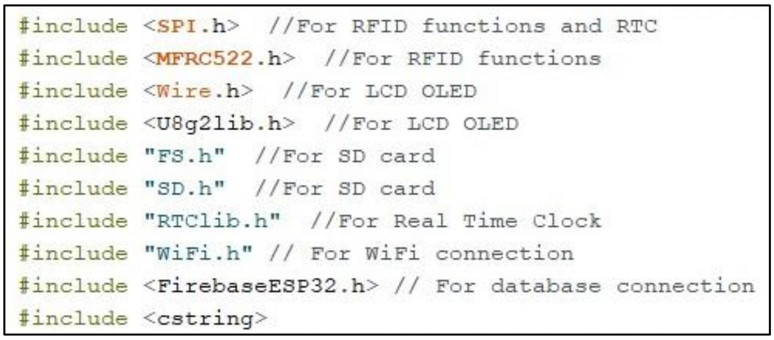


```
void setup() {
  // put your setup code here, to run once:

}

void loop() {
  // put your main code here, to run repeatedly:

}
```

```
5MB SPIFFS), 240MHz (WiFi/BT), QIO, 80MHz, 4MB (32Mb), 921600, None em COM3
```

Figure 27 – New File opened in the Arduino IDE Platform. With the Arduino IDE platform installed on a computer, when opened it displays the view shown in this Figure. Note that the "setup()" function is responsible for initializing the components, while the "loop()" function is responsible for the routines to be performed by the microcontroller while it is running.

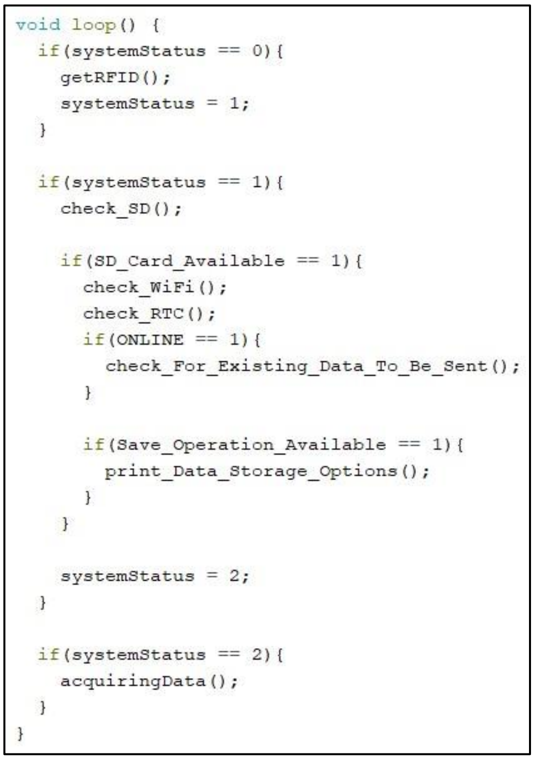
A very important aspect that concerns the components programming are the libraries required for their operation. Typically, all components that use communication protocols need to import libraries that simplify the use of each component. The "SPI.h" library is required for modules that use the SPI communication protocol, which is the case of the RFID reader module and the RTC. Although the RFID reader module needs the "SPI.h" library, this component also needs the "MFRC522.h" library, which allows to invoke predefined functions for the correct operation of this module. Although the RTC needs the "SPI.h" library, this component also needs the "RTClib.h" library, which allows to invoke predefined functions for the correct operation of this component. In the case of the OLED LCD display, this uses the I2C communication protocol, thus needing to import the library "Wire.h", in addition to the specific library for this component ("U8g2lib.h"). In the case of the module for reading/writing MicroSD memory cards, it needs to import the libraries "SD.h" (for writing and reading SD memory cards) and "FS.h" (file system wrapper). The import "cstring" allows to manipulate strings in the C language. In addition, and although the ESP32 microcontroller already has integrated the Wi-Fi module internally, it is necessary to import the library "WiFi.h". Another necessary import is related to the library that enables connection to Firebase specified for ESP32 microcontrollers ("FirebaseESP32.h").



```
#include <SPI.h>  //For RFID functions and RTC
#include <MFRC522.h>  //For RFID functions
#include <Wire.h>  //For LCD OLED
#include <U8g2lib.h>  //For LCD OLED
#include "FS.h"  //For SD card
#include "SD.h"  //For SD card
#include "RTClib.h"  //For Real Time Clock
#include "WiFi.h" // For WiFi connection
#include <FirebaseESP32.h> // For database connection
#include <cstring>
```

Figure 28 – Imported Library for Programming the Embedded System

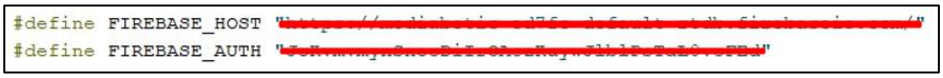
Regarding the "loop()" function (Figure 29 below), it performs infinitely as long as the microcontroller has a power supply, however, in more complex systems like the embedded system in question, there is the need to establish global variables that represent system states, so that within the "loop()" not everything is repeated infinitely, but depending on certain states, certain functions are run. So that the "loop()" function doesn't always repeat all the programmed functions, some global control variables were created, like the "systemStatus". This way, depending on the state, only a specific set of functions runs at that instant. In the "systemStatus==0" state, the RFID tag verification is performed, and only when an operational tag is identified, the state in question changes to "systemStatus==1". In the "systemStatus==1" state, the existence of the MicroSD memory card is checked, and if this is available, the establishment of a Wi-Fi connection is attempted and the existence of an RTC is checked. If a Wi-Fi connection is successfully established ("ONLINE==1"), the existence of data on the memory card to be sent to the database is checked. In the "systemStatus==2" state, all the procedures necessary for data acquisition are carried out.



```
void loop() {
  if(systemStatus == 0){
    getRFID();
    systemStatus = 1;
  }

  if(systemStatus == 1){
    check_SD();

    if(SD_Card_Available == 1){
      check_WiFi();
      check_RTC();
      if(ONLINE == 1){
        check_For_Existing_Data_To_Be_Sent();
      }

      if(Save_Operation_Available == 1){
        print_Data_Storage_Options();
      }
    }

    systemStatus = 2;
  }

  if(systemStatus == 2){
    acquiringData();
  }
}
```

Figure 29 – Microcontroller Loop Function

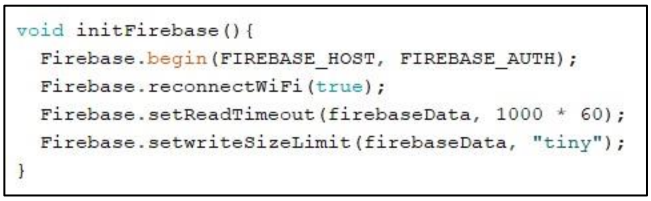
Another important aspect of this system is the preference for remote data storage in the Database (Firebase), and as such, it must be able to establish an authenticated connection with Firebase, requiring a host (HOST) and an authentication (AUTH) keys, as can be seen in the following Figure 30. Note that for security reasons, both access credentials have been censored in red.



```
#define FIREBASE_HOST "[redacted]"
#define FIREBASE_AUTH "[redacted]"
```

Figure 30 – Authentication Credentials for Accessing the Firebase Database

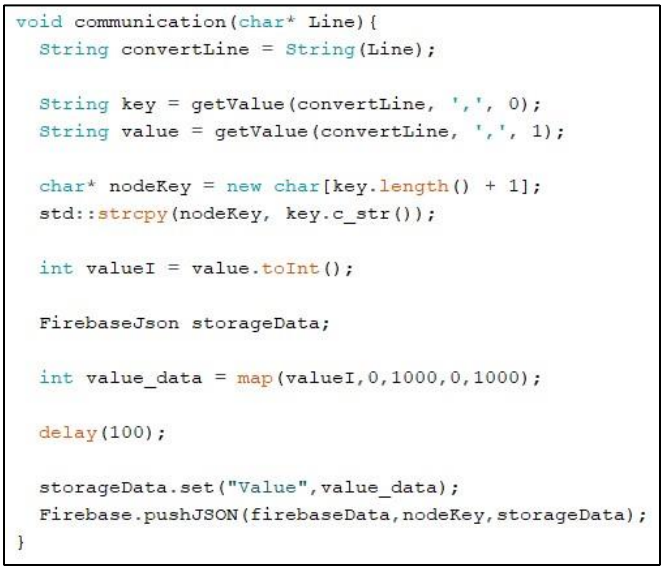
Once the host and authentication key are defined, whenever a system routine invokes the Firebase database connection initialisation function it must also invoke FIREBASE_HOST and FIREBASE_AUTH, as shown in the following Figure 31.



```
void initFirebase(){
  Firebase.begin(FIREBASE_HOST, FIREBASE_AUTH);
  Firebase.reconnectWiFi(true);
  Firebase.setReadTimeout(firebaseData, 1000 * 60);
  Firebase.setwriteSizeLimit(firebaseData, "tiny");
}
```

Figure 31 – Function for Initialising the Connection between Microcontroller and Firebase

Whenever the system tries to send data to the Firebase database, it must first check if there is any Wi-Fi connection previously established, and if so, the system must then initialise the connection to the Firebase database through the "initFirebase()" function. Once the connection to the Firebase database is established, data is sent by invoking the "communication(data)" function, which can be seen in detail in Figure 32 below. This function initialises a JSON File, fills it properly with data and identifying tags and sends it to the Firebase database, which itself is made up of JSON files organised in a tree structure.

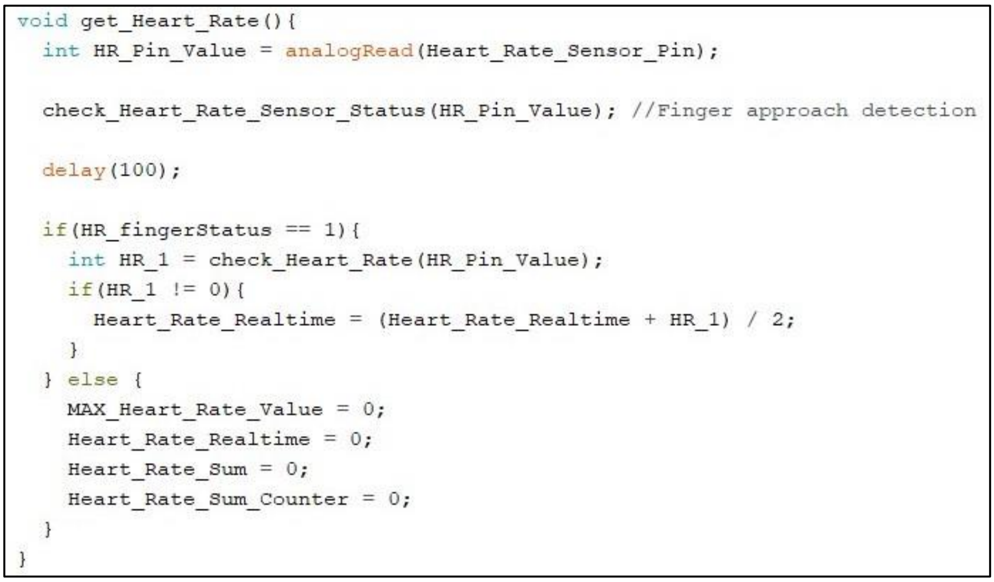


```
void communication(char* Line){
  String convertLine = String(Line);

  String key = getValue(convertLine, ',', 0);
  String value = getValue(convertLine, ',', 1);

  char* nodeKey = new char[key.length() + 1];
  std::strcpy(nodeKey, key.c_str());

  int valueI = value.toInt();

  FirebaseJson storageData;

  int value_data = map(valueI,0,1000,0,1000);

  delay(100);

  storageData.set("Value",value_data);
  Firebase.pushJSON(firebaseData,nodeKey,storageData);
}
```

Figure 32 – Function to Send Data to the Firebase database

Regarding the sensors programming in order to acquire the physiological parameters, there are not many details to highlight, however, in the case of the heart rate sensor the situation is different. As previously mentioned, the heart rate sensor acquires the ECG signal, needing to process it in order to obtain the HRV, and in turn the heart rate. Bearing in mind that no predefined libraries are imported, the entire operation of this sensor has been developed within the scope of this thesis.

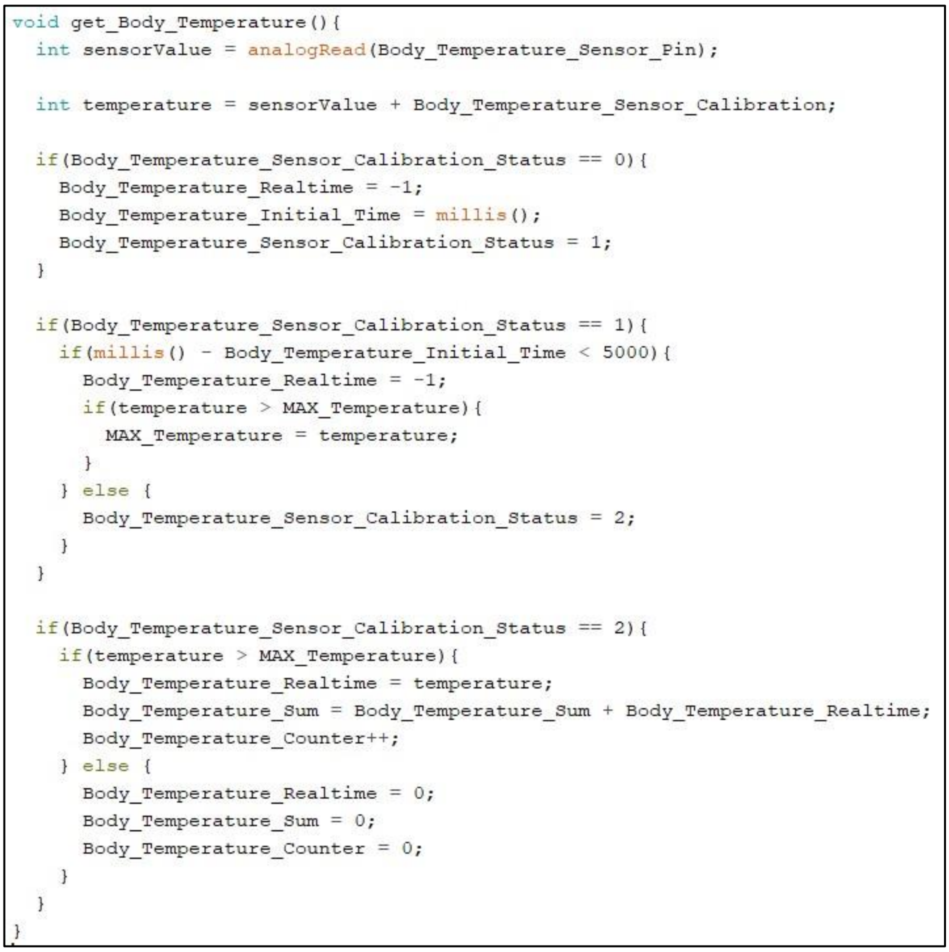
The heart rate acquisition function is shown in Figure 33 below. The heart rate sensor detects Analog Inputs, which relate to the ECG signal. These Inputs show a periodic behaviour and only after approaching the user's finger, their behaviour describes the typical ECG signal. Thus, the auxiliary function "check_Heart_Rate_Sensor_Status(int value)" was developed, which detects when the user's finger is close to the sensor or not, which requires some level of data processing. If the user's finger is detected, the system can then process the ECG signal in order to determine the heart rate, which is done using the auxiliary function "check_Heart_Rate_(int value)". For the user's visualisation of the heart rate data, the system averages two consecutive values, resulting in a much smoother and aesthetically acceptable transition of the heart rate values.



```
void get_Heart_Rate(){
  int HR_Pin_Value = analogRead(Heart_Rate_Sensor_Pin);

  check_Heart_Rate_Sensor_Status(HR_Pin_Value); //Finger approach detection

  delay(100);

  if(HR_fingerStatus == 1){
    int HR_1 = check_Heart_Rate(HR_Pin_Value);
    if(HR_1 != 0){
      Heart_Rate_Realtime = (Heart_Rate_Realtime + HR_1) / 2;
    }
  } else {
    MAX_Heart_Rate_Value = 0;
    Heart_Rate_Realtime = 0;
    Heart_Rate_Sum = 0;
    Heart_Rate_Sum_Counter = 0;
  }
}
```

Figure 33 – Function for Heart Rate Acquisition

Just as the acquisition of heart rate data involves some level of computational complexity, the acquisition of body temperature data also requires some methodology. The infrared temperature sensor enables the acquisition of both ambient and body/object temperature. Because it has a certain reading range, this sensor acquires temperature values even if the user has not approached any part of his body close to the sensor, which required the development of a mechanism that recognises the presence of a person. This mechanism acquires ambient temperature readings during a 5 second period (the system informs the user that it is performing the sensors calibration), so the user must wait until the calibration process is complete, and then he can approach a part of his body to the sensor. By acquiring an average value regarding the ambient temperature and considering that the body temperature is always higher than the ambient temperature, the system is then able to recognize the presence of a person, otherwise, the readings result in zero, because what is intended by the proposed system is only to acquire the body temperature values.

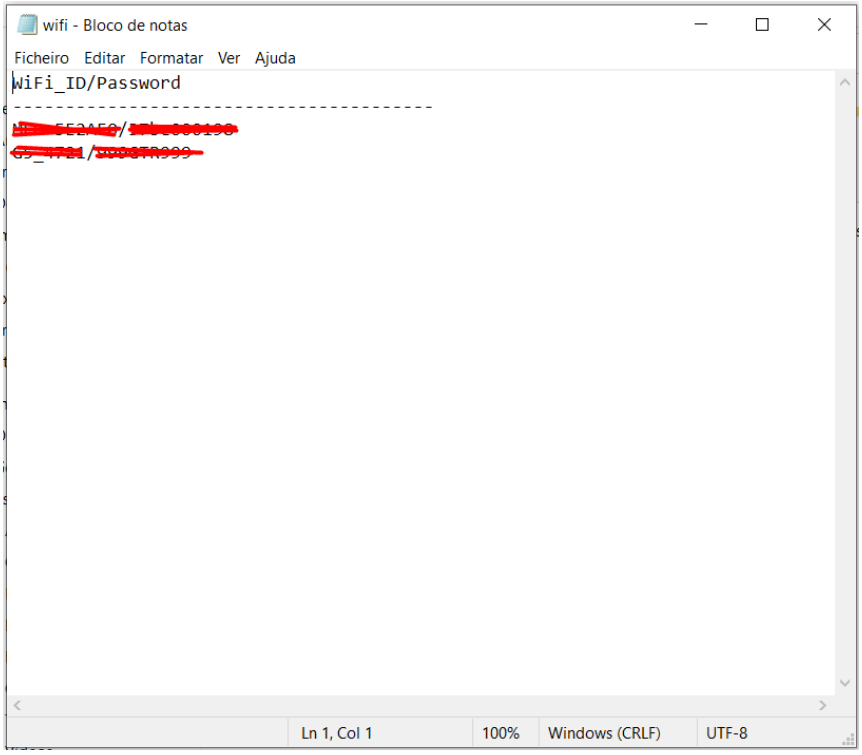


```
void get_Body_Temperature(){
  int sensorValue = analogRead(Body_Temperature_Sensor_Pin);

  int temperature = sensorValue + Body_Temperature_Sensor_Calibration;

  if(Body_Temperature_Sensor_Calibration_Status == 0){
    Body_Temperature_Realtime = -1;
    Body_Temperature_Initial_Time = millis();
    Body_Temperature_Sensor_Calibration_Status = 1;
  }

  if(Body_Temperature_Sensor_Calibration_Status == 1){
    if(millis() - Body_Temperature_Initial_Time < 5000){
      Body_Temperature_Realtime = -1;
      if(temperature > MAX_Temperature){
        MAX_Temperature = temperature;
      }
    } else {
      Body_Temperature_Sensor_Calibration_Status = 2;
    }
  }

  if(Body_Temperature_Sensor_Calibration_Status == 2){
    if(temperature > MAX_Temperature){
      Body_Temperature_Realtime = temperature;
      Body_Temperature_Sum = Body_Temperature_Sum + Body_Temperature_Realtime;
      Body_Temperature_Counter++;
    } else {
      Body_Temperature_Realtime = 0;
      Body_Temperature_Sum = 0;
      Body_Temperature_Counter = 0;
    }
  }
}
```

Figure 34 – Function for Body Temperature Acquisition

4.3.2. MicroSD Memory Card

As previously mentioned, the MicroSD memory card is essential for the system, as it is responsible for saving all the data acquired by the sensors in case it is not possible to establish Wi-Fi communication, thus ensuring that no data is discarded. On the other hand, the MicroSD memory card is also responsible for storing the Wi-Fi access credentials, and for such, users must insert the memory card in a computer, and after opening a new tab automatically with the contents of the memory card, open the file named "wifi.txt" (Figure 35). For the credentials to be entered correctly, the user must add a new line to this file with the network identifier and its password. For example, to allow access to a new network entitled "wifi-testing" and with the password "masterDegree", the user must insert a new line in the file containing the content "wifi-testing/masterDegree". Note that for security and privacy reasons, the access credentials to Wi-Fi connections are censored in red.



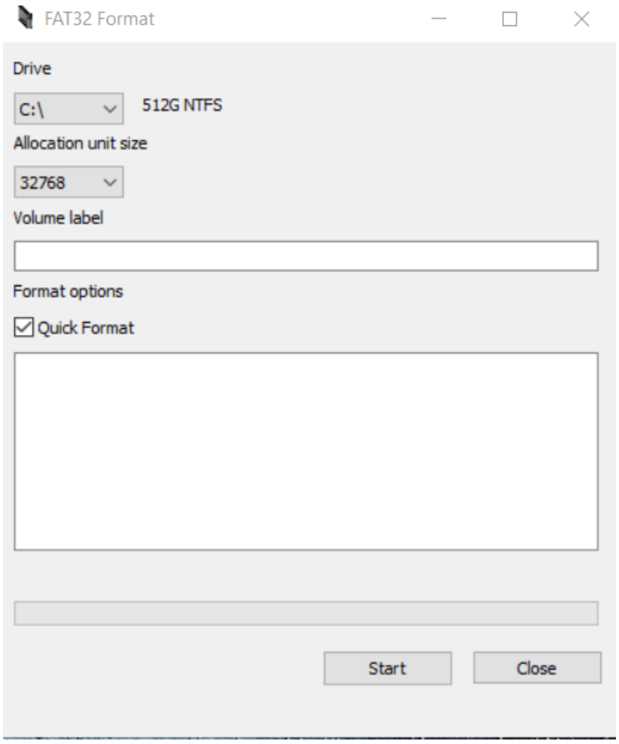
```
WiFi_ID/Password
----------------------------------------
[redacted]/[redacted]
[redacted]/[redacted]
```

Figure 35 – File "wifi.txt"

With the "wifi-txt" file open, the user can delete access credentials for networks that no longer wish to establish connection or insert access credentials to access new networks. To save the changes, the user just needs to select the "File" option from the upper tab and choose "Save". To finish, the user must safely inject the memory card from the computer and insert it in the embedded system. If the embedded system is running, it may be necessary to restart the system for it to recognise recent changes.

Another important aspect to mention is the possibility of adding a new MicroSD memory card, in addition to the one supplied with the embedded system. The Embedded System provides a MicroSD memory card, however, if there is a problem with this, users can simply purchase a new MicroSD memory card and insert it into the system.

The problem related to using any MicroSD memory card is that depending on the amount of memory available, the format of the card may differ. Typically, MicroSD memory cards with a memory capacity of more than 4GB come factory formatted in exFAT, however, to work correctly with the embedded system, it must be formatted in FAT32, which requires the use of additional software. In the case of this system, the software used was "guiformat (FAT32)", easily downloaded from the internet. Note that "guiformat (FAT32)" does not require installation on the computer, being an executable file. It is very intuitive to use and has all the detailed steps to proceed with any formatting, as can be visualised in Figure 36 below.



Drive
C:\ 512G NTFS
Allocation unit size
32768
Volume label
Format options
☑ Quick Format

Figure 36 – Software "guiformat (FAT32)". The user only needs to select "C:\" in order to choose the computer location of the memory card. After selecting the memory card that is to be formatted in FAT32, the user just needs to press "Start" and wait for the end of the operation.

Something important to keep in mind, is that when formatting the memory card, all the files contained on it will be permanently deleted. To work correctly with the system, after formatting the memory card, it is necessary to include two files in its content, the user just needs to create two .txt files entitled "data" and "wifi” and leave them empty.

CHAPTER 5

Database

This chapter is dedicated to the database used in the proposed system, and is organised into two sub-chapters, where the first presents the selection and characteristics of the database chosen, and the second sub-chapter presents its structure in detail.

5.1. Selection and Features

The choice of a database for any smart system and IoT infrastructures is a very important process. In my view, the choice of a database should not be made after sizing a system but before, always considering the purpose of the system to be developed, i.e., depending on the goals to achieve, the choice of the database should meet the possible needs to be found, which implies a correct and complete sizing at an early stage (first planning, second sizing, and third implementation).

In the specific case of the proposed system, the choice of the database was even more difficult to perform, because it should reconcile fast data access and ease of integration with the need to have a database capable of some level of data processing.

In a first phase, it was considered the use of a relational database Structured Query Language (SQL), which are databases specialized in data analysis and implementation of intelligent mechanisms for data processing (ML and AI). However, the major problem encountered was the integration of this type of databases in the context of the proposed system. In general, the implementation of the methods necessary for user authentication, database connection and data access, presented a much higher complexity when compared to other types of non-relational databases (NoSQL), which caused this hypothesis to be abandoned.

Given the negative aspects identified with SQL databases, I chose to use a database that I had already worked with before, and that I have some experience even in more complex operations (as long as a person masters a certain technology, he/she can adapt its use to almost anything). The database chosen was Google Firebase, a non-relational database with a tree structure composed of nodes, each of which is a JSON file.

Google's Firebase is a platform used to facilitate the development of web and/or mobile applications, however, it is also gaining strength in IoT solutions. This database prioritises fast data access and is far superior to SQL databases. Besides, Firebase is very malleable and adapts to the most diverse functionalities, with add-ons in order to cover some indispensable operations, such as authentication mechanisms, access to data in real time (eliminating delay almost completely), allowing to send notifications through the Cloud Messaging functionality, enabling the creation of data analysis processes with the Analytics function, providing error reports related to the operation of the applications, enabling the testing of access rules and pre-defined algorithms even before implementing them definitively, among others.

An important aspect to mention is the recent investment in ML, with Firebase even making available pre-defined algorithms ready to integrate in the most diverse projects. In addition, Firebase is betting more and more on extending its services to all development platforms, providing detailed documentation for the most diverse programming languages, such as Swift, Objective-C, Java Android, Kotlin+KTX Android, JavaScript, C++, Unity, among others.

Finally, it is important to mention that to use the full potential of Google Firebase, developers need to have an email account associated with Google (Gmail).

5.2. Database Structure

Regarding the database structure, as mentioned earlier, Google Firebase presents a tree structure, where each node is a JSON file. In order to better structure the data, three subsections were created, being them the DataStatus, the DataStorage and the Users, as can be seen in the following Figure 36. Thus, the DataStatus subsection stores status related to the values of the acquired physiological parameters, which are entered by the mobile application. DataStorage stores all data from the embedded system and the mobile application. Users stores the users' personal information.

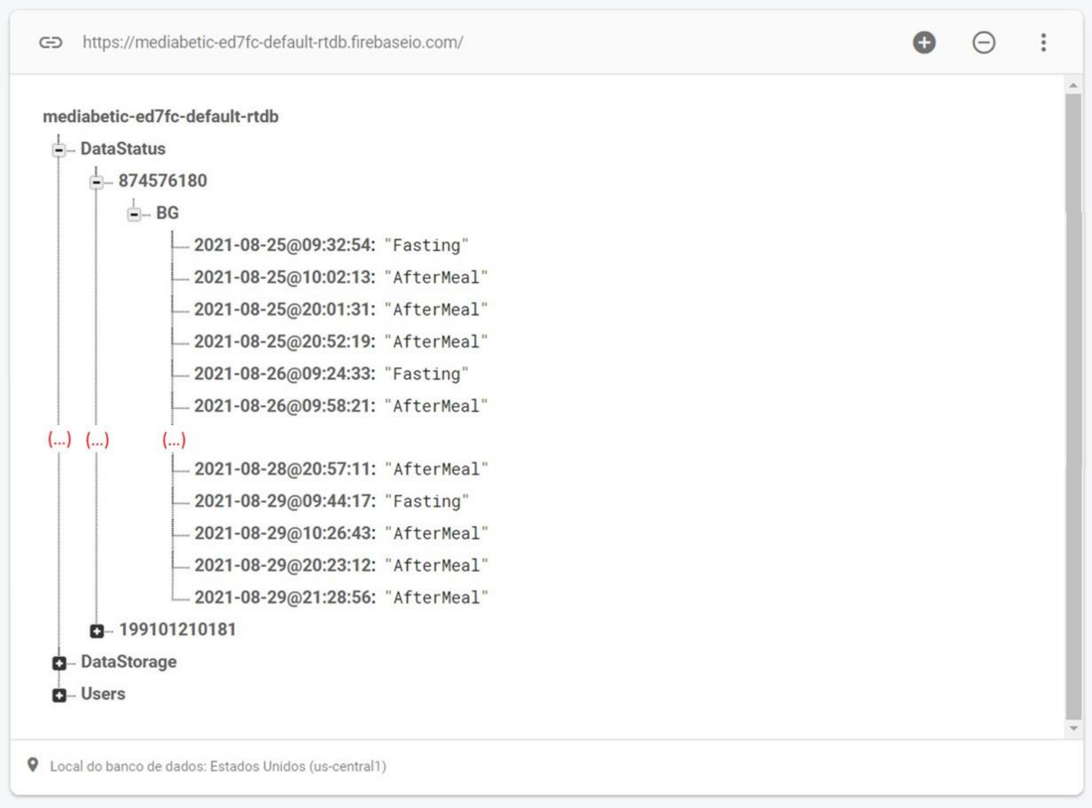
https://mediabetic-ed7fc-default-rtdb.firebaseio.com/

mediabetic-ed7fc-default-rtdb
- DataStatus
- DataStorage
- Users

Local do banco de dados: Estados Unidos (us-central1)

Figure 37 – Firebase Database Subsections

Regarding DataStatus, up to the moment of this thesis, it only groups the status related to the blood glucose levels by means of the identified number of the RFID tag of each user, as can be seen in Figure 38. In the future, other self-assessment mechanisms should be inserted into the system so that all the physiological parameters have associated status. As can be seen in Figure 38, the status are grouped according to the identifier of each user's RFID tag. As only status related to blood glucose levels are associated, only the BG subsection exists. Within BG, data are grouped by timestamp, and in the case of blood glucose levels, they can only be classified as "Fasting" or "AfterMeal".



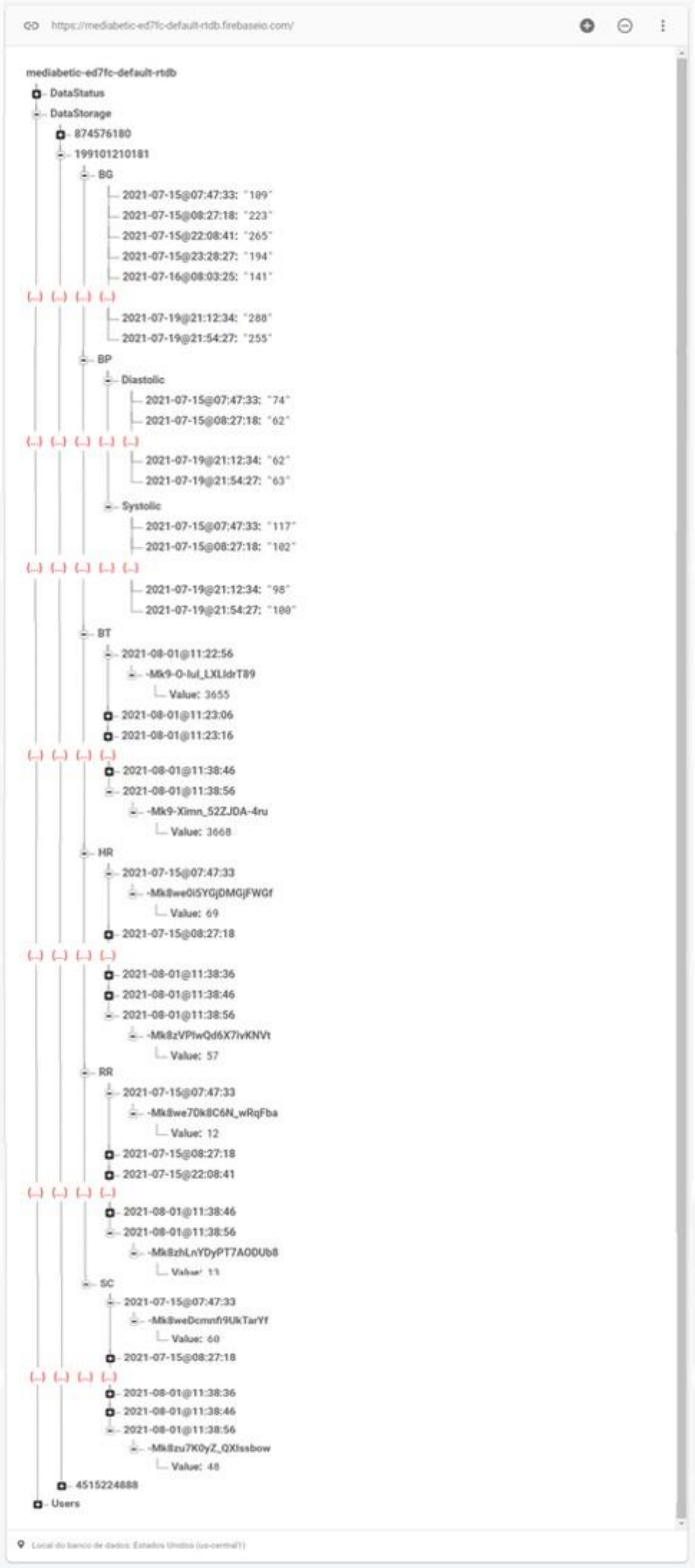
https://mediabetic-ed7fc-default-rtdb.firebaseio.com/

```
mediabetic-ed7fc-default-rtdb
  DataStatus
      874576180
          BG
              2021-08-25@09:32:54: "Fasting"
              2021-08-25@10:02:13: "AfterMeal"
              2021-08-25@20:01:31: "AfterMeal"
              2021-08-25@20:52:19: "AfterMeal"
              2021-08-26@09:24:33: "Fasting"
              2021-08-26@09:58:21: "AfterMeal"
(...)  (...)   (...)
              2021-08-28@20:57:11: "AfterMeal"
              2021-08-29@09:44:17: "Fasting"
              2021-08-29@10:26:43: "AfterMeal"
              2021-08-29@20:23:12: "AfterMeal"
              2021-08-29@21:28:56: "AfterMeal"
      199101210181
  DataStorage
  Users
```

Local do banco de dados: Estados Unidos (us-central1)

Figure 38 – Firebase Database DataStatus Subsection

Regarding DataStorage, it is similar to DataStatus in that it organises data by RFID tag identifier number, followed by the initials of the physiological parameter (BG - Blood Glucose; BP - Blood Pressure; BT - Body Temperature; HR - Heart Rate; RR - Respiratory Rate; SC - Skin Conductivity, also called GSR), as shown in the following Figure 39. Thus, after the RFID tag identifier of each user and the initials related to the physiological parameters, the data are also organized according to timestamp. Note that in the particular case of Blood Pressure, it is still organized by Systolic and Diastolic, even before applying the timestamp. Another detail is that all the data coming from the embedded system also have a unique identifier before the values related to the data (for example "-Mk9-Xlmn_52ZJDA-4ru"), which serves as data encapsulation when sending to Firebase.



```
https://mediabetic-ed7fc-default-rtdb.firebaseio.com/

mediabetic-ed7fc-default-rtdb
  DataStatus
  DataStorage
    874576180
    199101210181
      BG
        2021-07-15@07:47:33: "109"
        2021-07-15@08:27:18: "223"
        2021-07-15@22:08:41: "265"
        2021-07-15@23:28:27: "194"
        2021-07-16@08:03:25: "141"
(...) (...) (...) (...)
        2021-07-19@21:12:34: "288"
        2021-07-19@21:54:27: "255"
      BP
        Diastolic
          2021-07-15@07:47:33: "74"
          2021-07-15@08:27:18: "62"
(...) (...) (...) (...) (...)
          2021-07-19@21:12:34: "62"
          2021-07-19@21:54:27: "63"
        Systolic
          2021-07-15@07:47:33: "117"
          2021-07-15@08:27:18: "102"
(...) (...) (...) (...) (...)
          2021-07-19@21:12:34: "98"
          2021-07-19@21:54:27: "100"
      BT
        2021-08-01@11:22:56
          -Mk9-O-lul_LXLIdrT89
            Value: 3655
        2021-08-01@11:23:06
        2021-08-01@11:23:16
(...) (...) (...) (...)
        2021-08-01@11:38:46
        2021-08-01@11:38:56
          -Mk9-Ximn_52ZJDA-4ru
            Value: 3668
      HR
        2021-07-15@07:47:33
          -Mk8we0i5YGjDMGjFWGf
            Value: 69
        2021-07-15@08:27:18
(...) (...) (...) (...)
        2021-08-01@11:38:36
        2021-08-01@11:38:46
        2021-08-01@11:38:56
          -Mk8zVPlwQd6X7ivKNVt
            Value: 57
      RR
        2021-07-15@07:47:33
          -Mk8we7Dk8C6N_wRqFba
            Value: 12
        2021-07-15@08:27:18
        2021-07-15@22:08:41
(...) (...) (...) (...)
        2021-08-01@11:38:46
        2021-08-01@11:38:56
          -Mk8zhLnYDyPT7AODUb8
            Value: 11
      SC
        2021-07-15@07:47:33
          -Mk8weDcmnfi9UkTarYf
            Value: 60
        2021-07-15@08:27:18
(...) (...) (...) (...)
        2021-08-01@11:38:36
        2021-08-01@11:38:46
        2021-08-01@11:38:56
          -Mk8zu7K0yZ_QXlssbow
            Value: 48
    4515224888
  Users

Local do banco de dados: Estados Unidos (us-central1)
```

Figure 39 – Firebase Database DataStorage Subsection

Regarding the subsection Users, this store personal information of each user considered important for the good operation of the system, for example, the date of birth, from which the age of the user is retrieved, essential information for the calculation of the maximum value that a particular user can present for heart rate. This subsection can be viewed in more detail through the following Figure 40. This subsection presented in Figure 40 is responsible for storing all of the personal information of each user, information that is essential for the correct operation of the system. The information is organised by user identifier, which is obtained from the email address. Inside each user "profile", there is information relative to date of birth, email, first and last name, phone contact number and RFID tag identifier number. Note that most of the information has been censored in red, in order to safeguard users' privacy.

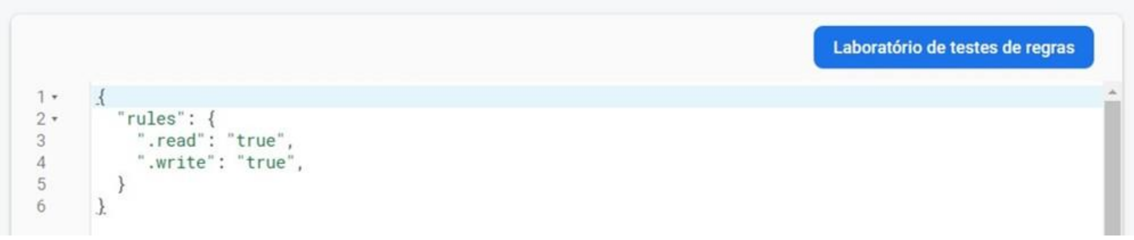
https://mediabetic-ed7fc-default-rtdb.firebaseio.com/

mediabetic-ed7fc-default-rtdb
- DataStatus
- DataStorage
- Users
  - [redacted]
  - [redacted]
    - birthday: [redacted]
    - email: [redacted]
    - firstName: [redacted]
    - lastName: [redacted]
    - phoneNumber: [redacted]
    - tagNumber: [redacted]
  - [redacted]

Local do banco de dados: Estados Unidos (us-central1)

Figure 40 – Firebase Database Users Subsection

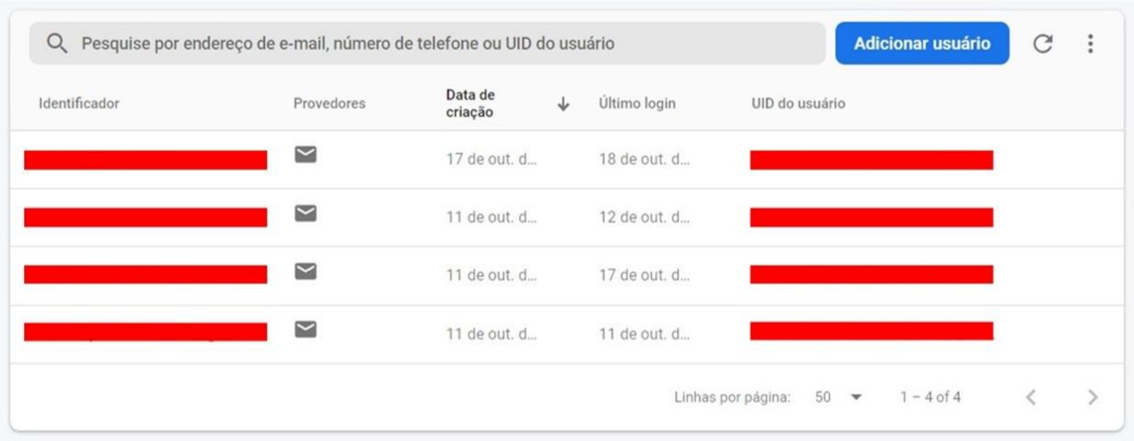
The Firebase database also allows developers to define a set of data access rules, however, due to the fact that the embedded system does not have access to each user's account, but only to the RFID tag identifier, the writing rules had to be simplified. On the other hand, the data reading rules were also simplified, since health professionals need to have access to data that is not theirs, but that of their patients. However, it is important to note that both the embedded system and the mobile application can only access the database if they have the authentication keys, which in a way ensures some data security and privacy.



```
{
  "rules": {
    ".read": "true",
    ".write": "true",
  }
}
```

Figure 41 – Database Access Rules. Both the read and write actions are true, which means that both the mobile application and the embedded system can always access the data, that is, if the connection establishment through private keys is successful.

Another important aspect to highlight is the user authentication method. In order not to overcomplicate the authentication process, this is done through email and password. Note that in the case of patients or users curious to try out the system, the mobile application requires account registration, in which each user must provide some personal data, including email and password, thus enabling the authentication method. On the other hand, if the users are health professionals, the authentication continues to be performed by email and password, however, the registration of user accounts is not done by the user himself but directly entered by the hospital management services where these health professionals are inserted, similarly to what happens with their access to the computers present in their offices. As can be seen in this Figure 42, when creating a new account, each user is registered in this section with a unique identifier and a UID access key. This unique identifier is the same identifier that organises the user's personal information in the Users subsection previously mentioned. Note that some information has been censored in red, in order to safeguard user privacy.



Identificador	Provedores	Data de criação ↓	Último login	UID do usuário
[redacted]	✉	17 de out. d...	18 de out. d...	[redacted]
[redacted]	✉	11 de out. d...	12 de out. d...	[redacted]
[redacted]	✉	11 de out. d...	17 de out. d...	[redacted]
[redacted]	✉	11 de out. d...	11 de out. d...	[redacted]

Figure 42 – Firebase Overview of the Authenticated Users List

CHAPTER 6

Mobile Application

Chapter 6 presents in a detailed way all the work conducted in the development of a mobile application to serve as the main interface to the system proposed in this thesis. As such, this chapter is divided into three sub-chapters, the first of which refers to the initial assessment (choice of development platform and target devices), the second refers to the level of intelligence embedded in the application, and the third and final sub-chapter refers to the design and implementation.

An important aspect to mention is that the mobile application developed is not available in application stores (Google Play for Android devices, and App Store for iOS devices), which requires it to be installed on mobile devices via USB debugging. For this to be possible, users simply need to access the developer options on their device and enable USB debugging. After this change is made, simply connect the device to the computer, open the development platform and choose to run the application on the device and not on an emulator. This way, the development platform will automatically compile the application and install it on the mobile device, making the application ready to use.

6.1. Initial Assessment

As previously presented in the review of the literature chapter, there are two types of operating systems implemented by mobile devices, Android, and iOS. From the total market of mobile devices, the largest percentage belongs to Android devices, which in a situation where it is not possible to develop a cross-platform application, makes the most viable choice to opt for Android development over iOS development.

If developers go down the path of cross-platform application development, typically software that allows for concurrent development rather than native development is used (unique software for Android development and unique software for iOS development). Of all the tools/software available for cross-platform development Visual Studio and React Native stand out.

In the case of Visual Studio, it not only allows developers to build Android and iOS applications, but also web applications. Although Visual Studio allows the development of a mobile application, which will be converted into native Android and iOS applications, if the developer wants to test them by running a simulation on his computer, using emulators for example, this action is abruptly interrupted by license limitations, i.e., if the developer owns a computer with Windows operating system, he can only run the application on Android, and to run it on iOS he/she will have to own a MAC or any other Apple device, and a key will be provided that will result in the surrender of a license. Likewise, a developer who uses a MAC computer can only run the application on iOS.

In the case of React Native, a single source of code is easily converted to Android or iOS, thus facilitating the development of cross-platform applications. However, aspects such as the poor availability of documentation, the confusing operation between the environment installed on the computer and the online environment, the still considerable waiting time to release the Android and IOS emulators, the impossibility of using more complex maps on Android devices, and even the confusing communication between platform and databases, made this solution also no longer viable.

Considering what was said before, the choice of software for the development of the mobile application focused on the Android or iOS environment, and faced with this dilemma, Android application development was eventually chosen, which made the chosen software Android Studio.

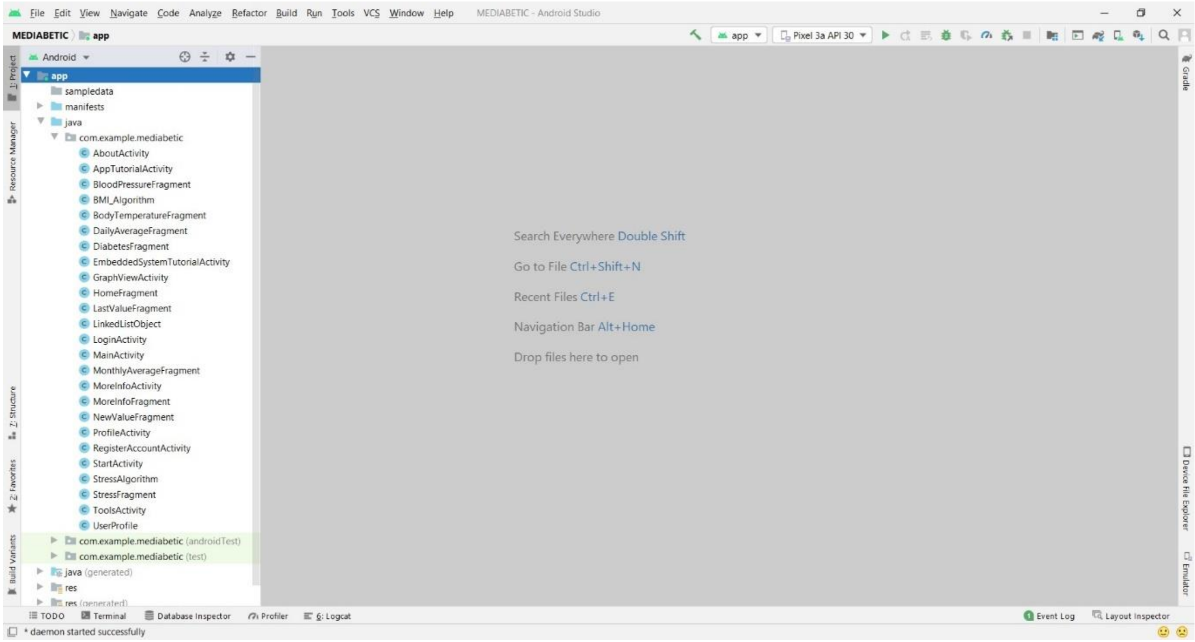


Figure 43 – Android Studio Desktop

6.2. Algorithm for Stress Estimation

Due to the choice of the Firebase database and not a relational database capable of implementing intelligent data processing, this level of intelligence passed to the mobile application, which processes each physiological parameter according to the tables presented in the review of literature chapter, i.e., according to the value that each parameter reaches, the mobile application is able to recognise and classify them, thus assisting users in the intelligent monitoring of their health.

Besides analysing and classifying physiological parameters on an individual basis, the mobile application also calculates the BMI based on the user's weight and height, as well as estimating stress levels based on heart rate, respiratory rate and GSR.

In more technical detail, the algorithm for estimating stress levels converts the values of heart rate and respiratory rate to percentages within the range of possible values. Note that in the case of GSR, the sensor library itself already performs the conversion from voltage to percentage, and in this case no extra digital processing is required.

An important detail in the conversion of the heart rate from beats per minute to percentage is the need to determine the maximum possible value for this parameter, which is performed through **Equation 3**. To determine the maximum value of the heart rate for each subject, it is necessary to know their age, which made it mandatory to include it in the registration of new users in the mobile application.

$$MAX_{Heart\_Rate} = 220 - age \tag{3}$$

Once the maximum heart rate for the subject is known, **Equation 4** can then be applied, i.e., this equals 100%, and making use of the heart rate collected by the sensor, the heart rate in percentage is obtained.

$$Heart\_Rate[\%] = \frac{Heart\_Rate \times 100}{MAX_{Heart\_Rate}} \tag{4}$$

As with the heart rate, to convert the respiratory rate from breaths per minute to percentage, it is also necessary to determine the maximum possible value for this, but this does not depend on age. There is no maximum value communicated by health entities for respiratory rate, but it is common in many athletes who practice sports with enormous physical effort, to present maximum values for respiratory rate in the order of 70 breaths per minute, and as such, in this system it was admitted as a maximum value (**Equation 5**), i.e., this equals 100%, and making use of the respiratory rate collected by the sensor, the respiratory rate in percentage is obtained through **Equation 6**.

$$MAX_{Respiratory\_Rate} = 70 \tag{5}$$

$$Respiratory\_Rate[\%] = \frac{Respiratory\_Rate \times 100}{MAX_{Respiratory\_Rate}} \tag{6}$$

After determining the heart rate and respiratory rate, both in percentage, and obtaining the GSR value also in percentage directly from the sensor, it is then possible to apply the developed algorithm for the estimation of the stress levels, which is based on the weighted average of the 3 parameters obtained by the sensory system at the exact same instant of time and defined by **Equation 7**.

$$Stress\ [\%] = \frac{Heart\_Rate[\%] + Respiratory\_Rate[\%] + Skin\_Conductivity[\%]}{3} \tag{7}$$

Another aspect that was identified through the review of literature is that there are no pre-defined values for stress, and as such, each researcher proposes their own model. In this way, after the mobile application estimates the stress levels based on the previous equations, it classifies the levels as follows:

- **0% - 25%**
    - Resting State.
    - No symptoms or consequences.
- **26% - 50%**
    - Low Stress Levels.
    - No symptoms or consequences.
- **51% - 75%**
    - Normal Stress Levels.
    - No symptoms or consequences.
- **76% - 100%**
    - High Stress Levels.
    - Difficulty controlling emotions, heart problems, teeth and gums problems, weight gain, weakened immune system.

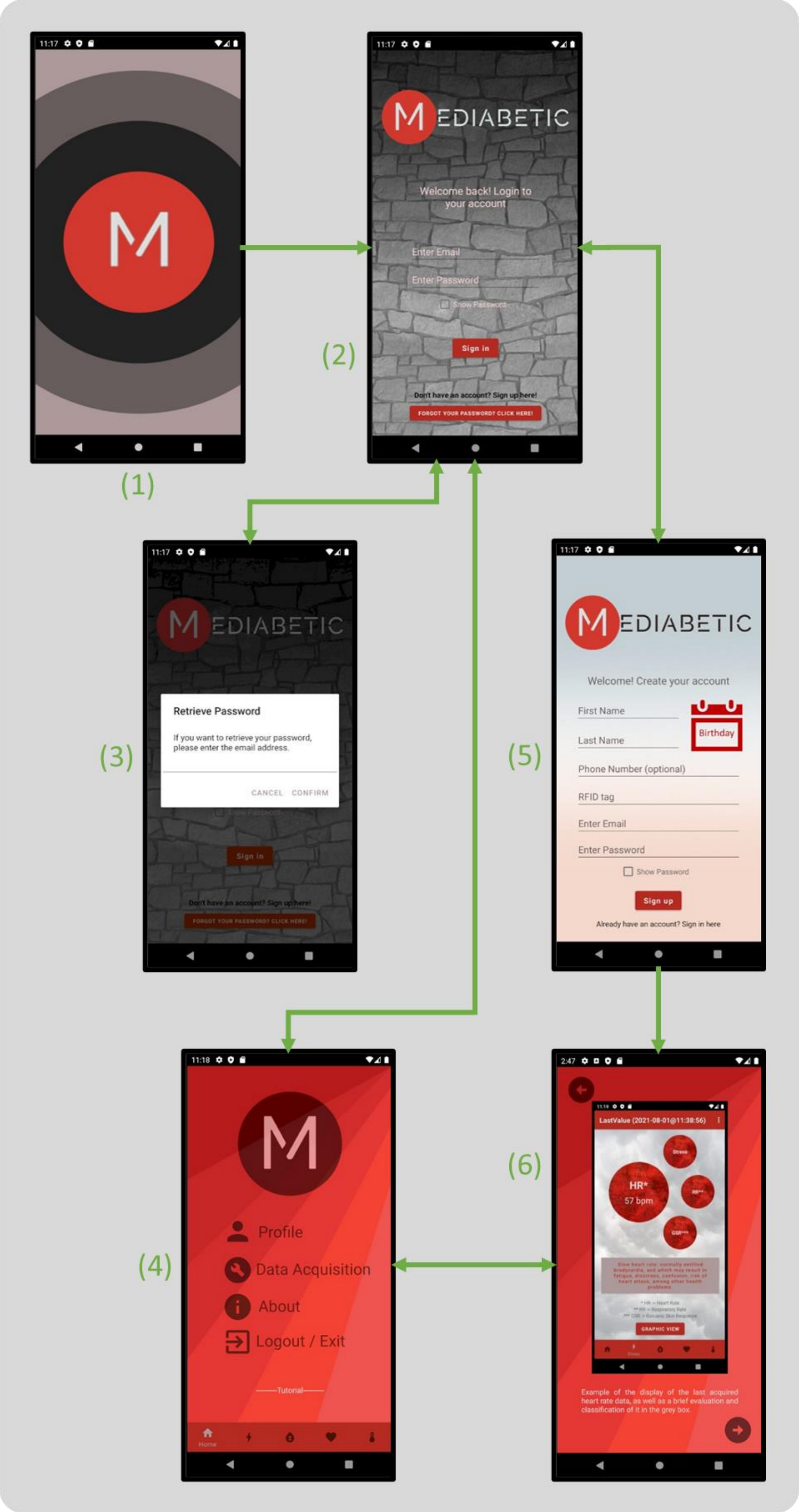
6.3. Design and Implementation

Initially, the mobile application was idealized for all types of users, whether they were patients, people curious about using the system, or health professionals such as doctors or nurses. However, due to the complexity of defining different behaviours for the application depending on the type of users, two mobile applications were created, the first being MEDIABETIC, intended for all types of non-health professional users, and the second being MEDIABETIC HPV (Health Professional Version), intended only for health professionals. Note that health professionals can also use MEDIABETIC, however, they should bear in mind that they will interact as patient and not as health professional.

6.3.1. MEDIABETIC

MEDIABETIC is the mobile application developed for use outside the context of health professionals, in that it serves to monitor the user's physiological parameters, enter new values, obtain classifications and information relating to the physiological parameters in question, in order to enlighten users about their health state. It also provides daily averages, monthly averages, and a theoretical content section where each user can learn a little more about different aspects related to diabetes, stress, blood pressure and body temperature.

Regarding the operation of MEDIABETIC, when it starts, it presents the login option, allowing users to authenticate and access their data. If the user does not remember his access password, he may request the replacement with a new password, and an email will be sent to him with instructions on how to proceed. If the user is not yet registered, he can create an account and will be asked to provide some personal data. Note that if the user creates an account, when gaining access to the application, this automatically launches a tutorial in order to clarify the user about its operation. Once the tutorial is finished, the user proceeds to the home screen. If the user accesses the application by the login method, it immediately proceeds to the home screen. These transitions of the mobile application can be seen in detail in Figure 44 below. Related the Figure 44, at the point 1 is represented the start screen with the application logo, which loaded all the essential resources, and transits to point 2. In turn, point 2 represents the login screen, where the user can gain access to the application, request password reset (point 3) or proceed to the account register (point 5). At point 5 the user can create an account, being requested some essential information, such as first and last name, date of birth, phone number (optional), RFID tag identifier, email, and password. At point 5 the user can always go back to point 2 or confirm account creation and access the application. Note that if the user has just created an account, before being able to explore the application, the application will provide a tutorial (point 6). If the tutorial is completed or the user comes from the login operation, he gains access to the home screen (point 4), MEDIABETIC's main screen.



Welcome back! Login to your account

Don't have an account? Sign up here!

If you want to retrieve your password, please enter the email address.

Welcome! Create your account

Already have an account? Sign in here

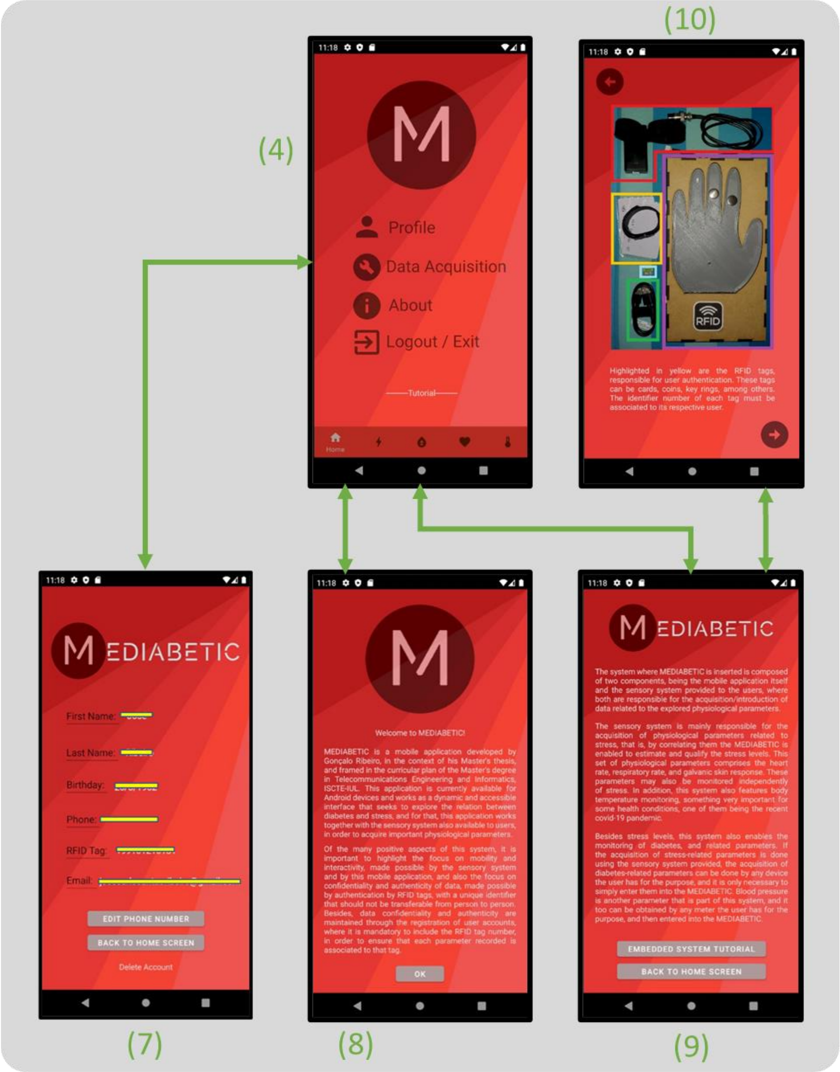
Slow heart rate, normally entitled bradycardia, and which may result in fatigue, dizziness, confusion, risk of heart attack, among other health problems

* HR = Heart Rate
** RR = Respiratory Rate
*** GSR = Galvanic Skin Response

Example of the display of the last acquired heart rate data, as well as a brief evaluation and classification of it in the grey box.

Figure 44 – Operation and Transitions of MEDIABETIC (Part 1)

The home screen is the main MEDIABETIC screen because it allows users to access important features, such as the user profile (personal information can be consulted, phone number updated or the application access account deleted), data acquisition methods (data acquisition methods are presented, and in the specific case of the embedded system, the application also provides a short tutorial), About option (presents a brief description of MEDIABETIC and context), end of session (user can logout, returning to the login screen, or exit the application, which keeps the session open for a short period of time, in which the user can return without having to login again), and the application tutorial. These transitions of the mobile application can be seen in detail in Figure 45 below. Thus, at the point 4 are represented the main MEDIABETIC screen, where the user can access his/her profile (point 7), discover the purpose and context of the application (point 8), and consult the data acquisition methods (point 9). Note that in the user profile, the phone number can be updated or removed, and the MEDIABETIC access account can be deleted. In the data acquisition methods, the user has at his disposal a short tutorial about the embedded system that is part of the proposed system.



Highlighted in yellow are the RFID tags, responsible for user authentication. These tags can be cards, coins, key rings, among others. The identifier number of each tag must be associated to its respective user.

First Name: [redacted]
Last Name: [redacted]
Birthday: [redacted]
Phone: [redacted]
RFID Tag: [redacted]
Email: [redacted]

Welcome to MEDIABETIC!

MEDIABETIC is a mobile application developed by Gonçalo Ribeiro, in the context of his Master's thesis, and framed in the curricular plan of the Master's degree in Telecommunications Engineering and Informatics, ISCTE-IUL. This application is currently available for Android devices and works as a dynamic and accessible interface that seeks to explore the relation between diabetes and stress, and for that, this application works together with the sensory system also available to users, in order to acquire important physiological parameters.

Of the many positive aspects of this system, it is important to highlight the focus on mobility and interactivity, made possible by the sensory system and by this mobile application, and also the focus on confidentiality and authenticity of data, made possible by authentication by RFID tags, with a unique identifier that should not be transferable from person to person. Besides, data confidentiality and authenticity are maintained through the registration of user accounts, where it is mandatory to include the RFID tag number, in order to ensure that each parameter recorded is associated to that tag.

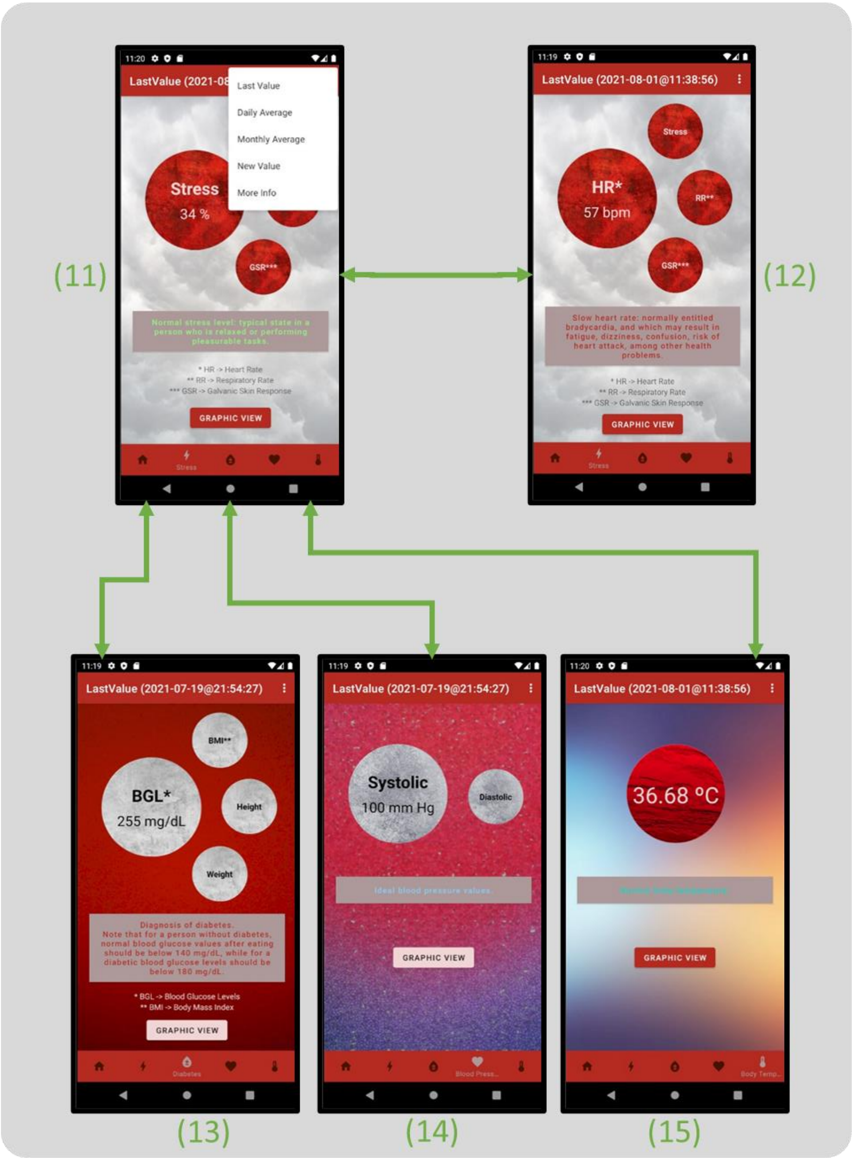
The system where MEDIABETIC is inserted is composed of two components, being the mobile application itself and the sensory system provided to the users, where both are responsible for the acquisition/introduction of data related to the explored physiological parameters.

The sensory system is mainly responsible for the acquisition of physiological parameters related to stress, that is, by correlating them the MEDIABETIC is enabled to estimate and qualify the stress levels. This set of physiological parameters comprises the heart rate, respiratory rate, and galvanic skin response. These parameters may also be monitored independently of stress. In addition, this system also features body temperature monitoring, something very important for some health conditions, one of them being the recent covid-19 pandemic.

Besides stress levels, this system also enables the monitoring of diabetes, and related parameters. If the acquisition of stress-related parameters is done using the sensory system provided, the acquisition of diabetes-related parameters can be done by any device the user has for the purpose, and it is only necessary to simply enter them into the MEDIABETIC. Blood pressure is another parameter that is part of this system, and it too can be obtained by any meter the user has for the purpose, and then entered into the MEDIABETIC.

Figure 45 – Operation and Transitions of MEDIABETIC (Part 2)

In addition to the home screen, accessible through the respective icon on the bottom menu, users can also navigate MEDIABETIC through features associated with stress, diabetes, blood pressure, and body temperature. The respective icons can be found in the bottom menu. The application also provides a top menu, where users can access the latest data (updates in real time), daily averages, monthly averages, adding new values, and a section of theoretical content where users can learn more about each topic (More Info). Next in the Figure 46, point 11 shows the screen obtained by combining the Stress option from the bottom menu with the Last Value option from the top menu. Point 13 represents the screen obtained by conjugating the Diabetes option from the bottom menu with the Last Value option from the top menu. Point 14 represents the screen obtained by combining the Blood Pressure option from the bottom menu with the Last Value option from top menu. Point 15 represents the screen obtained by combining the Body Temperature option from the bottom menu with the Last Value option from top menu. Note that in all the points shown in Figure 46, a brief assessment of the values is performed (grey background square that, depending on the assessment, may have different coloured text, depending on the severity). Users can also choose the "Graphic View" option to display more detailed data in a graphic format. Another particularity is the interaction between physiological parameters, in that if, for example, the Stress option is selected, users will have access to stress levels, heart rate, respiratory rate and GSR. In order for the user to be able to visualize the values, he/she just has to press the circle corresponding to the physiological parameter that he/she wants to consult, which is the case in point 12, where inside the section corresponding to Stress, the user has selected HR*, thus allowing him/her to visualize the last value obtained for heart rate.



Normal stress level: typical state in a person who is relaxed or performing pleasurable tasks.

* HR -> Heart Rate
** RR -> Respiratory Rate
*** GSR -> Galvanic Skin Response

Slow heart rate: normally entitled bradycardia, and which may result in fatigue, dizziness, confusion, risk of heart attack, among other health problems.

* HR -> Heart Rate
** RR -> Respiratory Rate
*** GSR -> Galvanic Skin Response

Diagnosis of diabetes.
Note that for a person without diabetes, normal blood glucose values after eating should be below 140 mg/dL, while for a diabetic blood glucose levels should be below 180 mg/dL.

* BGL -> Blood Glucose Levels
** BMI -> Body Mass Index

Ideal blood pressure values.

Figure 46 – Operation and Transitions of MEDIABETIC (Part 3)

The application also allows data to be filtered by daily averages, and as such, users simply access the top menu and select Daily Average. Through the bottom menu, users can view the daily averages for stress, diabetes, blood pressure, and body temperature, as well as the associated parameters (these parameters can be accessed by choosing from the selection box at the top of each screen). MEDIABETIC also allows users to filter data by monthly averages, a feature that is quite similar to daily averages. The only difference is that instead of presenting the possibility to choose another day, it allows filtering the data by month. These can be seen in detail in Figure 47 and Figure 48 below.

In Figure 47, regardless of the physiological parameter selected, the Daily Average feature allows users to view the number of daily samples, the maximum daily value, the minimum daily value, and the average daily value. In addition, users can select another day using the "Choose Another Day" button or view the data in detail in graphical format using the "Graphic View" button. Point 16 concerns the daily values in the context of stress. Point 17 concerns the daily values in the context of diabetes. Point 20 concerns the daily values in the context of body temperature. Point 18 concerns the daily values in the context of blood pressure, and the respective point 19 concerns the visualisation in graph format of the blood pressure values. Please note that all graphs have a coloured legend according to the boundary zones highlighted on the graph.

(18)

Number of samples retrieve: 4

Maximum value [mm Hg] : 117

Minimum value [mm Hg] : 101

Daily average [mm Hg] : 108

(11)

Normal stress level: typical state in a person who is relaxed or performing pleasurable tasks.

* HR -> Heart Rate
** RR -> Respiratory Rate
*** GSR -> Galvanic Skin Response

(16)

Number of samples retrieve: 102

Maximum value [%] : 59

Minimum value [%] : 27

Daily average [%] : 42

* HR -> Heart Rate
** RR -> Respiratory Rate
*** GSR -> Galvanic Skin Response

(17)

Number of samples retrieve: 4

Maximum value [mg/dL] : 265

Minimum value [mg/dL] : 109

Daily average [mg/dL] : 197

* BGL -> Blood Glucose Levels
** BMI -> Body Mass Index

(20)

Number of samples retrieve: 97

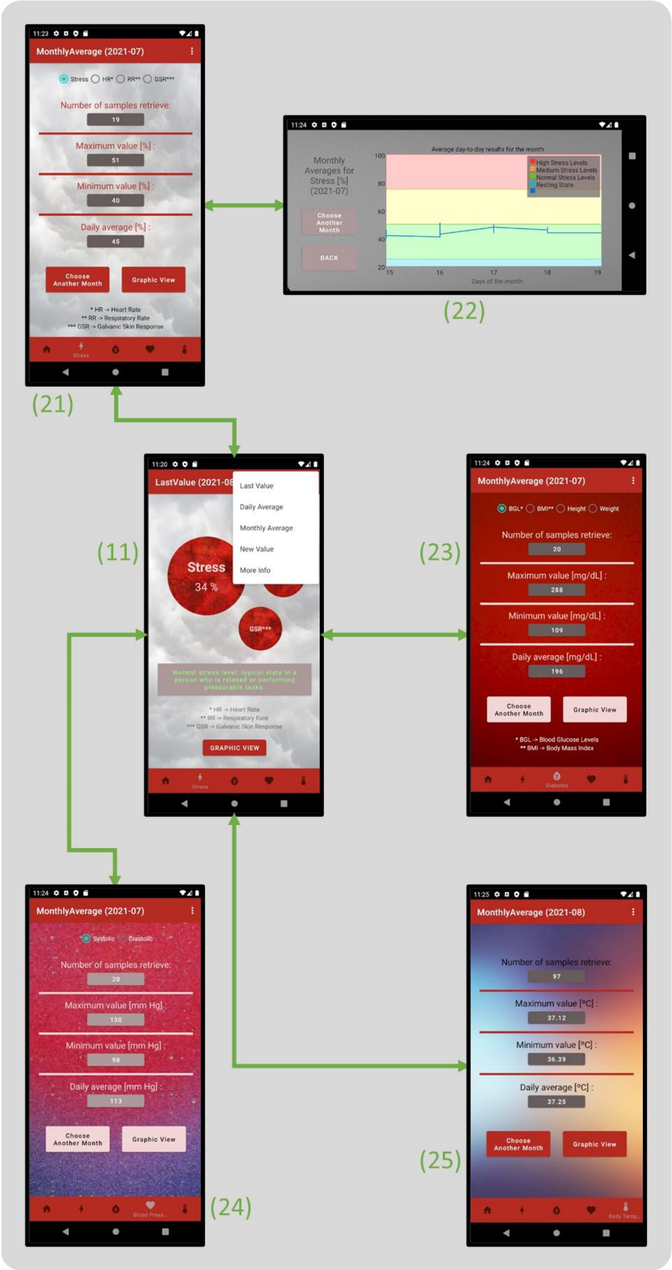
Maximum value [ºC] : 37.12

Minimum value [ºC] : 36.39

Daily average [ºC] : 37.25

Figure 47 – Operation and Transitions of MEDIABETIC (Part 4)

In Figure 48, regardless of the physiological parameter selected, the Monthly Average feature allows users to view the number of monthly samples, the maximum monthly value, the minimum monthly value, and the average monthly value. In addition, users can select another month using the "Choose Another Month" button or view the data in detail in graphical format using the "Graphic View" button. Point 23 concerns the monthly values in the context of diabetes. Point 24 concerns the monthly values in the context of blood pressure. Point 25 concerns the monthly values in the context of body temperature. Point 21 concerns the monthly values in the context of stress, and the respective point 22 concerns the visualisation in graph format of the stress values. Please note that all graphs have a coloured legend according to the boundary zones highlighted on the graph.



(21)
Number of samples retrieve: 19
Maximum value [%] : 51
Minimum value [%] : 40
Daily average [%] : 45
* HR -> Heart Rate
** RR -> Respiratory Rate
*** GSR -> Galvanic Skin Response

(22)
Monthly Averages for Stress [%] (2021-07)

(11)
Normal stress level: typical state in a person who is relaxed or performing pleasurable tasks.
* HR -> Heart Rate
** RR -> Respiratory Rate
*** GSR -> Galvanic Skin Response

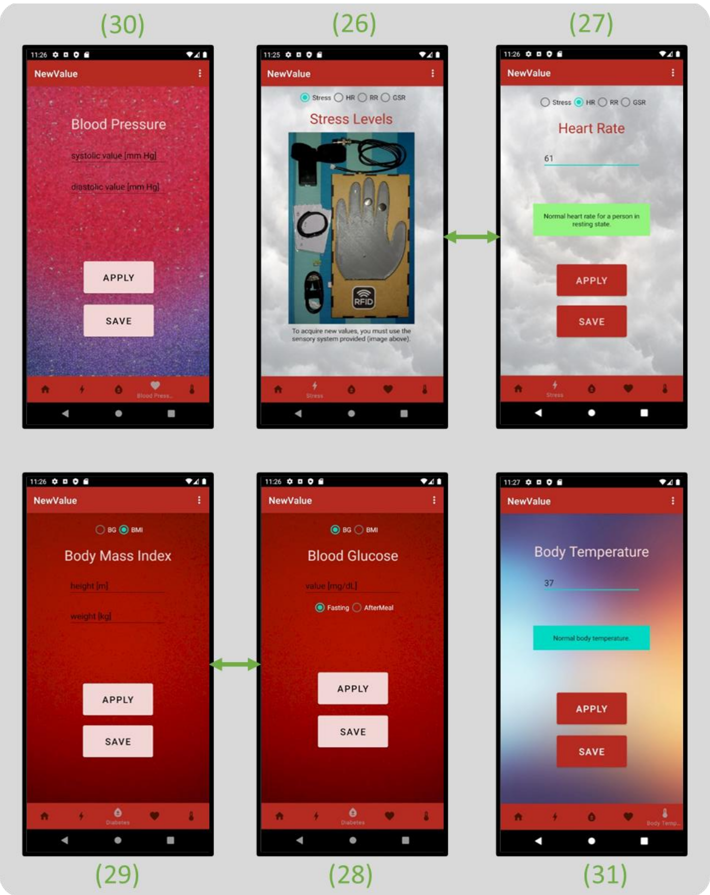
(23)
Number of samples retrieve: 20
Maximum value [mg/dL] : 288
Minimum value [mg/dL] : 109
Daily average [mg/dL] : 196
* BGL -> Blood Glucose Levels
** BMI -> Body Mass Index

(24)
Number of samples retrieve: 20
Maximum value [mm Hg] : 130
Minimum value [mm Hg] : 98
Daily average [mm Hg] : 113

(25)
Number of samples retrieve: 97
Maximum value [°C] : 37.12
Minimum value [°C] : 36.39
Daily average [°C] : 37.25

Figure 48 – Operation and Transitions of MEDIABETIC (Part 5)

Regarding the addition of new values through the mobile application, this process depends a lot on the type of physiological parameter selected, i.e., there are parameters such as stress and GSR, where the only way to acquire data is by using the embedded system, and this warning should be given by MEDIABETIC. On the other hand, there are parameters that require more than one value, which is the case with blood pressure (requires Systolic Blood Pressure and Diastolic Blood Pressure) and BMI (requires the height and weight of the user). In the case of blood glucose, the user must also identify if the value was obtained fasting or after eating. These details can be seen in Figure 49 below, where point 26 of the application provides a warning that stress-related values should be obtained using the embedded system, which figure is also shown on the screen. Also, in the context of stress, both heart rate and respiratory rate values can be added through the application (point 27). The screen relating to adding BMI values is shown in point 29, and blood glucose values can be added in point 28, where the user must also select whether the value was obtained fasting or after eating. The screen to add blood pressure values is shown at point 30. The screen to add body temperature values is shown at point 31. Note that after entering a new value, the user should use the "APPLY" button to obtain MEDIABETIC's opinion on the value. After the application has given its opinion, the user can then select the "SAVE" button, thus allowing MEDIABETIC to send the new value to the database, which is immediately available to be viewed in the Last Value, Daily Average and Monthly Average options.



To acquire new values, you must use the sensory system provided (image above).

61

Normal heart rate for a person in resting state.

37

Normal body temperature.

Figure 49 – Operation and Transitions of MEDIABETIC (Part 6)

Regarding the theoretical contents made available to users, they only need to select the "More Info" option in the top menu, and according to the context selected in the bottom menu, different contents are enabled. Typically, the resulting screen presents a list of selectable topics, which contain detailed information. This information has been assembled and laid out in a way that is accessible for the user to understand, thus avoiding the use of more technical vocabulary. These details can be seen in Figure 50 below, where point 32 concerns the arrangement of theoretical topics related to stress, as well as point 33 presents an example of resulting action after selecting a topic in the previous screen. Point 34 concerns the arrangement of theoretical topics related to diabetes. Point 35 concerns the arrangement of theoretical topics related to blood pressure. Point 36 concerns the arrangement of theoretical topics related to body temperature.

Normal stress level: typical state in a person who is relaxed or performing pleasurable tasks.

* HR -> Heart Rate
** RR -> Respiratory Rate
*** GSR -> Galvanic Skin Response

Stress Factors

There are several stress factors, but what is considered a factor will depend on some aspects, such as the existence of a social support network, personality characteristics, problem-solving and emotion regulation strategies that the person already has, among others.

Some stress factors are related to important life events, such as the death of a close person, an illness or unemployment.
Other stress factors are those that may be ongoing and recurrent in everyday life, and include:
- Environmental factors: pollution or unsuitable housing conditions
- Relational and family factors: dysfunctional marital relationships, being a carer for a chronically ill person
- Work-related factors: job dissatisfaction, overload of work or conflict at the workplace
- Social factors: poverty, racial and gender discrimination or social isolation

Figure 50 – Operation and Transitions of MEDIABETIC (Part 7)

6.3.2. MEDIABETIC HPV

MEDIABETIC HPV is intended only for health professionals, and as such, its operation resembles the operation of MEDIABETIC, however there are some features that have been removed for this version, namely the theoretical contents and the possibility of adding new values relating to the physiological parameters assessed by the system. All that concerns user profile, information about the application, and tutorials has also been removed, and instead, each time a health professional accesses the application, he/she must enter the RFID tag identifier of the patient he/she wants to consult. Other aspects removed were the possibility to recover the access password, which must be requested directly to the hospital management services, and the registration of new user accounts, which must again be performed by the hospital management services.

Regarding the operation of MEDIABETIC HPV, when it starts it displays the login option, which must be performed with the access credentials provided to health professionals by the hospital management services. Once the login has been successfully completed, the user gains access to the main screen of the application, where he/she will be asked to introduce the RFID tag identifier of the patient he/she wants to consult. In case the identifier is feasible, the applications provides the profile of the patient in question. From this moment, the health professional can access the patient's physiological parameters, namely last values, daily averages, and monthly averages. For both, the health professionals can also visualise all the data in graphic format, as well as obtain opinions provided by the application about the evaluation performed according to the value of the physiologic parameter in question. These transitions can be seen in more detail in Figure 51, Figure 52, and Figure 53, presented below.

In Figure 51, point 1 represents the start screen with the application logo, which loaded all the essential resources, and transits to point 2. In turn, point 2 represents the login screen, where the user can gain access to the application. When arriving to the main screen, the user must insert the identifier of the RFID tag of the patient to be consulted (point 3). After entering a valid identifier, the profile of that patient is displayed (point 4). Point 5 shows the screen obtained by combining the Stress option from the bottom menu with the Last Value option from the top menu. Point 6 represents the screen obtained by conjugating the Diabetes option from the bottom menu with the Last Value option from the top menu. Point 7 represents the screen obtained by combining the Blood Pressure option from the bottom menu with the Last Value option from top menu. Point 8 represents the screen obtained by combining the Body Temperature option from the bottom menu with the Last Value option from top menu. Note that in all the points shown in Figure 51, a brief assessment of the values is performed (dark blue background square that, depending on the assessment, may have different coloured text, depending on the severity). Users can also choose the "Graphic View" option to display more detailed data in a graphic format. Another particularity is the interaction between physiological parameters, in that if, for example, the Stress option is selected, users will have access to stress levels, heart rate, respiratory rate and GSR. In order for the user to be able to visualize the values, he/she just has to press the circle corresponding to the physiological parameter that he/she wants to consult.

Welcome back! Login to your account

Request
Please enter the RFID number of the patient you wish to see and confirm

First Name: [redacted]
Last Name: [redacted]
Birthday: [redacted]
Phone: [redacted]
RFID Tag: [redacted]
Email: [redacted]

LastValue (2021-07-19@21:54:27)

BGL* 255 mg/dL

Diagnosis of diabetes
Note that for a person without diabetes, normal blood glucose values after eating should be below 140 mg/dL, while for a diabetic blood glucose levels should be below 180 mg/dL.

* BGL -> Blood Glucose Levels
** BMI -> Body Mass Index

LastValue (2021-08

Stress 34 %

Normal stress level: typical state in a person who is relaxed or performing pleasurable tasks.

* HR -> Heart Rate
** RR -> Respiratory Rate
*** GSR -> Galvanic Skin Response

LastValue (2021-07-19@21:54:27)

Systolic 100 mm Hg

Ideal blood pressure values.

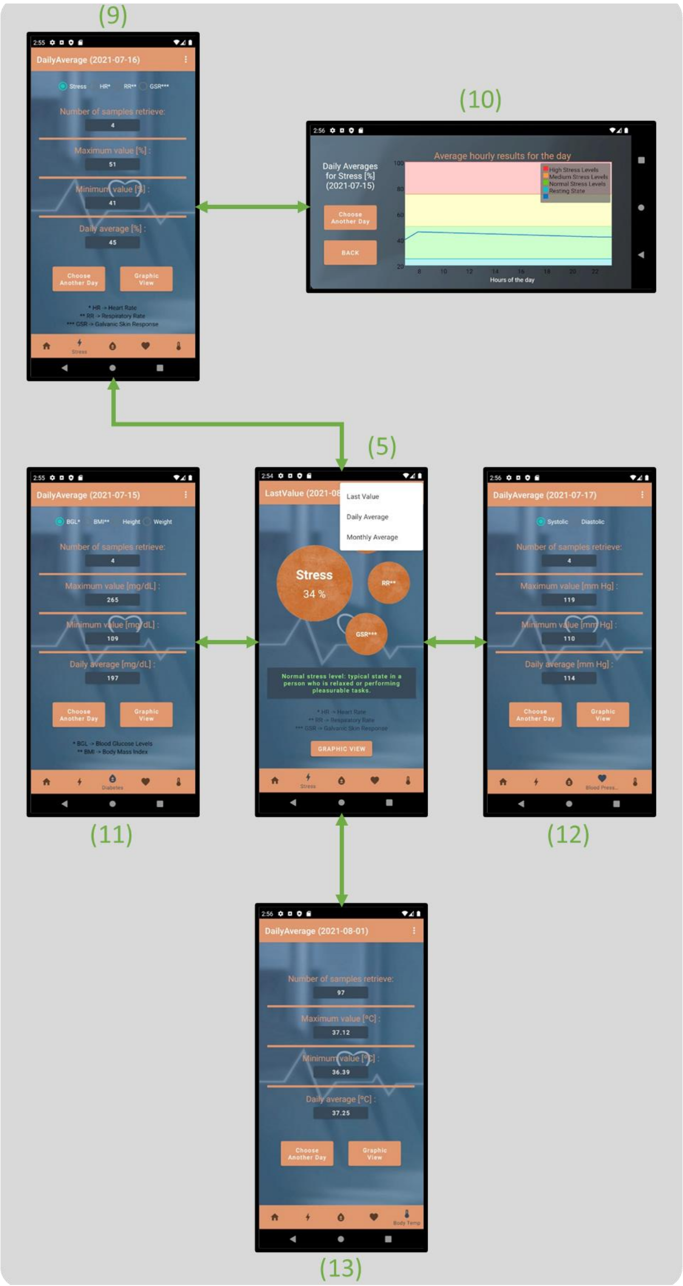
LastValue (2021-08-01@11:38:56)

36.68 °C

Normal body temperature.

Figure 51 – Operation and Transitions of MEDIABETIC HPV (Part 1)

In Figure 52, regardless of the physiological parameter selected, the Daily Average feature allows users to view the number of daily samples, the maximum daily value, the minimum daily value, and the average daily value. In addition, users can select another day using the "Choose Another Day" button or view the data in detail in graphical format using the "Graphic View" button. Point 11 concerns the daily values in the context of diabetes. Point 12 concerns the daily values in the context of blood pressure. Point 13 concerns the daily values in the context of body temperature. Point 9 concerns the daily values in the context of stress, and the respective point 10 concerns the visualisation in graph format of the stress values. Please note that all graphs have a coloured legend according to the boundary zones highlighted on the graph.



DailyAverage (2021-07-16)

Number of samples retrieve: 4

Maximum value [%] : 51

Minimum value [%] : 41

Daily average [%] : 45

* HR -> Heart Rate
** RR -> Respiratory Rate
*** GSR -> Galvanic Skin Response

Daily Averages for Stress [%] (2021-07-15)

LastValue (2021-08

Normal stress level: typical state in a person who is relaxed or performing pleasurable tasks.

* HR -> Heart Rate
** RR -> Respiratory Rate
*** GSR -> Galvanic Skin Response

DailyAverage (2021-07-15)

Number of samples retrieve: 4

Maximum value [mg/dL] : 265

Minimum value [mg/dL] : 109

Daily average [mg/dL] : 197

* BGL -> Blood Glucose Levels
** BMI -> Body Mass Index

DailyAverage (2021-07-17)

Number of samples retrieve: 4

Maximum value [mm Hg] : 119

Minimum value [mm Hg] : 110

Daily average [mm Hg] : 114

DailyAverage (2021-08-01)

Number of samples retrieve: 97

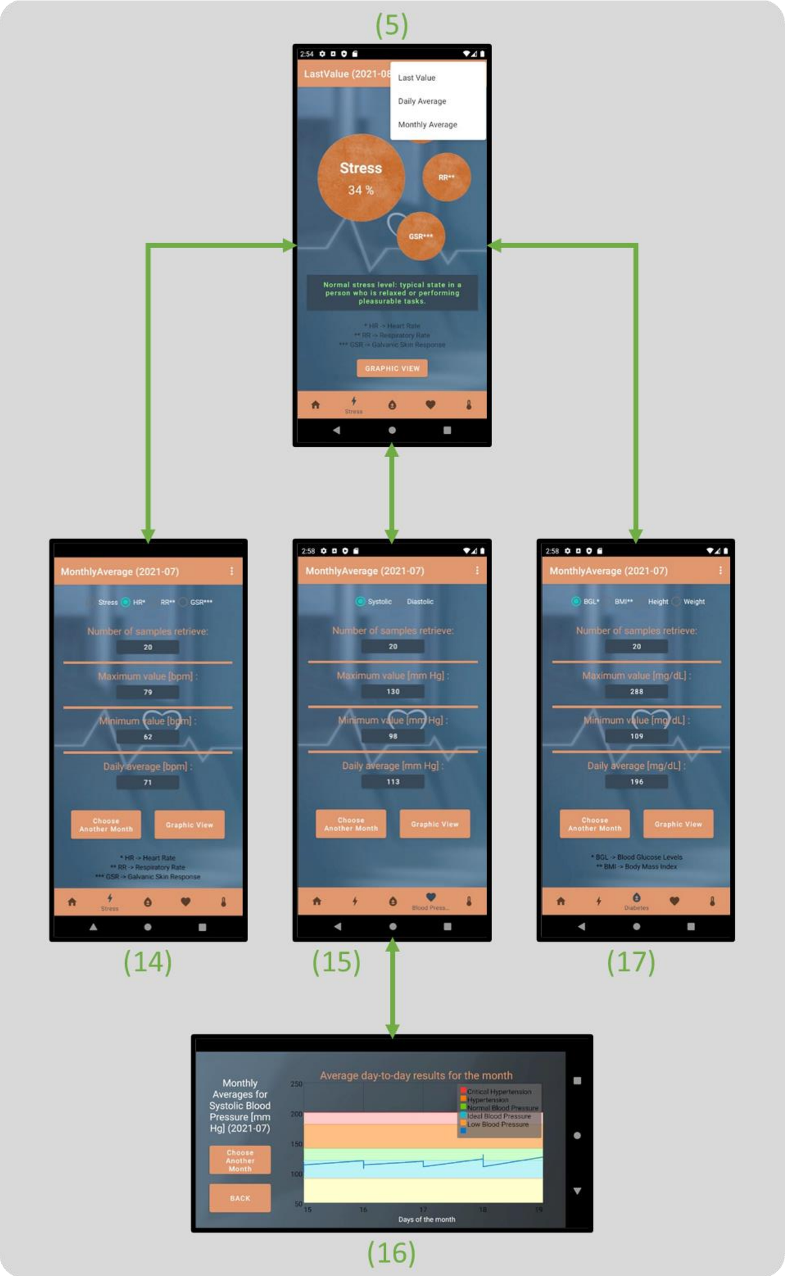
Maximum value [ºC] : 37.12

Minimum value [ºC] : 36.39

Daily average [ºC] : 37.25

Figure 52 – Operation and Transitions of MEDIABETIC HPV (Part 2)

In Figure 53, regardless of the physiological parameter selected, the Monthly Average feature allows users to view the number of monthly samples, the maximum monthly value, the minimum monthly value, and the average monthly value. In addition, users can select another month using the "Choose Another Month" button or view the data in detail in graphical format using the "Graphic View" button. Point 14 concerns the monthly values in the context of stress. Point 17 concerns the monthly values in the context of diabetes. Point 15 concerns the monthly values in the context of blood pressure, and the respective point 16 concerns the visualisation in graph format of the Systolic Blood Pressure values. Please note that all graphs have a coloured legend according to the boundary zones highlighted on the graph.



Normal stress level: typical state in a person who is relaxed or performing pleasurable tasks.

* HR -> Heart Rate
** RR -> Respiratory Rate
*** GSR -> Galvanic Skin Response

Number of samples retrieve: 20
Maximum value [bpm] : 79
Minimum value [bpm] : 62
Daily average [bpm] : 71

* HR -> Heart Rate
** RR -> Respiratory Rate
*** GSR -> Galvanic Skin Response

Number of samples retrieve: 20
Maximum value [mm Hg] : 130
Minimum value [mm Hg] : 98
Daily average [mm Hg] : 113

Number of samples retrieve: 20
Maximum value [mg/dL] : 288
Minimum value [mg/dL] : 109
Daily average [mg/dL] : 196

* BGL -> Blood Glucose Levels
** BMI -> Body Mass Index

Figure 53 – Operation and Transitions of MEDIABETIC HPV (Part 3)

CHAPTER 7

Experimental Results and Discussions

This chapter is dedicated to the experiments conducted with a reduced number of participants due to the covid-19 pandemic situation. Based on experimental results, a set of conclusions could be drawn about the reliability and efficiency of the proposed system for the master thesis. Thus, conclusion can be obtained regarding the interaction between physiological parameters and health conditions, such as diabetes and stress.

For a better understanding of the carried-out work, this chapter is divided into three sub-chapters, which are related to the Participants, Experiments and Procedures, and finally Results and Data Analysis.

7.1. Participants

The validation of the system proposed in this thesis was performed with the participation of volunteers, being divided into a control group (healthy people) and a group of people with diabetes.

Unfortunately, due to the covid-19 pandemic situation experienced at the date of delivery of this thesis, especially the restrictions implemented in Portugal, the country where this work was carried out, only three volunteers were present, however, the presence of one healthy individual and two individuals with diabetes was ensured. In the future, the tests should be extended to more people.

Describing the volunteers in more detail, both are men, aged 26 years, 69 years, and 90 years. It is important to note that the youngest volunteer is the healthy participant, and the middle-aged and older volunteers are diabetics. Note that the volunteers with diabetes also have associated cardiovascular problems, including hypertension.

7.2. Experiments and Procedures

To validate the proposed system for estimating stress levels, as well as the correlation between diabetes and stress, three experiments were carried out with the participants. Note that the results of both experiments will be presented in more detail in subchapter 7.3. (Results and Data Analysis).

7.2.1. Experiment 1: Performance of the Proposed System for Stress Monitoring

In this first experiment, the aim was to observe the behaviour of the proposed system upon stress induction, as well as in the relaxation process. In this way, no algorithm was implemented to estimate stress levels, but instead, the parameters were recorded individually (heart rate, respiratory rate and GSR), thus allowing the impact of this experiment on them to be analysed.

Before proceeding with data acquisition, a short introductory conversation was conducted with the participants, where some questions were asked, including situations and aspects that would affect their daily lives, in order to select videos that would fit into this stressful context, since each person reacts uniquely to each different event.

In order to obtain the data, and after the equipment was placed on each participant, they were asked to watch, for about 5 minutes, videos considered stressful and/or impactful by them (e.g., animal abuse, bullying, football games, irritating people, among others).

In the same way that stress was induced in each participant, the experiment also featured a relaxation period, which again consisted of a 5-minute period where each participant watched a selection of relaxing videos, including audible cues to decrease tension and stress, thus calming each participant.

7.2.2. Experiment 2: Validation of the Method for Stress Estimation

The previous experiment aimed to prove whether the parameters introduced by the proposed system could be used to identify stress, however, this second experiment aimed at something more specific, capable of quantifying stress levels. Therefore, the performance between different methods for estimating stress levels was tested, starting from a simpler method which only considered the GSR, passing through another which combined the GSR with the heart rate, until reaching the final method where the GSR, heart rate and respiratory rate are used simultaneously.

To better manage data collection time, and to avoid asking participants to perform numerous experiments, this experiment coincided with the next experiment (described in subchapter 7.2.3.), but in this case, each participant was asked to perform a self-assessment of the state of stress to compare it with the values obtained by the embedded system. Note that both experiments have different goals, however, the data collection is similar and does not interfere with the purpose of each one.

7.2.3. Experiment 3: Correlation between Stress, Glucose Levels and Blood Pressure

The previous experiment aimed at validating a model for estimating stress levels, and in this third experiment it was studied the correlation between stress, glucose levels and blood pressure.

This experiment lasted for 5 days, and for its realization, the participants were asked to collect data in four different phases of the day, which would allow the analyses of the effect of food intake, as well as the effect of diabetes medication. In these four phases of data collection, each participant would have to take stress measurements with the embedded system, as well as obtaining blood glucose and blood pressure values, both from meters prescribed by their doctors.

Describing more specifically the data collection phases, the first phase should be performed while fasting and the second about 30 minutes after breakfast and diabetes medication, in order to coincide with the beginning of food assimilation by the human body, causing a direct impact on the increase of blood glucose levels, but at the same time ensuring that the effect of the medication has not yet been established (the medication takes about 45 minutes to 1 hour to take effect).

As for the third phase, this takes place around 30 minutes after eating dinner and taking diabetes medication, at which point the body begins to respond to the effect of eating, while the fourth phase occurs between 1 hour and 1 hour and 30 minutes after eating dinner, at which point the medication taken begins to take effect.

7.3. Results and Data Analysis

Subchapter 7.2. (Experiments and Procedures) describes the three experiments carried out to validate the proposed system for the estimation of stress levels, and for the correlation between stress, blood glucose and blood pressure. The results obtained in each experiment are presented below.

7.3.1. Performance of the Proposed System for Stress Monitoring

The performance of the system for stress monitoring was estimated considering the procedure described in subchapter 7.2.1. Interesting results about the dynamics of stress levels were obtained from the tests conducted for the three participants.

Considering that each participant was asked to identify stressful situations for themselves, the results obtained from each were similar, i.e., both had a period of increase (during the stress induction phase) and a period of decrease (during the relaxation phase). These two periods can be observed in Figure 54, presented below. The presented data refer to one of the participants described in subchapter 7.1., more precisely, to the 26-year-old participant. This Figure 54 represents the evolution of the system parameters (heart rate, respiratory rate and GSR) in the face of stress induction over a 5-minute period (from timestamp "16:44:23" to "16:49:13"), and relaxation also over a 5-minute period (from timestamp "16:49:23" to "16:54:13"). Highlighted in orange are the values obtained for respiratory rate. Highlighted in blue are the values obtained for heart rate. Highlighted in green are the values obtained for GSR. Another detail to be highlighted is the graph's axes, as the left vertical axis shows the scale of values for respiratory rate and heart rate, while the right vertical axis shows the scale of values for GSR. In the case of the horizontal axis, this presents the temporal evolution to the second, but since the experiment took place over 10 minutes, the time scale is in the format "hour : minute : second".

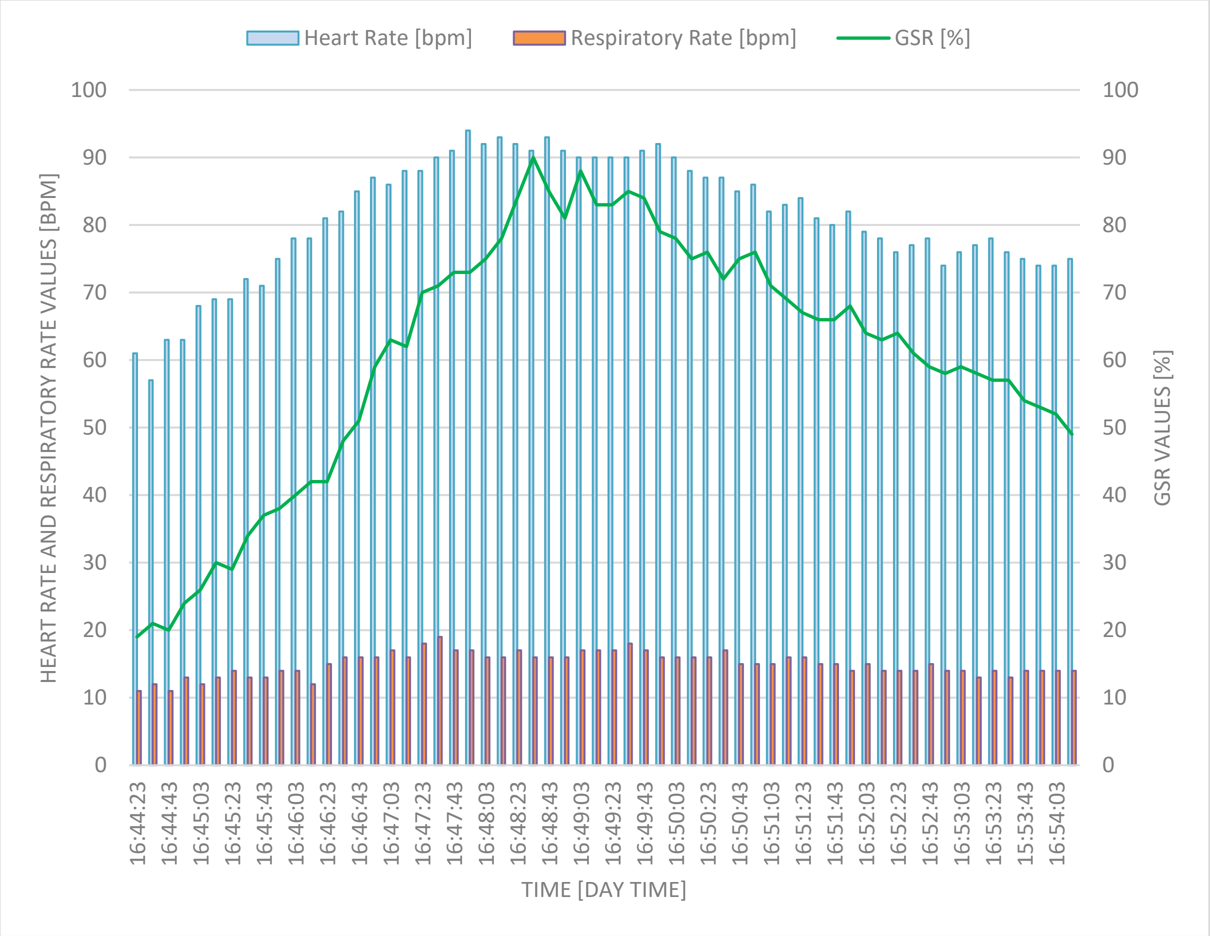


Figure 54 – Reaction of the Human Organism to Stress

Given the data obtained and presented in Figure 54, the process of stress induction was successful, and about 3 and a half minutes after the beginning of the process, the values related to the parameters of the system reached maximum peaks. From these values, I highlight those related to GSR, which present a more accentuated evolution in time, which is in accordance with the fact that most of the proposed works are based only on this parameter to try to estimate stress levels. However, GSR cannot be used alone to estimate stress, and in the case of people suffering from diseases such as hyperhidrosis (excessive sweating), this parameter would no longer be viable for estimating stress.

Another conclusion to be drawn is that the relaxation process is not as fast as the induction of stress, and if during the induction phase it can be observed an increase of around 70% in GSR values, during the relaxation phase, these values decreased by only around 40%. Note that for the remaining parameters the same thing happens, not as accentuated as for GSR, but in general it takes longer for the body to pass from a state of alertness/stress to a state of relaxation, than the opposite process.

Furthermore, it is also possible to conclude from this experiment that the temporal evolution is similar for both parameters, insofar as the induction of stress translates into an increase of the parameters values, and the relaxation translates into a decrease of them, which leads me to believe that the choice of using both parameters in the proposed system for the estimation of stress levels is the right one.

Although the results obtained in this experiment were positive, loud sound tests can be considered, cold stress can also be applied and the change in heart rate, respiratory rate and skin conductivity can always be recorded.

7.3.2. Validation of the Method for Stress Estimation

Through the conclusions drawn from the previous experiment, it was clear to me that the contribution of heart rate, respiratory rate and GSR was something to be considered, and as such, this experiment aimed to understand how these parameters could be used to quantify the stress levels. For this purpose, data regarding heart rate, respiratory rate and GSR were collected, however, in order to validate and determine the efficiency of each proposed method for estimating stress levels, was asked to each participant to record a self-assessment of the stress levels experienced during data acquisition, and this can be seen in Figure 55.

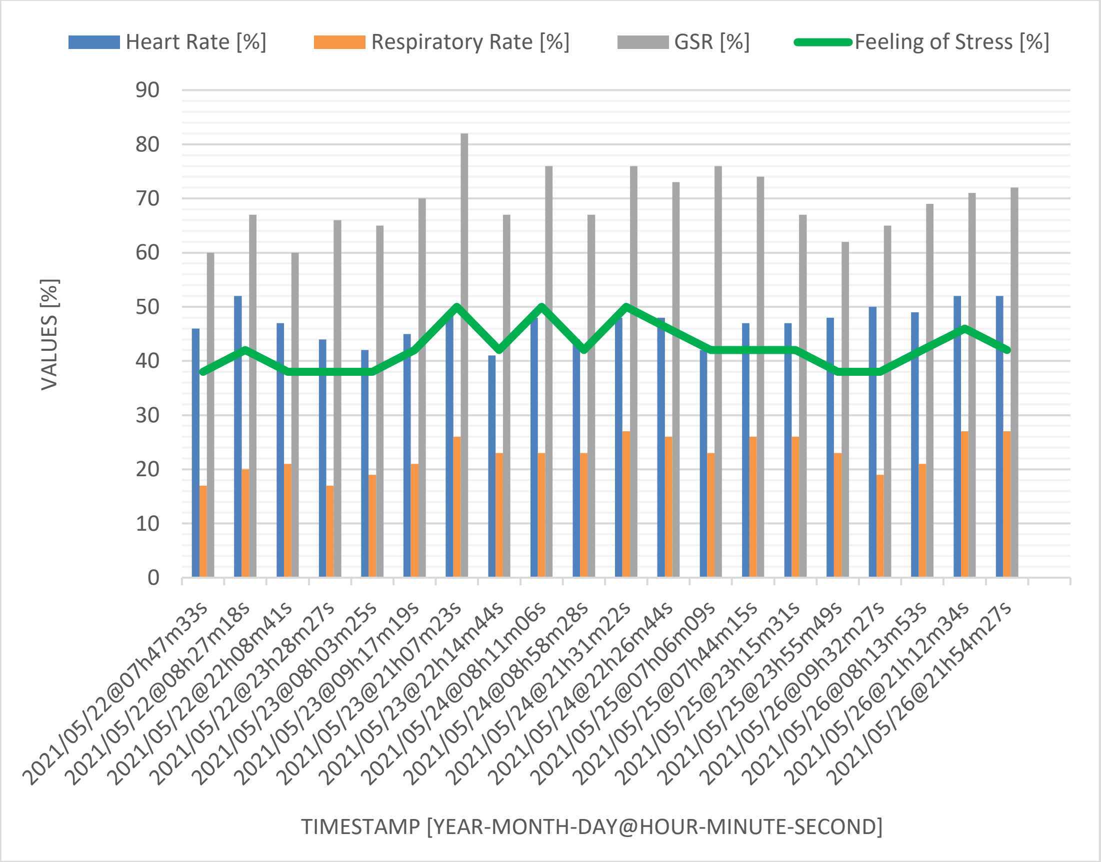


Figure 55 – Data Acquired and Participants' Self-Assessment of Stress Levels

The graph in Figure 55 presents the data obtained in this experiment and to substantiate the results presented in the following figure (Figure 56). These data were obtained from the diabetic participant aged 69 (identified in subchapter 7.1.). In order not to overload this figure with information, it was split between Figure 55 and Figure 56. The blue bars represent the evolution of the heart rate. The grey bars represent the evolution of the GSR values. The orange bars represent the evolution of the respiratory rate. The green curve represents the evolution of the participants' self-assessment of stress levels.

Based on the data obtained and shown in Figure 55, more precisely concerning heart rate, respiratory rate and GSR, some models for stress estimation were applied. The performance of these models is shown in Figure 56. Note that to better associate the data in the two figures, it was chosen to include the participant's self-assessment of stress.

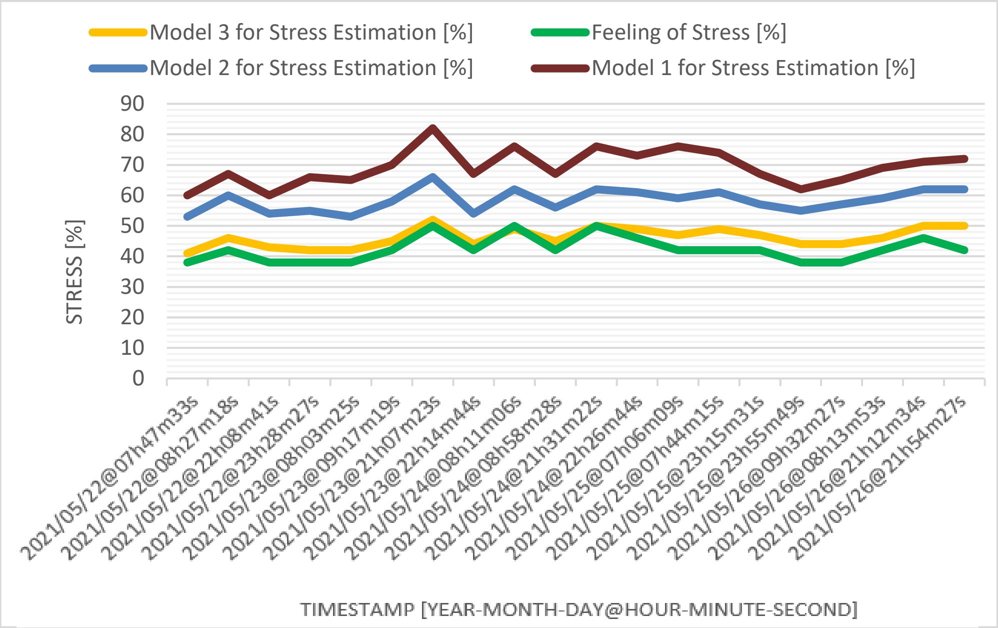


Figure 56 – Performance of the Models Developed for the Estimation of Stress Levels

In Figure 56 are presented, in a comparative way, the performance of the models created for stress estimation, as well as the self-assessment of stress levels by the diabetic participant aged 69 (detailed information on the participant in subchapter 7.1.). The brown curve of the graph represents the evolution of stress levels estimated a-cording to model 1 (based only on GSR). The blue curve represents the evolution of stress levels estimated according to model 2 (based on the correlation between GSR values and heart rate). The yellow curve represents the evolution of stress levels estimated according to model 3 (based on the correlation between GSR values, heart rate and respiratory rate). The green curve represents the evolution of the participants' self-assessment of stress levels.

Based on the data obtained in the first experiment and presented in Figure 54, in relation to the Performance of the Proposed System for Stress Monitoring, it was verified that the three parameters (heart rate, respiratory rate and GSR) showed a good response to stress, to the extent that when stress increased, the three parameters also increased, and when stress decreased, the three parameters also decreased. However, to estimate stress, I would have to understand which parameter would have greater weight in the estimation, which is why I applied the three models to the data obtained.

As can be seen in Figure 56, the model which most closely matches the values of stress self-assessed by the participant was model 3, which correlates heart rate, respiratory rate and GSR. Since there is no exact formula in the literature for estimating stress, the only validation I could do was with how the participant felt. To say that the validation is not grounded is to say that the participant does not know how to define what he feels, in which case it would make no sense for me to do experiments on people. In this way, my model comes close to what the participant communicated, which leads me to affirm that the method proposed, with the weighting of heart rate, respiratory rate and GSR is correct and viable for the estimation of stress levels.

Although the method in use shows very promising results, in further studies I have planned to use machine learning techniques to develop a dynamic and personalized model for each user. Thus, as this future algorithm evolves, I intend it to come closer and closer to the stress levels felt and reported by the participants.

Note that in future, it would also be more practical for participants to use a simple system where they could assess their level of stress by pressing a button, allowing them to change the colours of an RGB LED from green to red, or to light up a number of LED segments according to the self-assigned value of stress.

7.3.3. Correlation between Stress, Glucose Levels and Blood Pressure

In this third experiment, concerning the study of the correlation between stress levels, blood glucose levels and blood pressure, the data was obtained from a 69-year-old participant with health problems associated with diabetes and hypertension.

It is also important to mention that both the blood glucose levels, and the blood pressure values were obtained through the typical monitors available on the market. In this case, the iHealth Track meter was used, which operates according to the recommendations of the World Health Organization (WHO) and being a clinically validated and CE regulated medical device. This monitor has a Bluetooth communication interface, that facilitate the integration into the system considering also the ESP32 Bluetooth communication capabilities.

Regarding the method for data collection, the procedure described in the subchapter 7.2.3. (Experiment 3: Correlation between Stress, Glucose Levels and Blood Pressure) was carried out. The 4 measurement phases proposed in this procedure are intended to analyse the effect of food intake on blood glucose levels (fasting measurement and measurement after breakfast), as well as the effect of diabetes medication (measurement after dinner and measurement after medication has taken effect).

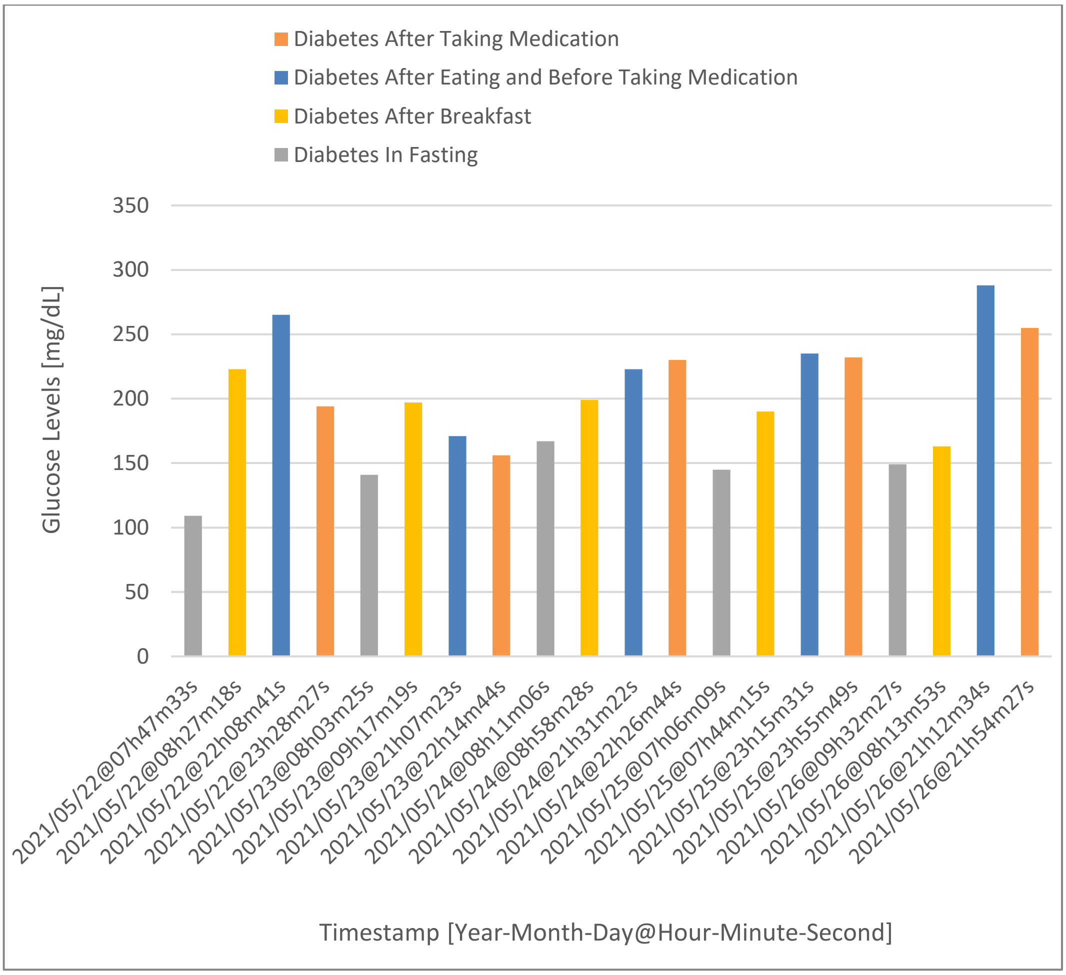


Figure 57 – Blood Glucose Values Obtained During the 5-day Period

In Figure 57 can be observed the evolution of blood glucose values obtained during the third experiment, as well as the separation of these into the 4 phases described in the procedure of this experiment (subchapter 7.2.3). In short, this information allows a visual comparison between the evolution of fasting blood glucose levels (grey bars) and the blood glucose levels after breakfast (yellow bars), as well as comparing the evolution of blood glucose levels after eating dinner and taking medication (blue bars) with the evolution of blood glucose levels after the medication starts to take effect (orange bars).

Based on the data obtained and presented in Figure 57, important conclusions can be drawn, such as the fact that after eating food, more precisely about 30 minutes after eating, the human body begins the process of food digestion, which results in an increase in blood glucose levels. Note that this reaction is normal for anyone, however, for diabetics, this reaction can be quite accentuated, which is why they must take medication after the meal to counteract this effect. On the other hand, it takes between one and one and a half hours for the medication to take effect, and this does not always translate into a decrease in blood glucose values.

The data obtained in Figure 57, are not very relevant for the correlation with stress, however, as the purpose of this study is to help diabetics to improve the management of their disease, I thought it appropriate to conduct this experiment in this way. I believe that the proposed mobile application should be able to recognize these situations and advise the patient, since if after the medication starts to work, the glucose levels do not decrease, this means that the medication is no longer efficient, and as such, the diabetic should seek medical assistance, in order to readjust their medication.

In addition to the conclusions already drawn, it is also important to mention that this data can be used to determine the effect of certain types of food on the body, thus helping patients to identify the best diet for them, i.e., the one that will have the least impact on the increase in blood glucose levels.

Regarding to the correlation between stress levels and blood glucose levels, the experiment carried out highlighted the high correlation, however, this cannot be considered as a correlation performed at the same time instant, that is, if in a certain instant of time the stress levels were increasing, this will not translate into an increase in the levels of blood glucose in that same instant of time.

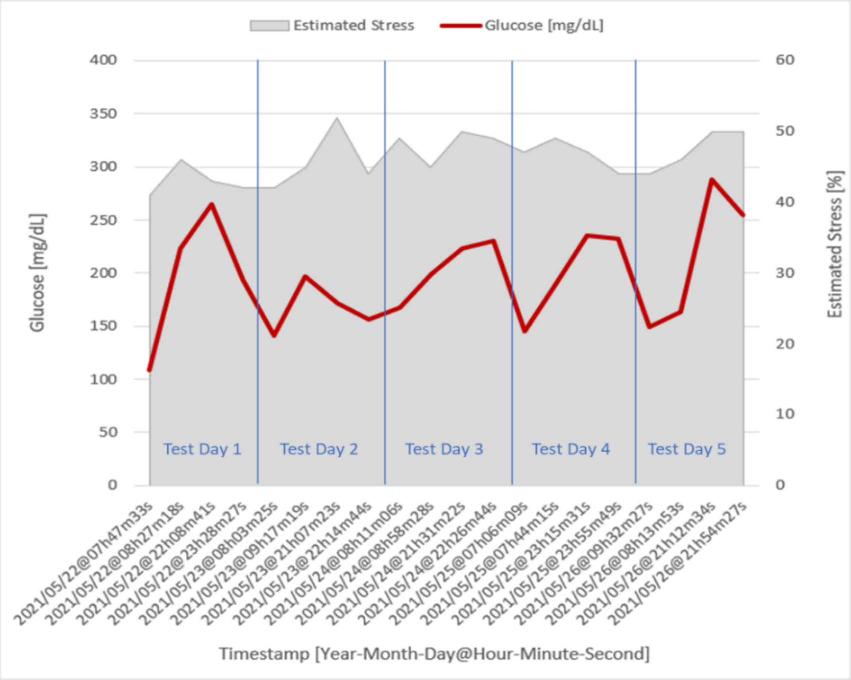


Figure 58 – Comparison Between Blood Glucose Levels and Estimated Stress

In Figure 58 can be observed the data obtained regarding the levels of stress over time, as well as the data obtained regarding the blood glucose levels over time. Note that these data were obtained by performing the third experiment (described in subchapter 7.2.3). Due to the relation between the stress levels and the blood glucose levels, it was decided to add horizontal dividing lines (blue lines), to delimit the days in which the experiment was carried out. Note that this correlation is most noticeable at night because during sleep, the person does not eat, and the body relies on the energy reserves built up during the day. During the day, food intake is constantly raising blood glucose levels, as well as having a stress-reducing effect.

Based on performed experiences, was proven by the data obtained and presented in the figure above (Figure 58), as well as the testimony of some diabetics, is that the levels of blood glucose do not present rapid changes, as the human organism takes time to demonstrate such effects. Besides, I can also add that the time needed for these changes to be quantified, varies from 6 to 10 hours, that is, if at the end of a day a diabetic has stress levels increasing, in the morning immediately after, the levels of blood glucose will be above normal, and this retarding effect is not small, even witnessing quite significant increases in relation to the values established as normal.

Another important point to note is that the relation between stress levels and blood glucose levels cannot be established by saying that when one is above normal, the other will also be above normal. These levels cannot be compared statically, but rather by analysing their behaviour over time. If stress levels remain constant or are decreasing over time, this will translate into a decrease in blood glucose levels. On the other hand, if stress levels are increasing over time, then blood glucose levels will increase.

To further exemplify what has been described above about the relation between stress levels and blood glucose levels, let us consider an example taken from the data presented in Figure 58. At the end of day 1, we can see that stress levels remain constant (about 43%), while blood glucose levels are decreasing. We can consider yet an-other example, this time exploring what was said about the relation between stress levels and blood glucose levels during the day. If we look at the evolution of the data during day 3, we can infer that there were variations in stress levels, as there was a rising phase and a falling phase. However, and by means of what was previously said, during the day the transitions in blood glucose levels are slower due to the activity of the human organism, and as such, we can observe that although there was a decrease in stress levels, when the organism went to react, the stress levels were already increasing again, which resulted in no reversal in the evolution of blood glucose levels, which in turn continued to increase.

Given the promising results obtained with the correlation of stress levels with blood glucose levels, in the future it would be interesting to explore this relation in more detail, and if possible, to implement algorithms capable of mapping the behaviour of one parameter against the other. Ultimately, to develop a predictive model for blood glucose levels based on stress levels, thus proposing a non-invasive method for the acquisition of blood glucose levels, eliminating the need to use the traditional invasive method (taking a blood sample).

Regarding to the correlation between blood pressure and blood glucose levels, no data was obtained which, after analysis, could prove such correlation. Although it is known that there is a relation between blood glucose levels and heart rate, just as there is a relation between blood pressure and heart rate, these facts are not sufficient to prove a correlation between blood pressure and blood glucose levels. However, when studying this possible correlation, an interesting fact concerning heart rate and blood pressure was detected.

In the search for evidence to prove the correlation between blood pressure and blood glucose levels, I found a correlation between blood pressure and heart rate, as they are inversely proportional, i.e., when one increases, the other tends to decrease. This can be seen in the following Figure 59, in which blood pressure and heart rate values were obtained from the participant aged 69 years (described in subchapter 7.1.). Another important aspect to mention is that blood pressure is represented in this figure through its two components, where the red curve represents the evolution of systolic blood pressure values, and the green curve represents the evolution of diastolic blood pressure values. In the case of the blue curve, it represents the evolution of heart rate. For most of the timestamps in which samples were obtained, it can be seen that while the heart rate decreases, the blood pressure increases.

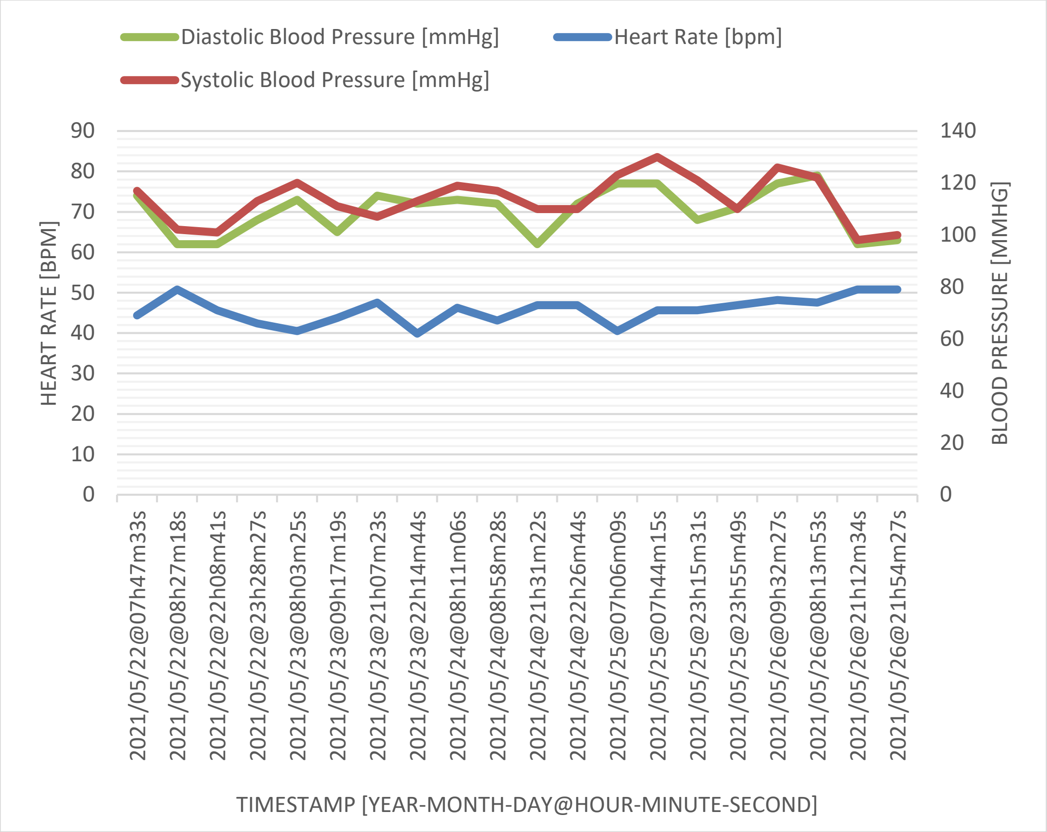


Figure 59 – Comparison Between Blood Pressure Values and Heart Rate

The data obtained and presented in Figure 59 is interesting because, in most cases, increased heart rate is associated with increased blood pressure, and this is due to blood viscosity. However, in this case, with the participant aged 69 years, diabetic and with hypertension, when the heart rate increases, the blood glucose levels decrease. This may be due to taking medication for arterial hypertension. When the heart rate increases, the veins and arteries dilate, thus compensating for the increase in pressure and eventually decreasing it to what are considered normal values. On the contrary, when the heart rate decreases, the veins and arteries decrease their volume, thus compensating for the decrease in pressure, and eventually increase the pressure to values considered normal.

Overall, the obtained results are satisfactory and can be considered the starting point in a general study of the relation between diabetes, stress, and blood pressure. Extended tests will be carried out with healthy and people with diabetes.

As regards limitations, it must be considered the types of blood pressure monitor available on the market, which are divided into wrist monitors and upper arm monitors. If wrist monitors invest more on mobility and reduced size, in terms of precision, they are not as efficient as upper arm monitors, and this is due to the fact that the wrist area is narrower, not containing so many arteries and of greater thickness. In addition, these monitors measure the pressure exerted on the cardiac muscle, and as such, they must be at the same level as the heart [80].

Finally, it is also important to mention that the values obtained for body temperature and the attempt to correlate them with diabetes and/or stress was not successful, as it is not possible to state that the increase in stress levels is associated with an increase in body temperature, because for certain people, a stressful event may lead to a decrease in body temperature, but for other people the same event may lead to an increase in body temperature. Moreover, the same person experiencing the same event may react differently, for example, depending on his/her mental state, and in this case, at the first time he/she may have presented a decrease in temperature, while at the following time he/she may have presented an increase in temperature. As such, it is possible to verify that there is indeed a relation between stress and body temperature, however, further studies are necessary to determine which factors are responsible for such behaviour. These conclusions are in line with the state of the art previously established concerning body temperature and stress.

Another aspect to be considered is that blood glucose levels are obtained in a single measurement, i.e., most glucose meters do not allow the continuous monitoring of blood glucose levels, which made it difficult to correlate them with body temperature. However, it should be considered that blood glucose levels affect the efficiency of the human body's regulation of body temperature. In the tests performed for stress induction, it can be verified that the behaviour of body temperature is a little different for non-diabetic individuals, diabetic individuals with controlled disease and diabetic individuals with poorly controlled disease, that is, for both the 26 year old participant (non-diabetic) and the 90 year old participant (diabetic with controlled disease), stress induction causes a variation in body temperature (slight rise or slight fall in temperature), followed by a longer period for its stabilisation.

On the other hand, in the 69-year-old participant (diabetic with poorly controlled disease), stress induction causes a considerable oscillation in body temperature (in this case, an increase), followed by a period in which it is maintained, until entering a third, longer phase in which body temperature begins to stabilise. Considering the behaviours described, it was found that uncontrolled diabetes (blood glucose levels considered above the recommended level), makes body temperature regulation more difficult, requiring more time to stabilise.

CHAPTER 8

Conclusions and Future Work

The implemented multichannel sensing system provides high level of interactivity and mobility, allowing the visualization of the user´s health status parameters in real time, including the stress levels. For this purpose, a mobile application was successfully developed and validated for a small number of users. The way in which this work combines an efficient system with a considerable number of important components and mechanisms for the acquisition of physiological parameters, with the mobility and appealing interface of the mobile application, is an asset to help patients with diabetes to understand a little better how their daily routines influence their well-being, especially when many of these patients think that controlling diabetes is the same as controlling what they eat. In addition, the use of RFID technology provides extra comfort to users in terms of user identification, along with the presence of an SD memory card, which in case there is no internet connection to store the data remotely, saves it locally, ensuring that none is discarded.

Regarding the experimental validation carried out to determine the correlation between stress, diabetes and blood pressure, important results were obtained that can be used to draw a relation between these considered parameters. Thus, can be highlighted the need to include mechanisms to monitoring and help to manage the nervous system responses in the daily lives of diabetics, who, even if they practice a healthy lifestyle and a dedicated monitoring of their blood glucose levels, should have redoubled concerns about how to manage their nervous system in the face of various situations.

As for future work, can be mentioned the development of intelligent algorithms for estimating stress levels with higher accuracy and the validation of these kind of algorithms form more than 10 volunteers (healthy and with diabetes). Considering that this work aims to help diabetics in their daily life, giving primacy to an intelligent and mobile interface of easy interaction with the user, in the future it will be interesting to add channels for measuring glucose levels and blood pressure incorporated into the system, and not resort to devices available on the market. Note that users of the developed mobile application can add the glucose and blood pressure values, however, if these meters are part of the system, the data would be synchronized and added automatically.

Furthermore, the developed system bets on mobility and simplicity for the user, however, it is not something that the user can use during his/her daily routine, i.e., the user can carry the equipment with him/her, and perform data acquisition at any time, however, he/she cannot move around at the same time that he/she acquires data. Stress is something complex and that varies from person to person, and varies particularly depending on the activity performed, and as such, for a better analysis and application of AI in the future, it will be essential to develop a wearable device capable of accompanying the user in any activity, similar to, for example, a smartwatch.

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Attachments

Appendix A – ATEE 2021 Certificate of Participation

This certificate serves as proof of participation in the 12th International Symposium on Advanced Topics in Electrical Engineering (ATEE), 25-27 March 2021, Bucharest, Romania, where the article included in Appendix D was accepted, presented, and published.

The 12th International Symposium on
ADVANCED TOPICS IN ELECTRICAL ENGINEERING
Bucharest, March 25-27, 2021

A RESOLUTION OF APPRECIATION

TO

Gonçalo Ribeiro, Octavian Postolache

FOR PRESENTING

SENSORS AND MOBILE INTERFACES FOR STRESS LEVEL MONITORING IN PEOPLE WITH DIABETES

Be it therefore resolved that the Conference Chairs shall express, on behalf of ATEE 2021, it's deep appreciation for this outstanding contribution to the advancement of the electrical engineering industry's technology.

Dragos NICULAE,
Technical Conference Chair

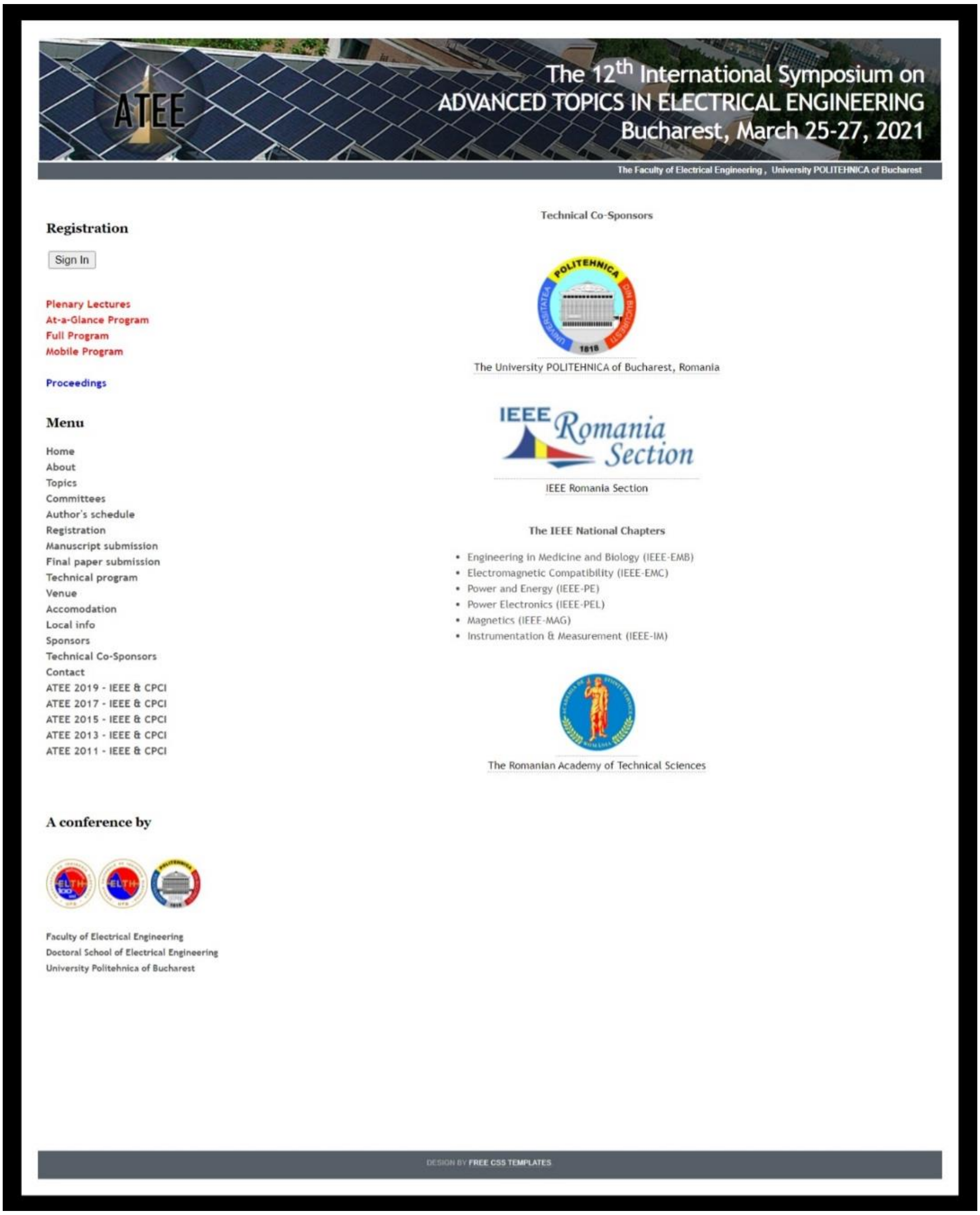
Alexandru MOREGA,
Scientific Conference Chair

Figure 60 – ATEE 2021 Certificate of Participation

Appendix B – Published Article

Article: **Sensors and Mobile Interfaces for Stress level Monitoring in People with Diabetes**

This article has been accepted, presented, and published in 12th International Symposium on Advanced Topics in Electrical Engineering (ATEE), 25-27 March 2021, Bucharest, Romania.



The 12th International Symposium on
ADVANCED TOPICS IN ELECTRICAL ENGINEERING
Bucharest, March 25-27, 2021

The Faculty of Electrical Engineering , University POLITEHNICA of Bucharest

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Figure 61 – 12th International Symposium on Advanced Topics in Electrical Engineering Homepage

THE 12th INTERNATIONAL SYMPOSIUM ON ADVANCED TOPICS IN ELECTRICAL ENGINEERING
March 25-27, 2021
Bucharest, Romania

Sensors and Mobile Interfaces for Stress level Monitoring in People with Diabetes

Gonçalo Ribeiro, *Student Member IEEE*, Octavian Postolache, *IEEE Senior Member*
ISCTE-Instituto Universitário de Lisboa and Instituto de Telecomunicações, Portugal
goncalo_tome_ribeiro@iscte-iul.pt, opostolache@lx.it.pt

Abstract **Stress is a natural feeling of not being able to cope with specific demands and events. The stress can become a chronic condition if a person does not take measures to manage it. Several stress meters have been proposed over the years, however still a reduced number of variables were considered mainly the skin conductivity and/or heart rate. Additional variables can be considered such as respiratory rate can be relevant to the estimation of stress level. In this paper, a prototype to measure and predict the stress levels is presented together preliminary experimental values. Moreover, a mobile application was also developed for users' stress assessment.**

Keywords**: Stress, Diabetes, Respiratory rate, Galvanic Skin Response, Heart Rate, Mobile Application.**

I. INTRODUCTION

Cities are large population centers, and daily, people have stressful lives, whether on the way to work, due to traffic, or even related to personal or professional problems. This lifestyle can bring people to form higher stress levels that cause a health problem, especially in subjects suffering from chronic diabetes.

This project was developed focusing on the large group of diabetes patients who suffer from complications due to the fickle variations of their nervous system. Diabetes has several types, the most common being type 2 diabetes, where in a large number of patients there is a strong relation between blood glucose levels and the nervous system, that is, there is a direct relation between increasing the levels of stress and increasing the levels of blood glucose.

In many cases, diabetes patients do not understand why glucose levels are so high, especially when they put in place a balanced diet and healthy lifestyles. In this situation, the purpose of a stress meter will be to provide patients with clear and detailed information not only about stress levels, but also about heart rate and respiratory rate, so that they realize the importance of maintaining good mental health, allowing them to identify and avoid stressful everyday situations.

There are some interesting solutions reported in the literature about stress monitoring systems [1]-[2]-[3]. However, most of them are using only the values of the skin conductivity, which does not allow an accurate calculation for stress levels. For accurate measurement of the stress level, additional physiological parameters may be considered such as heart rate and respiratory rate [4].

In this paper, a system for stress levels monitoring is proposed and described. To this end, some important health parameters will be collected, such as, heart rate, respiratory rate, and skin conductivity, which after analysis and correlation, aim to obtain a relatively accurate estimation of stress values. Furthermore, it is developed a mobile application to display the results, through tables and graphs, to give a more detailed perspective of the obtained values. The developed app allows the users to determine which environments are most stressful for them, so that they can be avoided. These results can even be presented in a singular or correlated manner, to provide users with an assessment of their current health status and possible guidelines for the future.

This paper is structured as follows. Section II present a small review of the literature for a better theoretical framework. In Section III, the system is described, and the materials used as well. In particular, the system architecture is presented and studied. Section IV is devoted to describing, in an easy way, the parameters used. In Section V some tests were performed to obtain the levels of stress, besides withdrawals of conclusions and identified limitations. Conclusion and future work follow.

II. RELATED WORK

Given that the main purpose of this project was to create something useful and complementary to diabetes, for type 2 patients, it is important to introduce key aspects about it and about stress.

A. Diabetes

Diabetes is a chronic disease resulting from the absence of insulin, caused by the body's inability to use the sugar that circulates in the blood, causing it to accumulate (hyperglycemia), which can even affect other systems of the body. Although blood glucose level is the most common parameter in diabetes control, there are also other important parameters to monitor, such as weight, blood pressure, heart rate or emotional state related to the human nervous system [5].

Currently diabetes is a widespread chronic disease which begins to be something quite common in the most developed countries, and can go up to 10 different types, from insulin-dependent diabetes, gestational diabetes in pregnant women, diabetes as a consequence of genetic mutations, or even

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diabetes derived from glucagonomas and pancreatic diseases [5].

Despite the variety of types, the most common is type 2 diabetes, having as main risk factors obesity, sedentary lifestyle, and genetic predisposition, which through prevention and control of these factors, can be avoided [5]. Basically, this condition is due to the imbalance of glucose levels, which can increase above normal, or even decrease drastically. Another very important aspect is the fact that this type is strongly linked to variations of the nervous system.

B. Stress

Stress is a feeling of tension or pressure, being directly associated with daily experiences or situations. In addition to exerting a burden on people's lives, stress can also negatively affect the management of chronic diseases, such as cardiovascular diseases, respiratory diseases, diabetes, among others. In this way, monitoring of stress should be part of the daily routine of the patients, being easily included in the period dedicated to medication, or in the case of diabetics, during the period for the measurement of glucose levels [2]-[3].

C. Market Study

In addition, it was also essential to conduct a market study on mobile applications dedicated to stress, however, their number is still small. Furthermore, of the mobile applications that fall into this small group, they only ask the user about his daily routine and how he feels in certain situations [16]-[17].

There are even applications that use the smartphone camera to estimate the heart rate and the activity performed by the user, however they do not make use of any smart sensor to directly acquire data, which consequently affects the quality and effectiveness of such applications [16]-[17].

Taking into account the limitations of the mobile application market for monitoring stress levels, then arises the opportunity to combine the best of both worlds, namely on the one hand to have an efficient system for obtaining and processing physiological parameters important for stress (heart rate, respiratory rate and skin conductivity) and, on the other hand, to attach this system to an accessible mobile interface, ensuring that users are able to monitor and obtain more accurate and reliable advices, thereby helping in their search for well-being.

III. SYSTEM DESCRIPTION

The architecture of the proposed system is presented in Fig.1. It includes multicore computation platform, a sensing unit, a real time database and a mobile application.

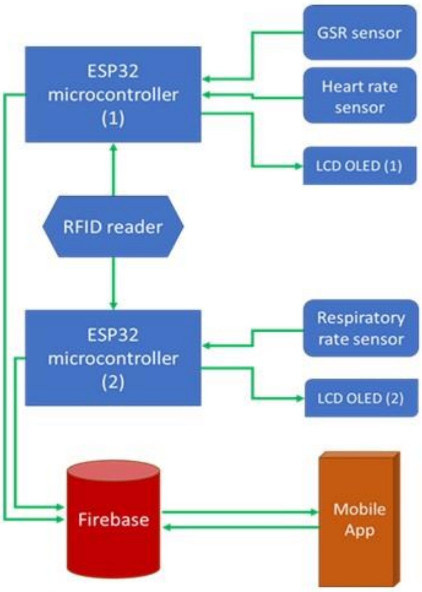


Fig. 1. Stress Assessment System Architecture

A. Sensory component

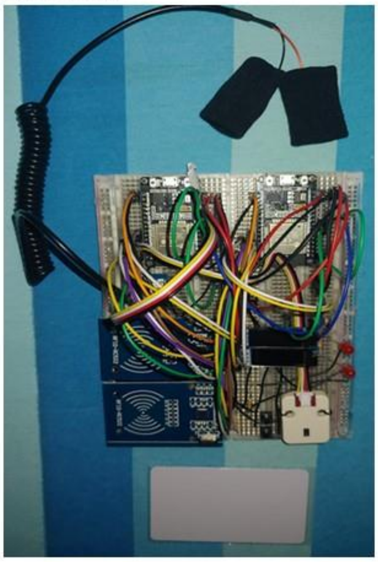


Fig. 2. Sensing unit prototype

The sensing unit includes two modules. The module 1 is responsible for data acquisition, data processing, and sending heart rate and skin conductivity data to the database. It includes:

- Pulsioximeter sensor (m5stack max30100) – to acquire heart rate.
- Skin conductivity sensor (GSR) with finger electrodes.
- Microcontroller ESP32 (1) - this is one of the two microcontrollers present in this system, being responsible for processing the values acquired by heart rate and skin conductivity sensors, and for sending the data via Wi-Fi to the database. This microcontroller also has the particularity of implementing a Real Time Clock (RTC) to enable an organized storage of the data, something fundamental for the correlation of the data and layout in graphs.
- LCD OLED 1636 (1) - it allows the user to check the heart rate and skin conductivity data being obtained by the respective sensors.

The module 2 is responsible for acquiring, processing, and sending respiratory rate data to the database, and contains the following materials:

- 3 Axis 16g Digital Accelerometer (BMA400) and elastic strip - these two materials were used in the development of a prototype for respiratory rate measurement, where the variation of the accelerometer axes results in the increment of a counter programmed to provide the number of breaths per minute within a period of 10 seconds.
- Microcontroller ESP32 (2) - this is the other of the two microcontrollers present in this system, being responsible for processing the values acquired by respiratory rate sensor, and for sending the data to the database as implemented in Microcontroller ESP32 (1). This microcontroller also implements an RTC.
- LCD OLED 1636 (2) - it allows the user to check the respiratory rate data being obtained by the respective sensor and the timer for the acquisition of these values.

In addition to the material presented above, the following materials were also used:

- RFID-RC522 - this reader, when approaching an RFID tag, allows the microcontroller to store a unique ID, which is sent to the database together with the processed data, thus ensuring privacy, that is, it allows the mobile application to access to them through authentication.
- Breadboard.
- Jumper cables.
- LEDs - to indicate that the data is being sent to the database.
- Push Buttons - allow user switching, in other words, stop data acquisition and allows the user to present new RFID tag.
- 220 Ω resistor for LEDs.
- 10 KΩ resistor for push buttons.
- RFID tags for user's identification.

To understand a little more about the functioning of the sensory system, especially about the two modules present, the wiring diagrams in figures 3 and 4 were created.

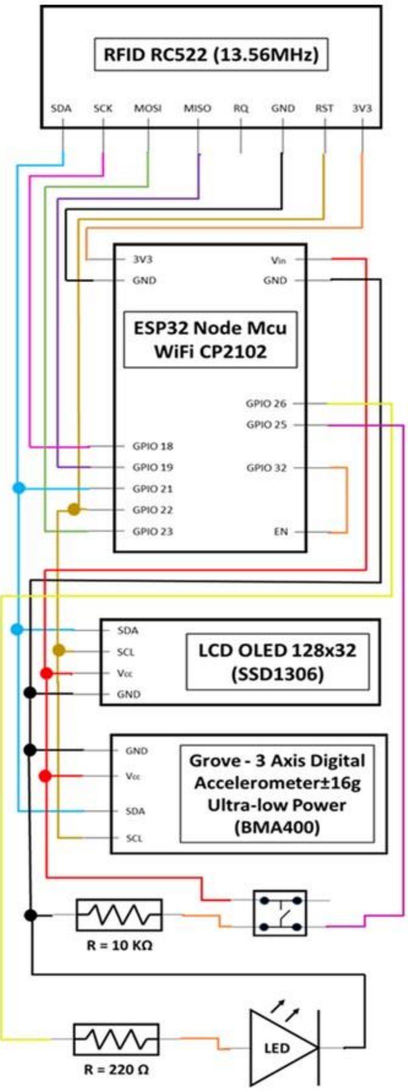


Fig. 3. Module 2 wiring diagram

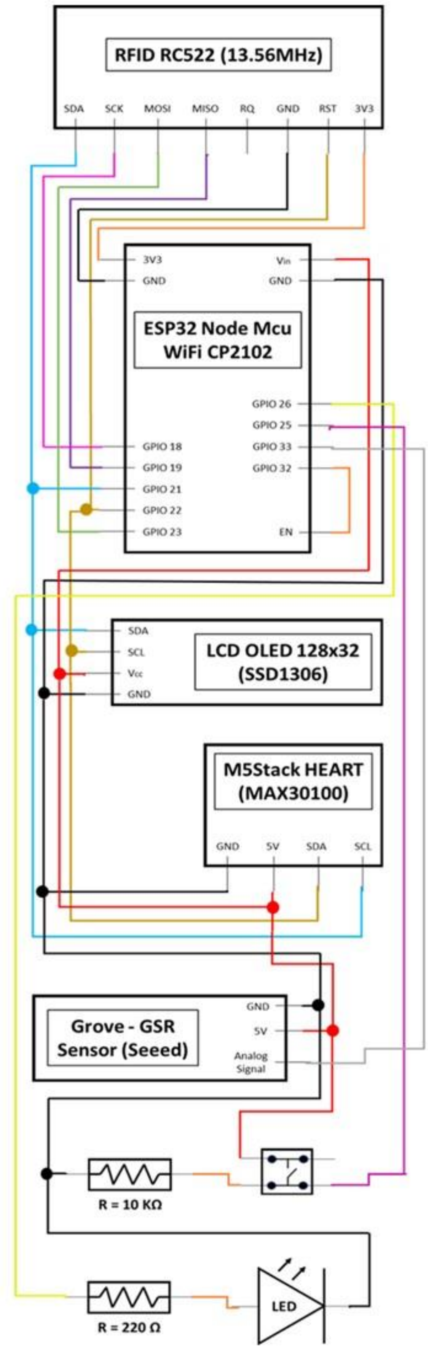


Fig. 4. Module 1 wiring diagram

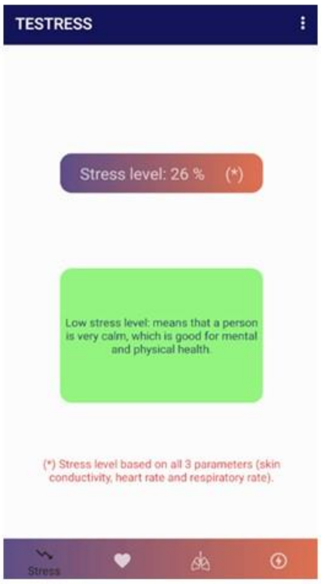
Regarding its operation, the user only must bring the RFID tag closer to the reader so that both microcontrollers recognize it and start the data collection process. In module 1 the values of heart rate and skin conductivity are collected, and in module 2 the values of respiratory rate are collected. It is important to note that this division into modules practically independent of each other was necessary because the sensor intended to obtain the respiratory rate requires a periodic cycle of 10 seconds, which interfered with the sensor intended to obtain the heart rate. At any time, the system can change users, simply by press the button available on breadboard.

B. Mobile application

The mobile application starts with the main screen, where the logo is displayed and where some resources are loaded for its operation, followed by the login screen, where the user can enter their access credentials (email and password) to log in, or if they have not yet registered, they can do so. Note that for the registration, some user data will be requested, such as first name, last name, date of birth, email, password, and RFID tag ID.

Fig. 5. Mobile application screen corresponding to the registration of new users

Once logged in, the user can choose to view each parameter in real time, i.e. heart rate, respiratory rate, skin conductivity and stress. In the event of stress, the remaining parameters are correlated using the algorithm implemented for estimating stress levels.



Stress level: 26 % (*)

Low stress level: means that a person is very calm, which is good for mental and physical health.

(*) Stress level based on all 3 parameters (skin conductivity, heart rate and respiratory rate).

Fig. 6. Mobile application screen corresponding to the viewing of real time data and little information related to these

In addition to the real-time values, the user can also view his daily averages (number of samples acquired, maximum value, minimum value and average value) or his monthly averages (similar to the daily averages, but in this case the averages are weighted according to month and not day), both for the parameters mentioned.

Number of samples retrieve today: 10

Maximum value: 30

Minimum value: 3

Daily average: 15

Fig. 7. Mobile application screen corresponding to stress daily averages

Another interesting feature is the possibility for the user to visualise their data in graphs. These graphs can be daily, where the hourly average of each parameter is taken, or monthly, where the daily average of each parameter is taken. There is also a third type of graph, where the last 30 values obtained are displayed, allowing the user to view the data acquired with a minimum period of every 10 seconds.

Overall, the mobile application plays an important role in this system, as it allows access to the data stored in database, thus enabling users to observe them arranged in tables and graphs. In addition, it implements the algorithm responsible for estimating stress levels based on the remaining parameters (heart rate, respiratory rate, and skin conductivity).

It is also important to mention that for the development of the mobile application, was chosen the platform "Android Studio", which allows to develop native Android applications, being made available for computers with Windows, MAC and Linux operating systems [6]. This platform has very useful features such as Smart Code Editor, Machine Learning (ML) [7], Security and Privacy [8]. In addition to these features, this platform, as regards access and writing of data, works very well with Firebase databases.

C. Firebase database

Databases are very important tools in data analysis and Machine Learning because they enrich and "feed" the intelligent algorithms used. As such, there are several platforms that can be used as a database, being some more specialized in data processing and implementation of algorithms, and others more advantageous for quick access and personalized organization by type of data [9].

For the implementation of this project, Google's "Firebase" platform was chosen. It is used for the creation of mobile applications and web applications, being compatible with IOS, Android, Web, Unity and C++. This platform not only allows to quickly connect with the application to manage the infrastructure (analysis, databases, messages, and error reports), but also provides high level of integration with cloud storage, use of machine learning techniques, fast and secure authentication methods, fast real-time access, and more [9].

The Firebase data is stored by account ID (RFID ID) and is divide into:

- Realtime – the values measured by the sensors in real time.
- Storage – all values stored and sourced from the sensors, as well as data processed by the mobile application.

IV. MEASURED PARAMETERS

Due to the covid-19 pandemic situation we are in, the data was obtained from two individuals, however, only one of them had diabetes. To evaluate the behavior of the system in different situations, tests were performed in different contexts, making each type of data vary at a time, to determine the relation of dependence between them.

For the type of data generated and analyzed, these relate to heart rate (expressed in Beats Per Minute and acquired from the Pulse oximeter sensor), respiratory rate (expressed in Breaths Per Minute and acquired from the prototype developed with the elastic tape and the accelerometer), skin conductivity (expressed in percentage and acquired from the GSR sensor) and stress levels (expressed in percentage and calculated from the correlation of the other data mentioned).

A. Heart rate (BPM)

Heart rate is the speed of the cardiac cycle measured by the number of heart contractions per minute (bpm). It may vary according to the body's physical needs, including the need for oxygen absorption and excretion of carbon dioxide. It is usually equal to or close to the arterial pulse measured at any peripheral point. It can be altered by physical exercise, sleep, anxiety, stress, disease, or drug ingestion [10] [11].

In a general way, heart rate can be categorized as follows:

TABLE I
LEVELS FOR HEART RATE

Heart rate	Information	Symptoms/Consequences
< 60	Low heart rate (bradycardia)	Fatigue, dizziness, confusion, feeling faint, possible infection, high blood potassium levels, active thyroid gland, risk of heart attack
60 – 100	Normal heart rhythm	--------------------
> 90	Relatively high heart rate	--------------------
> 100	High heart rate	Fatigue, dizziness, palpitations, chest pain, difficulty breathing, possible infection, low blood potassium levels, anemia, very active thyroid gland, heart disease (cardiomyopathy, tachycardia, among others)

Heart rate has a direct link to stress, in the way that when a person is stressed, his or her body releases adrenaline, temporarily causing an increase in heart rate, which in turn translates into an increase in blood pressure. Furthermore, high blood pressure can cause damage to the arteries, creating blood clots and increasing the risk of heart attack.

B. Respiratory rate

Respiratory Rate is the designation for the number of breathing cycles (breathing in and breathing out) that an individual completes per minute (Breath Per Minute - BPM). The rhythmic movement between inspiration and expiration is regulated by the nervous system and is repeated at a rhythm that is characteristic of the physiological state of everyone. Note that if an adult at rest exceeds 20 BPM, we are facing a situation of Tachypnea (violent physical exertions that can be indicative of lung disease, heart disease, fever, anxiety, or poison contamination), while if it is less than 12 BPM, we are facing a situation of Bradypnea (slow breathing that can lead to Apnea or low concentration of oxygen in the blood, which leads to situations of Hypoxia) [12].

The normal respiratory rate as a function of age is established as follows [12]:

- New-born: about 44 breaths per minute.
- Children: 18-30 breaths per minute.
- Pre-teens: 20-30 breaths per minute.
- Adolescents: 18-26 breaths per minute.
- Adults: 12-20 breaths per minute.
- Adults over 65: 12-28 breaths per minute.
- Elderly over 80 years: 10-30 breaths per minute.
- Adults practicing sports: 35-45 breaths per minute.
- Athletes: 60-70 breaths per minute.

Respiratory rate has a direct link to stress, in the way that during the human body's response to stress, a person breathes faster to quickly deliver oxygen-rich blood throughout his or her body. If a person has a breathing problem such as asthma or emphysema, stress can make breathing even more difficult.

C. Skin conductivity

It varies with the state of sweat glands in the skin. Sweating is controlled by the sympathetic nervous system, and skin conductivity is an indication of psychological or physiological arousal. If the sympathetic branch of the autonomic nervous system is highly aroused, then sweat gland activity also increases, which in turn increases skin conductivity.

Thus, skin conductivity can be a measure of emotional and sympathetic responses [13] [14] being categorized as follows:

TABLE II
LEVELS FOR SKIN CONDUCTIVITY

Skin conductivity	Information	Symptoms/Consequences
0% – 31%	Low levels	Does not pose a problem or risk to human health
32% – 82%	Normal levels	Does not pose a problem or risk to human health
83% – 100%	High levels	It does not pose any problem or risk to human health, however, there is a high psychological stimulation (increased emotional response) and greater sweat production

D. *Stress*

Stress is the response of our body to an event or situation of pressure in our lives [3] [15], and in a general way, can be categorized as follows:

TABLE III
LEVELS FOR STRESS

Stress	Information	Symptoms/Consequences
0% – 25%	Resting state	-------------------
26% – 50%	Low stress levels	-------------------
51% – 75%	Normal stress levels	-------------------
76% – 100%	High stress levels	Difficulty controlling emotions, heart problems, teeth and gums problems, weight gain, weakened immune system

V. RESULTS AND DISCUSSION

Initially, for the stress calculation, the algorithm developed only weighted the skin conductivity values, but this was not ideal, since for people suffering from diseases such as hyperhidrosis (excessive sweating), the algorithm would easily cease to be adequate.

In a second instance, the stress estimation algorithm was based on the correlation between heart rate values and skin conductivity values. The results obtained in this second model were more adequate and the estimation of stress was relatively efficient, although the component of the calculation corresponding to the skin conductivity overlapped with the component corresponding to the heart rate, which resulted in stress levels that were sometimes too low for real situations. Furthermore, in situations where the user suffers from heart disease, such as tachycardia (high heart rate), the method was no longer effective.

With the development of a sensor to measure respiratory rate, the final version of the algorithm for stress estimation then relies on the correlation between this, heart rate and skin conductivity.

In more technical detail, the algorithm for estimating stress levels converts the values of heart rate and respiratory rate to percentages within the range of possible values. Note that in the case of skin conductivity, the GSR sensor library itself already performs the conversion from voltage to percentage, and as such, this data does not require further treatment.

An important detail in the conversion of the heart rate from beats per minute to percentage is the need to determine the maximum possible value for this parameter, which is performed through equation (1). To determine the maximum value of the heart rate for each subject, it is necessary to know their age, which made it mandatory to include it in the registration of new users in the mobile application.

$$MAX_{Heart\ Rate} = 220 - age \tag{1}$$

Once the maximum heart rate for the subject is known, equation (2) can then be applied, i.e. this equals 100%, and making use of the heart rate collected by the sensor, the heart rate in percentage is obtained.

$$Heart\_Rate[\%] = \frac{Heart\_Rate \times 100}{MAX_{Heart\ Rate}} \tag{2}$$

As with the heart rate, to convert the respiratory rate from breaths per minute to percentage, it is also necessary to determine the maximum possible value for this, but this does not depend on age. There is no maximum value communicated by health entities for respiratory rate, but it is common in many athletes who practice sports with enormous physical effort, to present maximum values for respiratory rate in the order of 70 breaths per minute, and as such, in this system it was admitted as a maximum value (3), i.e. this equals 100%, and making use of the respiratory rate collected by the sensor, the respiratory rate in percentage is obtained through equation (4).

$$MAX_{Respiratory\ Rate} = 70 \tag{3}$$

$$Respiratory\_Rate[\%] = \frac{Respiratory\_Rate \times 100}{MAX_{Respiratory\_Rate}} \tag{4}$$

After determining the heart rate and respiratory rate, both in percentage, and obtaining the skin conductivity value also in percentage directly from the sensor, it is then possible to apply the algorithm developed in this system for the estimation of stress levels, which is based on the weighted average of the 3 parameters obtained by the sensory system, and defined by equation (5).

$$Stress\ [\%] = \frac{Heart\_Rate[\%] + Respiratory\_Rate[\%] + Skin\_Conductivity[\%]}{3} \tag{5}$$

Although the method in use presents very positive results, further study will be necessary, possibly using machine learning techniques, to find a dynamic model completely customizable to each user.

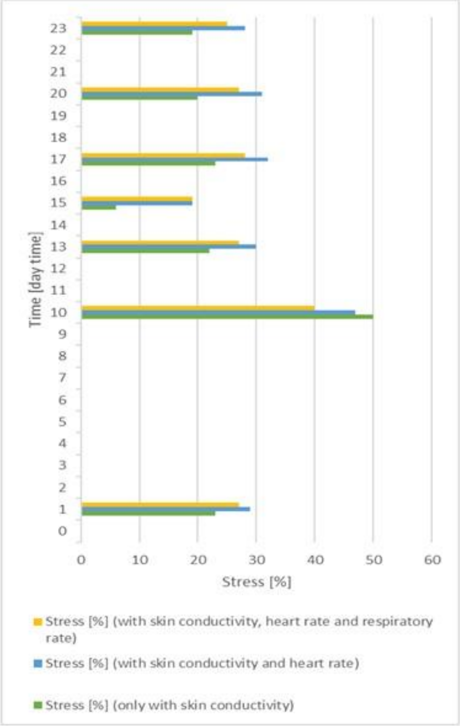


Fig. 8. Stress levels over the course of a day for a 50-year-old person

Despite the fact that a dynamic algorithm needs to be developed in the future, several experiments were conducted until it was well understood how heart rate, respiratory rate and skin conductivity interacted with each other, and what activity could be performed to obtain concrete results. As such, the way chosen to force the human organism to have an unusual reaction was with the viewing of disturbing videos, such as animal abuse. Thus, the response was immediate, and quickly within 2 minutes the stress levels increased from 40% to 85%. However, it took twice as long for stress levels to stabilize at 40%.

Other important results were those obtained during a typical day with multiple tasks and activities, as can be seen in the previous detailed graph (figure 8), which presents hourly averages of stress levels

This graphic has the particularity of representing the evolution of the developed system, that is, from a first phase where the algorithm to estimate stress only made use of the skin conductivity, passing through a second phase where data regarding the heart rate was added, until the current phase where the system makes use of the skin conductivity, heart rate and respiratory rate.

In general, and with the help of the graph in figure 8, it is possible to verify that the purpose of the model proposed in this work was fulfilled, with a balancing of the stress values. The values resulting from the application of the proposed method for the estimate of stress are generally found between the model with only skin conductivity and the model with skin conductivity and heart rate, which makes me believe that this one adapts a little better to the physical condition of each person.

As such, the goal in developing this type of algorithm is not to obtain more and more high or low values, but to obtain values closer to each other, that is, a greater accuracy in the dispersion of values.

The system also allows the user to view graphs that show the last 30 values obtained, and as such, it is possible to analyze the evolution for a minute or more, depending on the amount of data acquired. Note that the respiratory rate sensor has a period of acquisition of values every 10 seconds, in addition to which sending them to the database may take an additional 5 seconds, and as such, for one minute, the system has the capacity to collect 4 to 5 values, as shown in the following graph (figure 9).

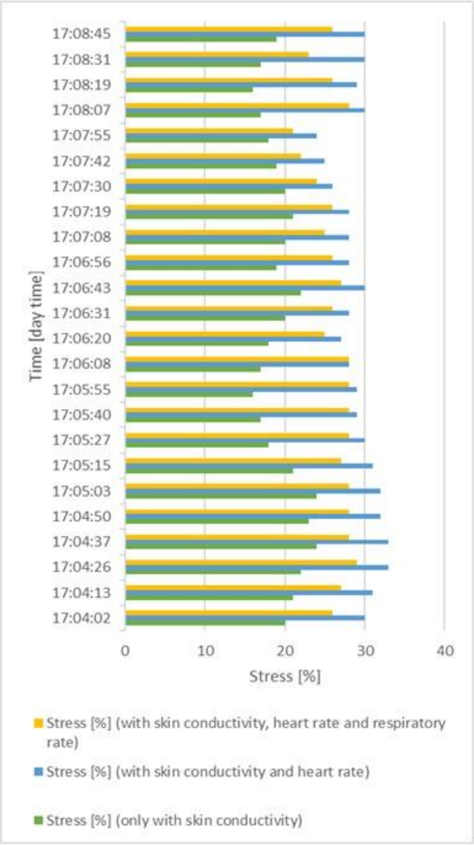


Fig. 9. Variations in stress levels over minutes for a 50-year-old person

Regarding the problems and limitations detected during the realization of this project, they are mostly related to the equipment and ways to induce changes in the human organism, especially ways to induce/reduce stress levels.

Several experiments were conducted, but it was difficult to cause significant variations in stress levels. Although we found a way to induce stress, exceeding normal values, in terms of reducing stress, we did not find an effective way to do so, and even viewing videos and relaxing songs, the stress levels oscillated just below 40%.

Regarding the algorithm used to estimate stress levels, different weights should be assigned to the various parameters used, which is not the case at present, where only an average of these is taken.

Finally, it is important to highlight that the heart rate sensor has 2 libraries available, however, none of them was 100% usable, and as such, to avoid the constant blocking of the sensor, it was necessary to adapt both libraries.

VI. CONCLUSIONS AND FUTURE WORK

The implemented system provides high level of interactivity and mobility allowing the visualization of user health status parameters in real time, including stress level. For this purpose, a mobile application was successfully developed. The way in which this work combines an efficient system with a considerable number of important components and mechanisms for the acquisition of physiological parameters, with the mobility and appealing interface of the mobile application, is an asset to help diabetes patients understand a little better in which way their daily routines influence their well-being, especially when many of these patients think that controlling diabetes is the same as controlling what they eat. In addition, the use of RFID technology gives extra comfort to users, regarding the user identification.

As for future work can be mentioned the development of intelligent algorithms for estimation of the stress levels with higher accuracy. In addition, and bearing in mind that this work concerning the estimation of stress levels is intended to be part of a larger project related to diabetes additional glucose and blood pressure measurement channels will be considered.

VII. ACKNOWLEDGMENT

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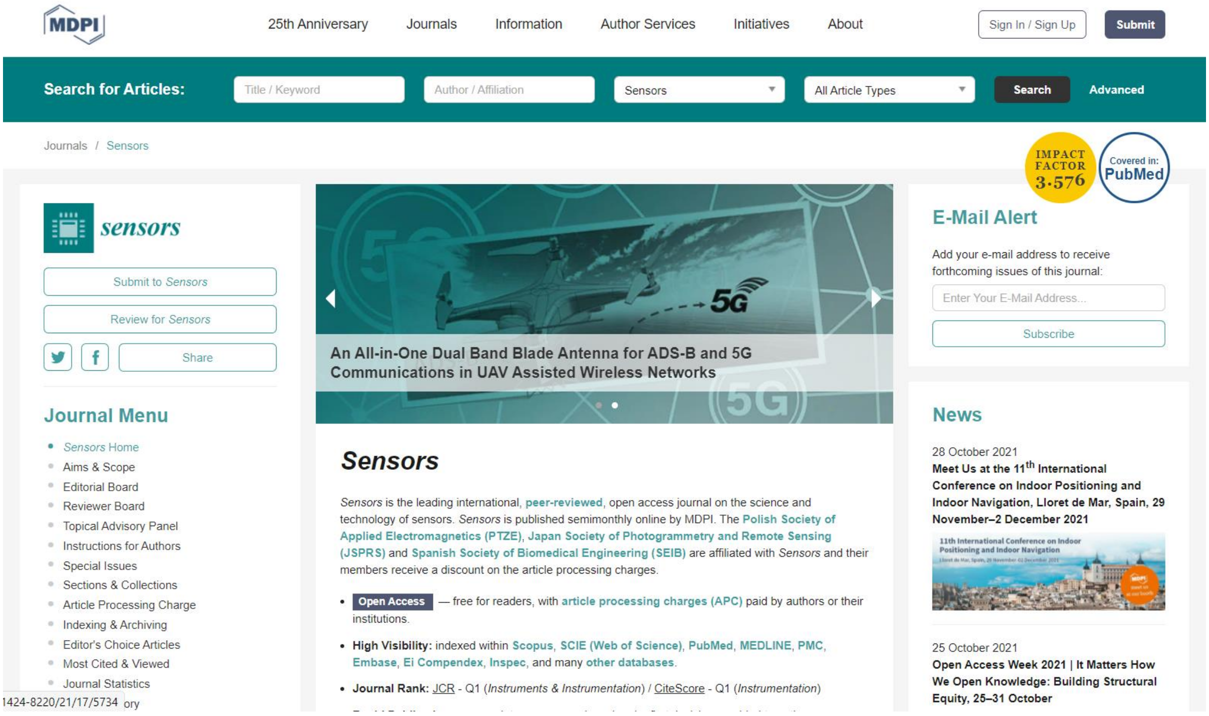
Appendix C – Paper Submitted for Publication in MDPI Scientific Journal, Sensors Section (Q1 / Q2)

Article: **Multichannel Sensing System and Mobile Application For Stress Level Assessment and Correlation with Diabetes**

This article was submitted but not approved for publication. According to the reviewers, major changes should be made to achieve approval for publication, however, at the time of submission of this master thesis, no changes have been made and no new version has been submitted.



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Article

Multichannel Sensing System and Mobile Application For Stress Level Assessment and Correlation with Diabetes

Gonçalo Ribeiro [1,2], João Monge [1,2], Octavian Postolache [1,2,3,*] and Madina Mansurova [3]

[1] ISCTE-Instituto Universitário de Lisboa, Portugal goncalo_tome_ribeiro@iscte-iul.pt
[2] Instituto de Telecomunicações, IT-IUL, Lisbon, Portugal; opostolache@lx.it.pt
[3] Al-Farabi Kazakh National University, Kazakhstan,

Abstract: Stress is a natural feeling of not being able to cope with specific demands and events. The stress can become a chronic condition if a person does not take measures to manage it, extending to other health problems such as heart diseases and/or diabetes. Several stress meters have been proposed over the years, along with different methods for its estimation, however still a reduced number of variables were considered, mainly the skin conductivity and/or heart rate. Additional variables can be relevant to the estimation of stress level, such as respiratory rate. In this paper, a multichannel distributed sensing computing platform has been designed and implemented to measure and predict stress levels through a proposed algorithm that correlates heart rate, respiratory rate and skin conductivity. Experimental validation tests were carried out and preliminary results are included in the paper. Furthermore, experiments were conducted with chronical patients suffering from diabetes. Thus, were performed measurements not only stress-related parameters, but also parameters such as blood glucose levels and blood pressure levels, seeking to extract correlations between stress and diabetes condition. Moreover, a mobile application was also developed for users' stress assessment.

Keywords: Smart Sensors, Stress, Diabetes, Respiratory rate, Galvanic Skin Response, Heart Rate, Blood Glucose Monitoring, Blood Pressure, Embedded Systems, Mobile Application.

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1. Introduction

Cities are large population centers, and daily, people have stressful lives, whether on the way to work, due to traffic, or even related to personal or professional problems. This lifestyle can bring people to higher stress levels that can originate health problems, especially in subjects suffering from chronic diseases such as diabetes.

This project was developed focusing on the large group of diabetes patients who suffer from complications due to the fickle variations of their nervous system. Diabetes has several types, the most common being type 2 diabetes, where in a large number of patients there is a strong relation between blood glucose levels and the nervous system, that is, there is a direct relation between increasing the levels of stress and increasing the levels of blood glucose.

In many cases, diabetes patients do not understand why blood glucose levels are so high, especially when they put in place a balanced diet and healthy lifestyles. In this situation, the purpose of a stress meter system will be to provide patients clear and detailed information about the stress and stress related values of heart rate and respiratory rate. This details that can be measured in direct manner will be the starting point of biofeedback allowing people to identify and avoid stressful everyday situations.

There are some interesting solutions reported in the literature about stress monitoring systems [1-3], most of them based on skin conductivity measurement, which does not allow an accurate calculation for stress levels. For accurate measurement of the stress level, additional physiological parameters may be considered such as heart rate and respiratory rate [4].

In this paper, a system for stress levels monitoring is proposed and described. As the main measured parameters were considered the heart rate, respiratory rate, and skin conductivity, which after analysis and correlation, aim to obtain a relatively accurate estimation of stress values. The interface with user and informal caregiver is assured through a smart phone that runs a mobile application that presents the data analysis results, through tables and graphs, to give a more detailed perspective of the obtained values and correlations. The developed app allows the users to determine which environments and events are most stressful for them, so that they can be avoided. These results can even be presented in a singular or correlated manner, to provide users with an assessment of their current health status and possible guidelines for the future.

This paper is structured as follows. Section II present a small review of the literature for a better theoretical framework. In Section III, the system and the main components are described. In particular, the system architecture is presented and studied. Section IV is devoted to describing, in an easy way, the parameters used. In Section V some tests were carried out to obtain stress, blood glucose, and blood pressure levels, thus allowing conclusions to be drawn and limitations to be identified. Conclusion and future work follow.

2. Review of the Literature

The main purpose of this work was to create a system useful and accessible to assist diabetics in their daily routine and to extract information about key aspects of stress. As such, an in-depth literature research was conducted.

2.1. Diabetes

Diabetes is a chronic disease resulting from the absence of insulin, caused by the body's inability to use the sugar that circulates in the blood, causing it to accumulate (hyperglycemia), which can even affect other systems of the body such as diabetic retinopathy, which can lead to blindness, kidney failure, periodontal disease, which can lead to falling teeth, loss of sensation in the extremities, which can lead to limb amputation, aggravation of cardiovascular diseases, among others [5].

In the specific case of insulin-dependents, it is essential to use devices which can constantly monitor glucose levels and, if necessary, automatically inject insulin doses. However, this automatic intake of insulin can be life-threatening, and as such, this type of system must be capable of recognizing different physiological parameters of the patient, thus determining the exact dosage of insulin to be injected.

Although blood glucose level is the most common parameter in diabetes control, there are also other important parameters to monitor, such as weight, blood pressure, heart rate and human nervous system response, more precisely stress levels.

During the year 2020, the "Centers for Diseases Control and Prevention" (CDC) in the USA, published a report regarding diabetes-related statistics, of which the following are highlighted [6]:

- People with Diabetes:
    - Total: 34.2 million people have diabetes (10.5% of the US population)
    - Diagnosed: 26.9 million people, including 26.8 million adults
    - Undiagnosed: 7.3 million people (21.4% are undiagnosed)

- People with Pre-Diabetes:
    - Total: 88 million people aged 18 years or older have prediabetes (34.5% of the adult US population)
    - 65 years or older: 24.2 million people aged 65 years or older have prediabetes

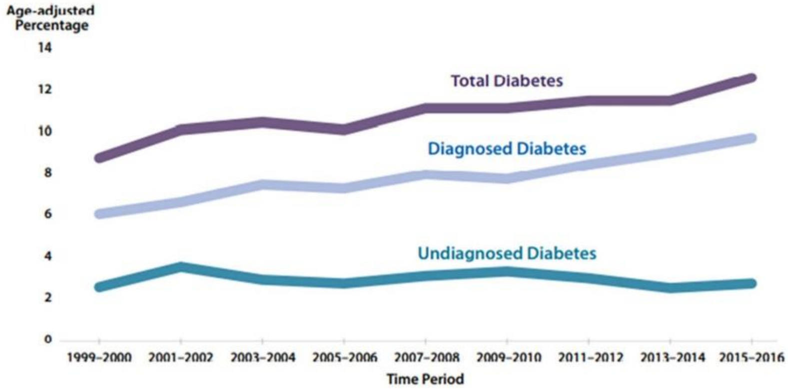


Figure 1. Trends in age-adjusted prevalence of diagnosed diabetes, undiagnosed diabetes, and total diabetes among adults aged 18 years or older, United States, 1999-2016 (figure taken from the article [6]).

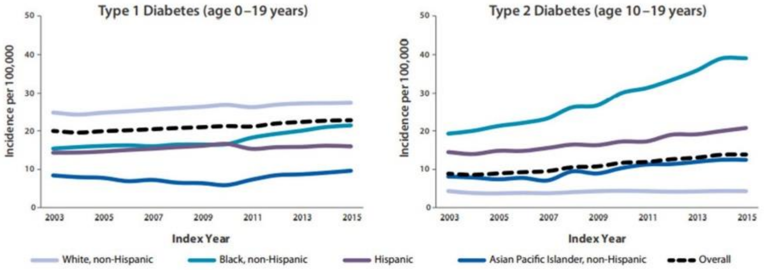


Figure 2. Trends in incidence of type 1 and type 2 diabetes in youth, overall and by race/ethnicity, 2002-2015 (figure taken from the article [6]).

As evidenced by, currently diabetes is a widespread chronic disease which begins to be something quite common in the most developed countries, and can go up to 10 different types, from insulin-dependent diabetes, gestational diabetes in pregnant women, diabetes as a consequence of genetic mutations, or even diabetes derived from glucagonomas and pancreatic diseases [5].

Despite the variety of types, the most common is type 2 diabetes, having as main risk factors obesity, sedentary lifestyle, and genetic predisposition, which through prevention and control of these factors, can be avoided [5]. Basically, this condition is due to the imbalance of glucose levels, which can increase above normal, or even decrease drastically. Another very important aspect is the fact that this type is strongly linked to autonomous nervous system sympathetic branch responses.

The activation of the sympathetic branch od autonomic nervous system not only translates into increased stress levels, but is also related to increased levels of adrenaline, noradrenaline, cortisol, and growth hormones, which consequently affect human metabolism [7]. To try to predict and counter these changes, it is important to create innovative devices that monitor important physiological parameters, such as eye movement, skin conductivity and temperature, Heart Rate variability (HRV), among others [7]. Besides the need to develop this type of devices, it is important to note that, for some of these physiological parameters, there is no equipment on the market yet, being mostly proposed in scientific articles.

2.2. *Stress*

Stress is a feeling of tension or pressure, being directly associated with daily experiences or situations. In addition to exerting a burden on people's lives, stress can also negatively affect the management of chronic diseases, such as cardiovascular diseases, respiratory diseases, diabetes, among others. In this way, monitoring of stress should be part of the daily routine of the patients, being easily included in the period dedicated to medication, or in the case of diabetics, during the period for the measurement of glucose levels [2,3].

There are several methods proposed for estimating stress levels, such as facial expression recognition, multi-sensor systems with the option of applying fuzzy logic or more complex approaches like classifiers based on Machine Learning algorithms, and last but not least, the use of electrocardiography (ECG) [8-10].

Facial recognition aims to determine a person's emotional state by comparing the facial expression captured with a database full of examples of expressions associated with a given meaning [8]. However, this facial recognition mechanism may present a high computational complexity, and by itself, it is not a reliable method for estimating stress levels. Note that even the software used in areas like psychology, does not allow estimating human emotions with 100% accuracy.

Regarding multisensory systems, generally it is performed the monitoring of several parameters such as body temperature (lower temperature in the hands is a symptom of stress), sweat quantity (increase of sweat production is proportional to the increase of stress levels), and walking through an accelerometer (50 steps per minute is a normal value, however, the increase of this value also translates into an increase of stress) [9]. However, the use of sensors that have not been developed specifically for the purpose of measuring stress levels may pose limitations to the system, especially if the acquired parameters do not correlate with each other or with stress.

With the technological evolution, it is increasingly common for intelligent systems to combine multisensory systems with the processing and classification of data through Machine Learning techniques, and in this context of stress, levels of classification are predefined, such as "low", "normal" or "high" [9]. These definitions for stress levels vary greatly from researcher to researcher, because in the literature no specific criteria are established for the calculation of stress, and as such, each researcher who proposes a method has the difficulty of trying to quantify and classify the various levels of stress, just as they find it difficult to establish an ideal formula for this calculation.

In the case of ECG, the data from the sensors represent the electrical activity of the heart, that is, the time and strength of the electrical impulses in the heart, resulting from the contraction of the heart muscle or heart valves. From the ECG waves, and by means of signal conditioning and processing, it is possible to determine HRV, which in turn also makes it possible to estimate the heart rate and respiratory rate. Besides the estimation of these parameters, it is also possible to relate the HRV to the blood pressure, muscle tension and skin conductivity, that is, the decrease in HRV leads to an increase in the blood pressure, heart rate and skin conductivity, resulting in an increase in stress levels, and vice-versa [10]. In this way, obtaining these parameters enables researchers to develop correlative models, with the aim of creating solid and precise systems for estimating stress levels.

The ECG is the gold standard for heart rate measurement however nowadays the photoplethysmography (PPG) becomes a common measurement solution for heart rate caused od simplicity and the integration of PPG measurements units in different wearable devices such as smart watches. The problem of using PPG is the poor accuracy caused by motion artifacts which requires a additional digital signal processing through the implementation of high order Butterworth analog band-pass filters [10] and additional digital signal processing associated filtering and peak detection as part of heart rate measurement.

2.3. *Mobile Applications Market Research*

It was also essential to conduct a market study on mobile applications dedicated to stress, however, their number is still small. Furthermore, of the mobile applications that fall into this small group, they only ask the user about his daily routine and how he feels in certain situations [11,12]. In addition, there are even applications that use the smartphone camera to estimate the heart rate and the activity performed by the user, although the quality and effectiveness of such applications is questionable [11,12].

Taking into account the limitations of the mobile application market for monitoring stress levels, then arises the opportunity to combine the best of both worlds, namely on the one hand to have an efficient system for obtaining and processing physiological parameters important for stress (heart rate, respiratory rate and skin conductivity) and, on the other hand, to deliver the information to a mobile interface, ensuring that users are able to monitor and obtain more accurate and reliable advices, thereby helping in their search for well-being.

3. System Description

The architecture of the proposed system is presented in figure 3. It includes multicore computation platform, a multichannel sensing unit, a real time database and a mobile application.

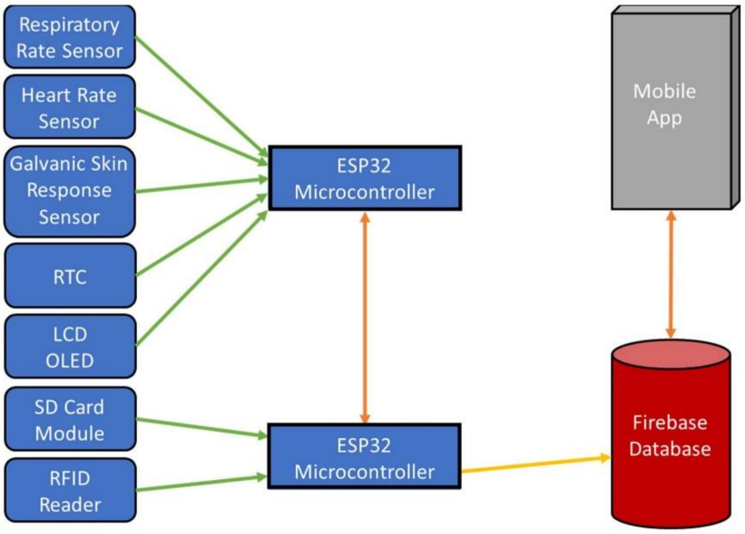


Figure 3. Stress Assessment System Architecture.

3.1. Sensory Component

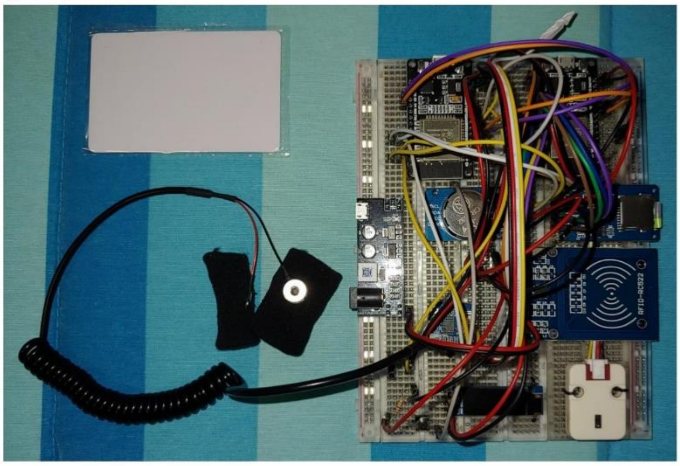


Figure 4. Sensing Unit Prototype

The multichannel sensing unit includes two modules. Module 1 is responsible for acquiring and processing the data coming from the sensors, with corresponding timestamps, and data transmission to module 2 via UART. It includes:

- Pulsioximeter Sensor (m5stack max30100) – to measure heart rate.
- Galvanic Skin Response (GSR) with finger electrodes.
- Respiratory Sensor – laboratory developed prototype to estimate the number of breaths per minute.
- Real Time Clock (RTC) – physical module with battery, to add timestamp to acquired data associated with datalogger functionality (so that it can later be stored in the database or on the SD memory card).
- LCD OLED 1636 – is a system user interface that provides various information, such as the progress of the data acquisition, the moment at which the user must present his RFID tag to authenticate the data, whether the data was saved in the database or in the SD memory card, and the results obtained in the measurement.
- ESP32 Microcontroller (micro1) – this is one of the two microcontrollers present in this system, being responsible for acquisition and processing of the sensors signals. Through the connected RTC the microcontroller associates the timestamp to the acquired samples. At the same time the micro1 control and transmit the important information to the user through the OLED LCD. This microcontroller also has the particularity of establishing a communication via UART with the ESP32 microcontroller (micro2), allowing it to store data remotely or locally.
- Push Button – allows user to start new data acquisition.

Module 2 is responsible for storing the data obtained by module 1, either in the remote database associated with this system, or alternatively in the SD memory card. The module 2 includes:

- ESP32 Microcontroller (micro2) – responsible for acquired data storage. It is also connected to the RFID reader that is related to the user identification. After user identification (user must present an RFID passive tag), the module will try to establish a Wi-Fi connection, allowing sending the acquired data, along with the timestamp and the RFID tag number. If it is not possible to establish Wi-Fi communication, the module saves the data locally on the SD memory card. Note that this module will constantly check if there is data stored on the SD memory card, and if it is possible to establish a Wi-Fi communication with the database to store the data remotely.

- RFID-RC522 – represents the reader that communicates I2C with micro2. When the user presents RFID tag the microcontroller will store a unique ID, that will be sent to the database together with the processed data, thus the privacy requirements are satisfied.
- SD Card Module – this component allows the system to save locally the obtained data, on an SD memory card, if a Wi-Fi connection is not available.

In addition to the material presented above, a Power Supply Adapter was also used, allowing the whole system to be powered from a single source, with a regulated voltage of 5 volts or 3.3 volts.

About the ESP32 microcontrollers used, the following specifications [13] stand out:

- CPU: Xtensa Dual-Core 32-bit LX6
- Processor: Xtensa P2P 32-Bit LX6 Dual Core
- ROM: 448 Kbytes
- RAM: 520 Kbytes
- Flash: 4 MB
- Maximum Clock: 240 MHz
- Standard Wireless 802.11 b/g/n
- 2.4 GHz Wi-Fi connection
- Embedded antenna
- Micro-USB connector
- Wi-Fi Direct (P2P), P2P Discovery, P2P Group Owner mode and P2P Power Management
- Operating modes: STA/AP/STA+AP
- Bluetooth BLE 4.2
- GPIO pins: 11
- GPIO with functions PWM, I2C, SPI, among others
- Transfer rate: 110-460800bps
- Allows remote firmware upgrade
- Analogic Digital Converter (ADC)
- Distance between pins: 2.54mm
- Dimensions: 49 x 26 x 7 mm (length x width x height)

Regarding the multichannel sensing system internal connection, the system block diagram is presented below (figure 5).

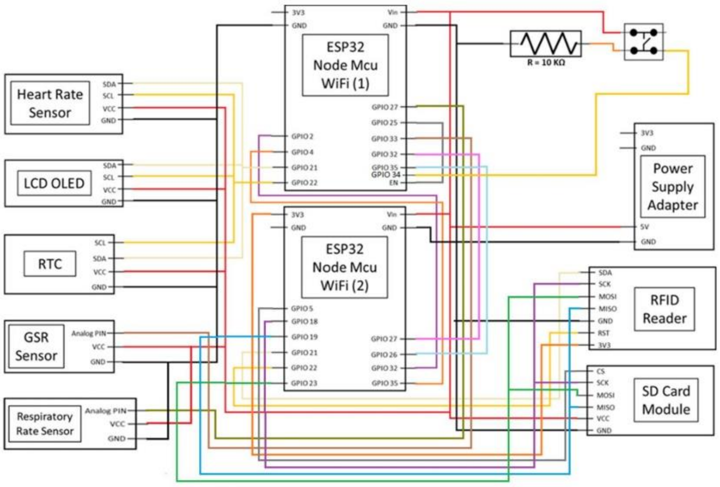


Figure 5. Multichannel Sensing System Connection Block Diagram

Regarding the functioning of the sensorial system, it informs the user that it will acquire heart rate for 20 seconds, skin conductivity for 10 seconds, and respiration rate for 1 minute. During these processes, microcontroller 2 will be checking if there are data in the SD memory card and if so, if there is a Wi-Fi connection so that it can send them to the database, waiting for the RFID tag to approach.

When the acquisition of values finishes, the user is informed if he wants to save the data, and if so, he is asked to approach the RFID tag to the reader. Once the RFID tag is approached, the system checks if there is Wi-Fi connection. If so, it stores the data remotely in the database, otherwise it stores the data locally in the SD memory card.

It is important to highlight that at any time the system allows the user to start new data acquisition and/or to change the RFID tag, simply by enabling the Push Button.

3.2. *Mobile Application*

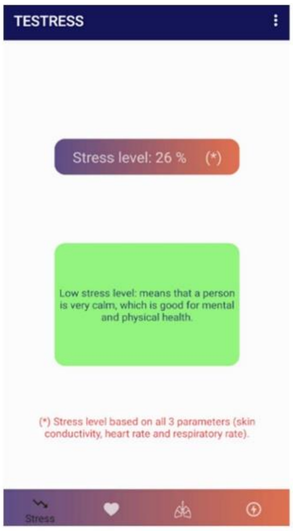
The mobile applications market is divided between two categories of devices, those that implement the Android operating system (developed by Google), and those that implement the iOS operating system (developed by Apple). In the case of the iOS operating system, it is only available on Apple equipment, which greatly restricts users' choice to purchase equipment from other brands. By contrast, the Android operating system is available on all mobile devices on the market, except for Apple's equipment, thus making it much more popular among users. In 2019 it was estimated that only 22.17% of mobile devices on the market made use of the iOS operating system, compared to an overwhelming majority of Android devices, which are estimated to reach 87% of the market listing by 2022 [14].

Based on the statistics presented above, for the development of the mobile application was chosen the platform "Android Studio", which allows to develop native Android applications, being made available also for computers with Windows, MAC and Linux operating systems [15]. This platform has very useful features such as Smart Code Editor, Machine Learning (ML) [16], Security and Privacy [17]. In addition to these features, this platform, as regards access and writing of data, works very well with Firebase database, which is also used in this work.

Regarding the operation of the mobile application, it starts with the main screen, where the logo is displayed and where some resources are loaded for its operation, followed by the login screen, where the user can enter their access credentials (email and password) to log in, or if they have not yet registered, they can do so. Note that for the registration, some user data will be requested, such as first name, last name, date of birth, email, password, and RFID tag ID.

Figure 6. Mobile Application Screen Corresponding to the Registration of New Users

Once logged in, the user can choose to view each parameter in real time, i.e. heart rate, respiratory rate, skin conductivity and stress. In the event of stress, the remaining parameters are correlated using the algorithm implemented for estimating stress levels.



Stress level: 26 % (*)

Low stress level: means that a person is very calm, which is good for mental and physical health.

(*) Stress level based on all 3 parameters (skin conductivity, heart rate and respiratory rate).

Figure 7. Mobile Application Screen Corresponding to the Real Time Data Visualization

In addition to the real-time values, users can also view their daily averages, including the maximum value, minimum value and average value, or their monthly averages, similar to the daily averages, but in this case the averages are weighted according to month and not day. Note that these averages are taken for all system parameters (heart rate, respiratory rate, skin conductivity and stress).


TESTRESS

Number of samples retrieve today:
10

Maximum value:
30

Minimum value:
3

Daily average:
15

Figure 8. Mobile Application Screen Corresponding to Daily Stress Values

Another interesting feature is the possibility for users to visualize their physiological data in graphs. These graphs can be daily, where the hourly average of each parameter is taken, or monthly, where the daily average of each parameter is taken. There is also a third type of graph, where the values obtained in the last 5 minutes are displayed, allowing the user to view the data acquired with a minimum period of every 10 seconds.

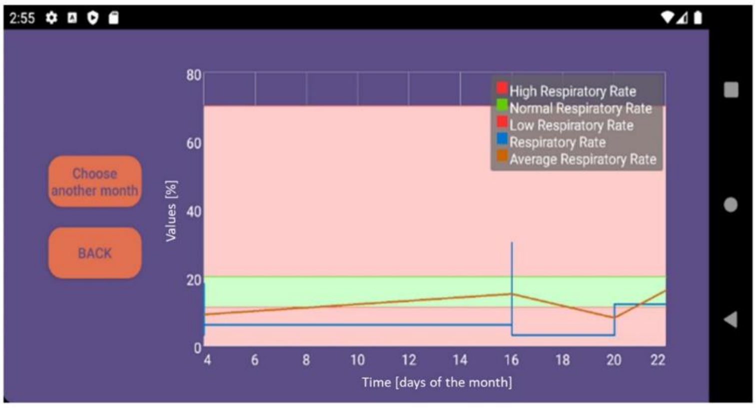


Figure 9. Mobile Application Screen Corresponding to the Respiratory Rate Values Obtained During the Selected Month

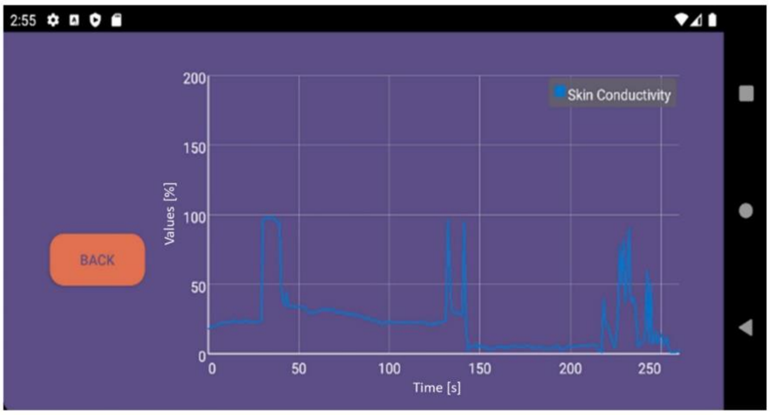


Figure 10. Mobile Application Screen Corresponding to the Skin Conductivity Values Obtained During a 5 Minutes Test Interval

Overall, the mobile application plays an important role in this system, as it allows access to the data stored in database and visualize it. In addition, it implements the algorithm responsible for estimating stress levels based on the heart rate, respiratory rate, and skin conductivity.

3.3. *Firebase Database*

With technological evolution, intelligent systems increasingly rely on tools capable of processing data in a fast and automated way, such as Machine Learning techniques, Neural Networks, Deep Learning, Data Mining, among others. For these tools to be able to perform their functions efficiently and accurately, they need large amounts of data stored in databases. As such, the choice of the most suitable database for a system is something crucial, existing some more specialized in the processing and implementation of algorithms, and others more advantageous for quick access and custom organization by data type [18].

For the implementation of this project, Google's "Firebase" platform was chosen. It is used for the creation of mobile applications and web applications, being compatible with IOS, Android, Web, Unity and C++. This platform not only allows to quickly connect with the application to manage the infrastructure (analysis, databases, messages, and error reports), but also provides high level of integration with cloud storage, use of machine learning techniques, fast and secure authentication methods, fast real-time access, and more [17].

The Firebase data is stored by account ID (RFID ID) and is divide into:

- Realtime – the values measured by the sensors in real time.
- Storage – all values stored and sourced from the sensors, as well as data processed by the mobile application.

```
suportdiabetes-default-rtdb
  ESP32_Core1
    874576180
      Realtime
        Skin Conductivity: 3
      Storage
    199101210181 + ×
      Realtime
      Storage
        Heart Rate
          2021-03-04@01:19:42
          2021-03-04@01:19:43
            -MUuoQHL6TkrV39JidjT
              Value: 72
          2021-03-04@01:52:38
(...)   (...) (...)
          2021-03-22@16:23:23
          2021-03-22@16:23:24
        Skin Conductivity
          2021-03-04@01:19:14
          2021-03-04@01:19:23
          2021-03-10@20:40:59
            -MVSrkggoN4TBtE7MI16
              Value: 95
          2021-03-10@20:41:00
          2021-03-16@14:21:13
          2021-03-16@14:21:14
(...)   (...) (...)

(...)   (...) (...)
        Respiratory Rate
          2021-03-04@01:08:35
          2021-03-04@01:08:46
          2021-03-04@01:08:57
          2021-03-04@01:09:33
            -MUum5QBLz25NeCSB7Ns
              Value: 18
          2021-03-04@01:10:05
          2021-03-16@14:36:21
          2021-03-16@14:37:36
(...)         (...)
          2021-03-22@16:24:46
          2021-03-22@16:24:57
  Users
    jose_gmail_com
      birthday: "25/3/1952 ×
      email: "jose@gmail.com
      firstName: "José'
      lastName: "Ribeiro
      tagNumber: "199101210181
```

Figure 11. Firebase Data Storage Architecture

4. Measured Parameters

Due to the pandemic situation of covid-19 in which we find ourselves, the validation tests of the system were conducted on reduced number of participants (two participants). In the case of stress, the data was obtained from both participants, but since only one of them had diabetes, the data related to diabetes was not obtained from both. To evaluate the behavior of the system in different situations, validation tests were carried out in different contexts.

Regarding the type of data generated and analyzed, these relate to:

- Heart Rate (expressed in Beats per Minute and acquired from the pulse oximeter sensor).
- Respiratory Rate (expressed in Breaths per Minute and acquired from the respiratory rate sensor prototype developed).
- Skin Conductivity (expressed in percentage and acquired from the GSR sensor).
- Stress (expressed in percentage and calculated from the correlation of the other data mentioned before).
- Blood Pressure (composed of systolic and diastolic blood pressure, both expressed in millimeters of mercury, and acquired from a typical meter sold on the market)
- Blood Glucose (expressed in milligrams per deciliter and acquired also from a typical meter sold on the market).

4.1. Heart Rate

Heart rate characterizes the heart activity (the speed of the cardiac cycle) and is measured by the number of heart beats per minute (bpm). It may vary according to the body's physical needs. It is usually equal to the arterial pulse measured at any peripheral point associated with systolic and diastolic sequence. It can be altered by physical exercise, sleep, anxiety, stress, disease, or drug ingestion [19,20].

Heart rate has a direct link to stress, in the way that when a person is stressed, his or her body releases temporarily adrenaline, causing an increase in heart rate. Additionally, heart rate can be classified as follows [21]:

Table 1. Tabulated Levels for Heart Rate

Heart Rate	Information	Symptoms/Consequences
< 60	Low heart rate (bradycardia)	Fatigue, dizziness, confusion, feeling faint, possible infection, high blood potassium levels, active thyroid gland, risk of heart attack.
60 - 100	Normal heart rate	No symptoms or consequences.
> 100	High heart rate	Fatigue, dizziness, palpitations, chest pain, difficulty breathing, possible infection, low blood potassium levels, anemia, very active thyroid gland, heart disease (cardiomyopathy, tachycardia, among others).

4.2. Respiratory Rate

Respiratory Rate is the designation for the number of breathing cycles (breathing in and breathing out) that an individual completes per minute (Breath Per Minute - BPM). The rhythmic movement between inspiration and expiration is regulated by the nervous system and is repeated at a rhythm that is characteristic of the physiological state of everyone. Note that if an adult at rest exceeds 20 BPM, we are facing a situation of Tachypnea (violent physical exertions that can be indicative of lung disease, heart disease, fever, anxiety, or poison contamination), while if it is less than 12 BPM, we are facing a situation of Bradypnea (slow breathing that can lead to Apnea or low concentration of oxygen in the blood, which leads to situations of Hypoxia) [22].

The normal respiratory rate as a function of age is established as follows [22]:

- New-born: about 44 breaths per minute.
- Children: 18-30 breaths per minute.
- Pre-teens: 20-30 breaths per minute.
- Adolescents: 18-26 breaths per minute.
- Adults: 12-20 breaths per minute.
- Adults over 65: 12-28 breaths per minute.
- Elderly over 80 years: 10-30 breaths per minute.
- Adults practicing sports: 35-45 breaths per minute.
- Athletes: 60-70 breaths per minute.

Respiratory rate has a direct link to stress, in the way that during the human body's response to stress, a person breathes faster to quickly deliver oxygen-rich blood throughout his or her body [23]. If a person has respiration impairment such as asthma or emphysema, the stress condition can make breathing even more difficult.

4.3. Skin Conductivity

It varies with the state of sweat glands in the skin. Sweating is controlled by the sympathetic nervous system, and skin conductivity is an indication of psychological or physiological arousal. If the sympathetic branch of the autonomic nervous system is highly aroused, then sweat gland activity also increases, which in turn increases skin conductivity.

Thus, skin conductivity can be a measure of emotional and sympathetic responses [24,25] being categorized as follows:

Table 2. Tabulated Levels for Skin Conductivity

Skin Conductivity	Information	Symptoms/Consequences
0% - 31%	Low levels	Does not pose a problem or risk to human health.
32% - 82%	Normal levels	Does not pose a problem or risk to human health.
83% - 100%	High Levels	It does not pose any problem or risk to human health, however, there is a high psychological stimulation (increased emotional response) and greater sweat production.

4.4. Stress

Stress is the response of our body to an event or situation of pressure in our lives and are typically estimated by correlating skin conductivity and/or heart rate [3,26]. In a general way, can be categorized as follows:

Table 3. Tabulated Levels for Stress

Stress	Information	Symptoms/Consequences
0% - 25%	Resting state	No symptoms or consequences.
26% - 50%	Low stress levels	No symptoms or consequences.
51% - 75%	Normal stress levels	No symptoms or consequences.
76% - 100%	High stress levels	Difficulty controlling emotions, heart problems, teeth and gums problems, weight gain, weakened immune system.

4.5. Blood Pressure

Blood pressure is expressed in millimeters of mercury (mmHg), and is the pressure exerted by the blood as it travels through the circulatory system and is normally above atmospheric pressure, which prevents this system from collapsing.

In a healthy human, the blood pressure value can vary continuously depending on stress, emotional response or physical activity performed. This variation is due to the cardiac cycle characterized by two stages. In the first stage, the cardiac cycle begins, in other words, the heart relaxes, stops pumping and starts receiving blood. At this stage blood pressure is minimal, and the term used to define it is diastolic blood pressure. In the second stage, the heart contracts, and pumps blood into the arteries. At this stage the blood pressure is maximum, and the term used to define it is systolic blood pressure.

Regarding the values that the blood pressure can take [27], these are presented in Table 4:

Table 4. Tabulated Levels for Blood Pressure

Systolic [mmHg]	Diastolic [mmHg]	Blood Pressure Category
< 120	< 80	If these systolic and diastolic values have occurred, then the blood pressure is considered normal.
120 - 129	< 80	If these systolic and diastolic values have occurred, then the blood pressure is considered elevated.
130 - 139	80 - 89	If these systolic or diastolic values have occurred, then the blood pressure is considered high and we are facing the first stage of hypertension.
> 140	> 90	If these systolic or diastolic values have occurred, then the blood pressure is considered high and we are facing the second stage of hypertension.
> 180	> 120	If these systolic and/or diastolic values have occurred, then the blood pressure is considered critical and we are facing the last and more dangerous stage of hypertension.

Although blood pressure is related to stress, there is not always such a connection, i.e. the increase of the blood pressure is associated to the increase of the heart rate, which in turn is associated to the increase of the stress levels. However, the increase of the heart rate does not always translate into an increase of the blood pressure, which is quite common in people with high elasticity/dilation of the blood vessels, whether this is something natural or a result of taking medication. In this way, a decrease in blood pressure can be seen when there is an increase in heart rate.

4.6. Blood Glucose

Blood glucose is expressed in milligrams per deciliter (mg/dL), and is one of the most important carbohydrates in biology, used by cells as an energy source for metabolism. If glucose values reach above normal values over long periods of time, a person is typically diagnosed with diabetes.

Simply put, diabetes occurs when the human body's natural production of insulin is insufficient (type 1 diabetes), or when the body's cells do not respond adequately to insulin (type 2 diabetes).

For the diagnosis of diabetes, patients usually carry out a blood glucose and hemoglobin test, which may vary depending on whether the patient has not eaten any food that day (fasting), or has done so. Thus, blood glucose values can vary as follows [28] and described in Table 5:

Table 5. Tabulated Levels for Blood Glucose

Blood Glucose Levels in Fasting [mg/dL]	Blood Glucose Levels After Meals [mg/dL]	Blood Glucose Category
< 70	< 70	Low blood glucose levels associated with Hypoglycemia.
70 - 99	70 - 139	Normal blood glucose levels.
100 - 125	140 - 199	Pre-Diabetes status.
> 125	> 199	Diabetes diagnosis.

After being diagnosed with diabetes, patients should take some precautions in terms of diet, physical exercise, regular diabetic consultations, and daily measurement of blood glucose levels, using meters provided by pharmacies and reimbursed by the national health system. Thus, when performing daily measurements, diabetics should pay attention to the following levels presented in [29]:

- Blood Glucose levels in Fasting:
    - Person without Diabetes: 70 - 99 mg/dL.
    - Person with Diabetes: 80 - 130 mg/dL.

- Blood Glucose levels After Meals:
    - Person without Diabetes: less than 140 mg/dL.
    - Person with Diabetes: less than 180 mg/dL.

5. Results and Discussion

The multichannel sensing system validation was carried out following a test protocol that involved the participation of healthy (control group) and people with diabetes. Preliminary tests were performed on two male participants, with ages between 26 and 69 years old. In the case of volunteer with chronical diseases, diabetes and cardiovascular problems were considered. Besides, several tests were conducted in two experiments, where in the first experiment, a model for estimating stress levels was created, based on data regarding heart rate, respiratory rate and skin conductivity, and in the second experiment, the correlation between stress (stress estimated through the model proposed in the previous experiment and the feeling of stress identified by the participants), glucose levels and blood pressure was studied.

5.1. Proposed model for stress levels estimation

Initially, for the stress calculation, the algorithm developed only weighted the skin conductivity values, but this was not ideal, since for people suffering from diseases such as hyperhidrosis (excessive sweating), the algorithm would easily cease to be adequate.

In a second instance, the stress estimation algorithm was based on the correlation between heart rate values and skin conductivity values. The results obtained in this second model were more adequate and the estimation of stress was relatively efficient, although the component of the calculation corresponding to the skin conductivity overlapped with the component corresponding to the heart rate, which resulted in stress levels that were sometimes too low for real situations. Furthermore, in situations where the user suffers from heart disease, such as tachycardia (high heart rate), the method was no longer effective.

With the development of a sensor to measure respiratory rate, the final version of the algorithm for stress estimation then relies on the correlation between respiratory rate, heart rate and skin conductivity.

In more technical detail, the algorithm for estimating stress levels converts the values of heart rate and respiratory rate to percentages within the range of possible values. Note that in the case of skin conductivity, the GSR sensor library itself already performs the conversion from voltage to percentage, and in this case no extra digital processing is required.

An important detail in the conversion of the heart rate from beats per minute to percentage is the need to determine the maximum possible value for this parameter, which is performed through equation (1). To determine the maximum value of the heart rate for each subject, it is necessary to know their age, which made it mandatory to include it in the registration of new users in the mobile application [30].

$$MAX_{Heart\_Rate} = 220 - age \tag{1}$$

Once the maximum heart rate for the subject is known, equation (2) can then be applied, i.e. this equals 100%, and making use of the heart rate collected by the sensor, the heart rate in percentage is obtained.

$$Heart\_Rate[\%] = \frac{Heart\_Rate \times 100}{MAX_{Heart\_Rate}} \tag{2}$$

As with the heart rate, to convert the respiratory rate from breaths per minute to percentage, it is also necessary to determine the maximum possible value for this, but this does not depend on age. There is no maximum value communicated by health entities for respiratory rate, but it is common in many athletes who practice sports with enormous physical effort, to present maximum values for respiratory rate in the order of 70 breaths per minute [31], and as such, in this system it was admitted as a maximum value (3), i.e. this equals 100%, and making use of the respiratory rate collected by the sensor, the respiratory rate in percentage is obtained through equation (4).

$$MAX_{Respiratory\_Rate} = 70 \tag{3}$$

$$Respiratory\_Rate[\%] = \frac{Respiratory\_Rate \times 100}{MAX_{Respiratory\_Rate}} \tag{4}$$

After determining the heart rate and respiratory rate, both in percentage, and obtaining the skin conductivity value also in percentage directly from the sensor, it is then possible to apply the developed algorithm for the estimation of the stress levels, which is based on the weighted average of the 3 parameters obtained by the sensory system, and defined by equation (5).

$$Stress\ [\%] = \frac{Heart\_Rate[\%] + Respiratory\_Rate[\%] + Skin\_Conductivity[\%]}{3} \tag{5}$$

Although the method in use presents very positive results, in further studies machine learning techniques may be used to develop a personalized dynamic model to each user.

Despite the fact that a dynamic algorithm needs to be developed in the future, several experiments were conducted until it was well understood how heart rate, respiratory rate and skin conductivity are related to the stress level and the protocol that can be considered to obtain appropriate results. As such, the chosen way to force the human organism to have an unusual reaction was with the viewing of disturbing videos, such as animal abuse. Thus, the response was immediate, and quickly within 2 minutes the stress levels increased from 40% to 85%. However, it took twice as long for stress levels to stabilize at 40%. In addition, loud sound tests can be considered, cold stress can also be applied and the change in heart rate, respiratory rate and skin conductivity can always be recorded.

Other important results were those obtained during a typical day with multiple tasks and activities, as can be seen in figure 12, which presents hourly averages of stress levels.

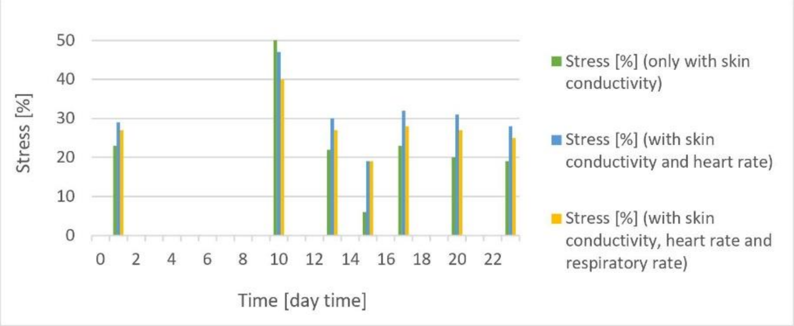


Figure 12. Stress Levels Over the Course of a Day for a 26-year-old Person

The figure 12 represents the comparison between three phases in the development of the system, from the first phase where the algorithm to estimate stress only made use of the skin conductivity, passing through a second phase where data regarding the heart rate was added, until the current phase where the system makes use of skin conductivity, heart rate and respiratory rate.

In general, and with the help of figure 12, it is possible to verify that the aim of the model proposed in this work was fulfilled, with a balancing of the stress values. The values resulting from the application of the proposed method for the estimate of stress are generally found between the model with only skin conductivity and the model with skin conductivity and heart rate, which makes me believe that this one adapts a little better to the physical condition of each person.

The system also allows the user to view graphs that show the values obtained during a 5 minutes test interval as shown in the following graph (figure 13).

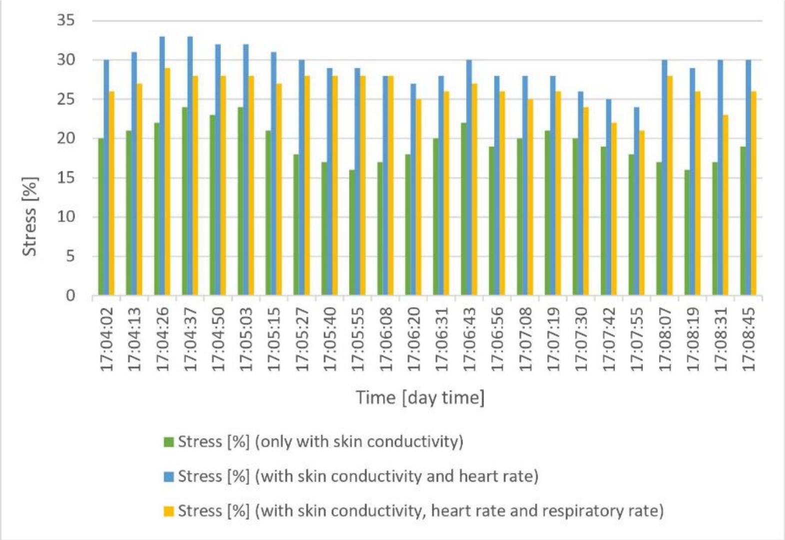


Figure 13. Variations in Stress Levels over 5 Minutes Test Interval for a 26-year-old Person

Overall, the tests carried out showed solid and satisfactory results, however, it was important to prove the efficiency of the proposed method, and as such, a new set of tests was carried out, where after obtaining data, each participant was asked to self-assess their stress levels from 0 to 10, from which resulted the graph in figure 14. Note that in future, it would be more practical for participants to use a simple system where they could assess their level of stress by pressing a button, allowing them to change the colours of an RGB LED from green to red, or to light up a number of LED segments according to the self-assigned value of stress

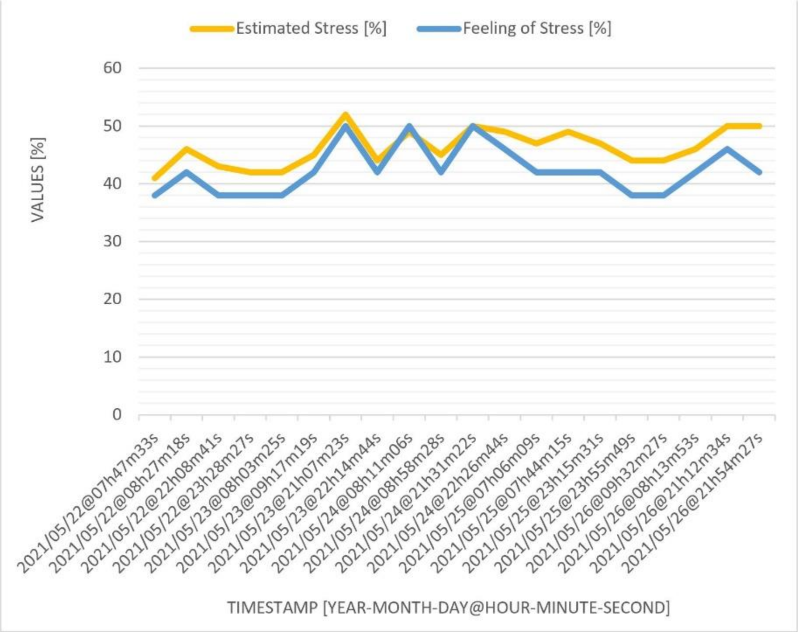


Figure 14. Comparison Between Stress Estimated and Self-rated Stress by the Participants

As can be seen in figure 14, the sensation of stress classified by the participants was quite close to the values estimated by the system, with small disparities, which are due to the fact that the implemented algorithm assigns equal weights to the various parameters used, which in the future should be changed to personalized dynamic algorithm.

Another important aspect analysed was the link between the different measured parameters and the estimated stress. Based on analysed data was observed that the skin conductivity has greatly influence on the stress estimation. However, in the tests that were carried out, it was possible to observe an important weight of heart rate in the estimation, i.e. the curve relating to the evolution of heart rate is very similar to the evolution of the estimated stress. This can be justified by the fact that the participant whose data are shown in the graph of figure 15 has cardiovascular problems, and as such, the dynamic algorithm to be developed in the future should give more weight to skin conductivity and heart rate, rather than respiratory rate. In this case, additional tests, and an analysis of the dispersion of results through Machine Learning algorithms will be considered.

Figure 15. Comparison Between Acquired Data and Estimated Stress

Regarding the detected problems and system limitations during the system validation, can be mentioned limitations related to the equipment and the followed protocol to induce changes in the human organism, especially ways to induce/reduce stress levels.

5.2. Correlation between Stress, Blood Glucose Levels and Blood Pressure

In this experiment, data regarding stress (heart rate, respiratory rate, and skin conductivity), blood pressure and blood glucose levels were obtained from the participant who was 69 years old and had health problems associated with diabetes and hypertension.

It is also important to mention that both the blood glucose levels, and the blood pressure values were obtained through the typical monitors available on the market. These monitors have a Bluetooth communication interface, that facilitate the integration into the system considering also the ESP32 Bluetooth communication capabilities (micro1).

To obtain the data, four measurements were taken per day, over 5 days, where the data was collected from the participant fasting, after having breakfast, after dinner and finally sometime after dinner.

The four moments of day chosen for data collection were crucial to the success of this experiment. Note that diabetics should take their mediation during meals or immediately after meals, which also contributed to the choice of the four moments.

The data obtained while fasting allow reference values to be obtained, without the influence of food or the effect of medication. On the other hand, the data obtained after breakfast, more specifically less than one hour later, allow us to check the effect of the diet on the organism; however, the effect of the medication does not occur because it takes relatively more than one hour for it to take effect. These obtained results can be visualized through the graph in figure 16.

Figure 16. Effect of Food Intake on Blood Glucose Levels

The data obtained after the meal, more specifically less than an hour after, take into account not only the effect of the food on the organism, but also the overload of a day with the typical routine of travelling in traffic to work, performing duties, coming home in traffic, among other activities. With the data obtained sometime after dinner (at least more than an hour and a half after dinner), it was possible to verify the effect of the medication, and in most cases, a decrease in blood glucose levels. These results can be visualized through the graph in figure 17.

Figure 17. Effect of Taking Medication on Blood Glucose Levels

Another important analysis was the correlation between blood glucose levels and the stress estimated by the proposed system. Apparently there was no direct link between stress and blood glucose; however, when the data were grouped according to measurement period, an interesting dependencies were observed, in the sense that if on the previous day the stress levels were decreasing, on the following day the blood glucose levels followed this evolution (decreased, too). In the same way, if on the previous day the stress levels were increasing, on the following day the blood glucose levels also increased in relation to the values obtained on the previous day. These results can be visualized in figure 18.

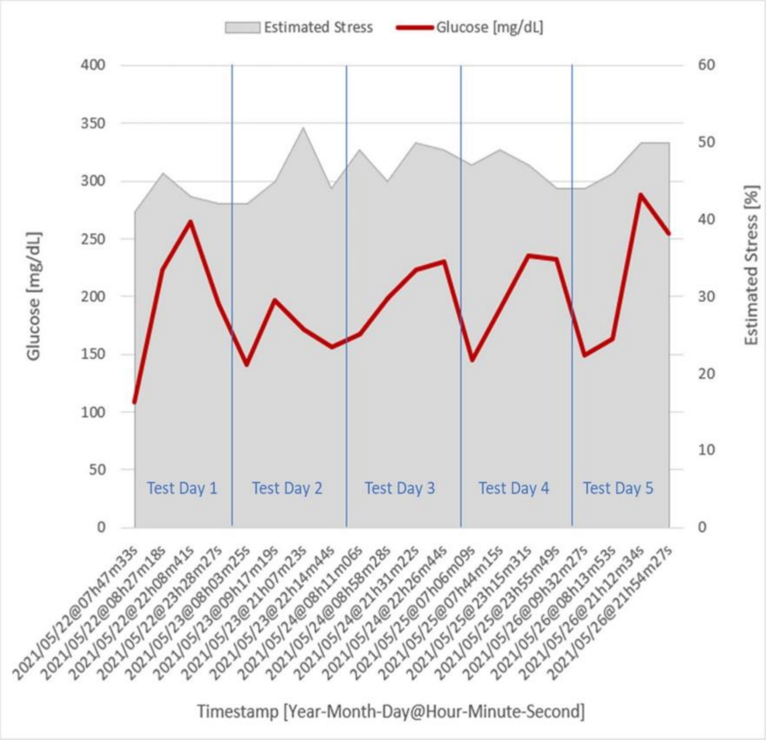


Figure 18. Comparison Between Blood Glucose Levels and Estimated Stress

Through the conclusions drawn from the correlation between blood glucose levels and estimated stress, it is possible to state that there is a relation of dependence, and that in the process of diabetes control, patients should pay attention to their emotional state and nervous system responses, avoiding stressful situations in their daily lives.

Regarding the correlation between blood pressure and blood glucose levels, and as previously mentioned, the participant on which this experience is focused is a 69-year old individual who suffers from problems related to diabetes and cardiovascular diseases, one of the conditions being hypertension. In this way, a correlation was observed between heart rate and blood pressure, as they are inversely proportional, i.e. when one increases, the other tends to decrease. This detail is important because the increase in heart rate is related to the increase in stress levels, which in turn will influence blood glucose levels, as previously proved.

Analyzing the data obtained and presented in figure 19, we can see that, contrary to what was expected due to blood viscosity, the increase in blood pressure is associated with the decrease in blood glucose levels.

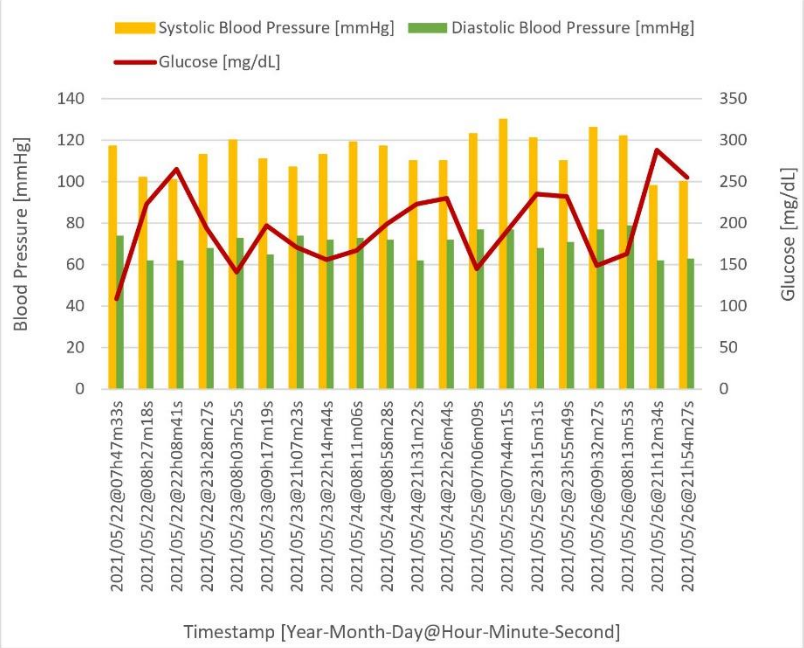


Figure 19. Comparison Between the Values Obtained for Blood Pressure and Glucose Levels

Overall, the obtained results are satisfactory and can be considered the starting point in a general study of the relation between diabetes, stress, and blood pressure. Extended tests will be carried out with healthy and people with diabetes.

As regards limitations, we must consider the types of blood pressure monitor available on the market, which are divided into wrist monitors and upper arm monitors. If wrist monitors invest more on mobility and reduced size, in terms of precision, they are not as efficient as upper arm monitors, and this is due to the fact that the wrist area is narrower, not containing so many arteries and of greater thickness. In addition, these monitors measure the pressure exerted on the cardiac muscle, and as such, they must be at the same level as the heart [32]. Another detail verified in blood pressure monitors, is that the precision of the values obtained for heart rate is not as good as those verified, for example, in pulse oximeters.

6. Conclusions and Future Work

The implemented multichannel sensing system provides high level of interactivity and mobility allowing the visualization of user health status parameters in real time, including stress level. For this purpose, a mobile application was successfully developed and validated for a reduced number of users. The way in which this work combines an efficient system with a considerable number of important components and mechanisms for the acquisition of physiological parameters, with the mobility and appealing interface of the mobile application, is an asset to help diabetes patients understand a little better in which way their daily routines influence their well-being, especially when many of these patients think that controlling diabetes is the same as controlling what they eat. In addition, the use of RFID technology gives extra comfort to users, regarding the user identification, along with the presence of an SD memory card, which in case there is no internet connection to store the data remotely, saves it locally, ensuring none is discarded.

Regarding the experimental validation conducted to determine the correlation between stress, diabetes and blood pressure, important conclusions were drawn that prove the relation between these parameters, and once again highlight the need to include the management of nervous system responses in the daily lives of diabetics, who, even if they practice a healthy lifestyle and a dedicated monitoring of their glucose levels, should have redoubled concerns about how to manage their emotional system in the face of various situations.

As for future work can be mentioned the development of intelligent algorithms for estimation of the stress levels with higher accuracy. In addition, and taking into account that this work aims to help diabetics in their daily lives, giving primacy to an intelligent and mobile interface of easy interaction with the user, in the future it will be interesting to add channels for measuring glucose levels and blood pressure incorporated into the system, and not resorting to devices available on the market. Note that the users of the mobile application developed can add the values for glucose and blood pressure, however, if these meters are part of the system, the data would be added automatically.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, G.R. and O.P..; methodology, G.R, J.M. O.P. and M.M; hardware GR; software, GR.; validation, G.R., J.M. and O.P..; formal analysis, G.R, O.P. and M.M.; investigation, G.R. and O.P..; resources, G.R. and O.P.; data curation, G.R. .; writing—original draft preparation, G.R.; writing—review and editing, G.R., O.P. and M.M.; visualization, O.P. and M.M..; supervision, O.P..; funding acquisition, G.R and O.P..

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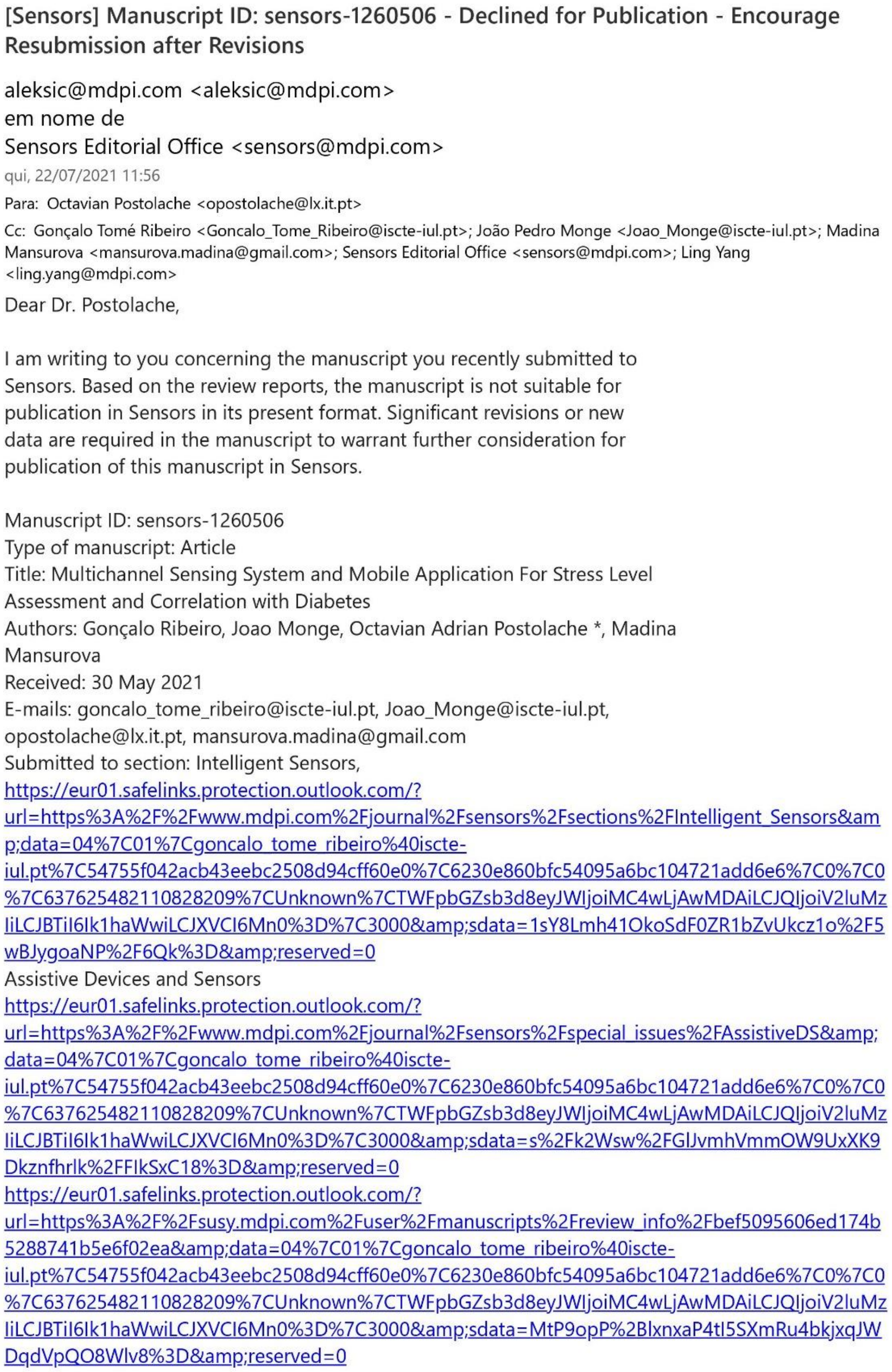
Appendix D – Proof of Paper Submission and Revision

Although the article presented in **Appendix C** was not published in the scientific journal MDPI, Sensors section, the reviewers did not reject it, requesting that Significant Revisions be made, or New Data be added.



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Authors: Gonçalo Ribeiro, Joao Monge, Octavian Adrian Postolache *, Madina Mansurova
Received: 30 May 2021
E-mails: goncalo_tome_ribeiro@iscte-iul.pt, Joao_Monge@iscte-iul.pt, opostolache@lx.it.pt, mansurova.madina@gmail.com
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