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DEVELOPMENT OF A LOW COST, HIGH PRECISION CARDIAC MONITOR SYSTEM WITH INTERNET OF THINGS TECHNOLOGY

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Abstract: Heart disease has been a major problem in Brazil and in the world due to its high mortality rate, being one of the main causes of unexpected deaths. Based on these observations, this article proposes the development project of a low-cost, high-precision cardiac monitoring system based on the Internet of Things for remotely monitoring the cardiac activity of patients. With the aid of software, the possibility of acquiring the complete signal of cardiac activity was identified with an ECG module and a microcontroller. In addition, to accommodate the circuit, a 3D modeling of the prototype of a "case" was designed. Thinking about the development of an application interface to display the acquired data, we opted for the use of free software that transfers the data to the cloud. At the end of the structuring of the project and the tests with virtual prototyping, it was concluded that the construction of an electrocardiograph integrated with the concepts of Internet of Things for the availability of data at a distance proved to be feasible due to its low budget for production and acquisition for the users.
Keywords: IoT. Technology. Cardiac Monitoring. Electrocardiogram. Microcontrollers.

INTRODUCTION

According to data from the official website of WHO (World Health Organization), cardiovascular diseases represent the lead when it comes to causes of global death. It is estimated that about 17.9 million people died from heart-associated diseases in 2019, among them, 85% were due to heart attacks and pericardial effusion. This global trend is reflected in Brazil with mortality rates from cardiovascular diseases (CVD). In the period from 2016 to 2019, for example, there was an increase in rates that varied according to region and race. (PELLENSE et al., 2021)

According to Kamble (2019) heart disease is one of the main reasons for unexpected deaths. A variety of medical devices have been developed by engineers to diagnose a variety of heart-related illnesses. The international classification of diseases (ICD) groups codes that identify diseases related to heart disease, which include the 9th and 10th Revisions (ICD-9 and ICD-10) such as cardiomyopathies and heart failure identified as ICD-9 :420.0 and 429.9 respectively.

The Electrocardiogram (ECG) signal plays an important role in detecting heart problems. Continuous monitoring of the elderly patient requires a special and simple device as the traditional hospital ECG machine is not commonly used in the home environment. Thus, a proposal for a simple and economically viable ECG device is very valid for contexts like this. (RASSAL RAJ et al., 2022).

According to the manual entitled "Medical-Hospital Equipment and Maintenance Management" by the Ministry of Health, by detecting the electrical activity it is possible to produce the electrocardiogram that gives a graphic record of the electrical voltage as a function of time. With the amplitude of millivolts, this detection is captured on the surface of the body and is presented as a non-invasive method of diagnosing and monitoring the evolution of pathologies (MINISTÉRIO DA SAÚDE, 2002).

Kamble (2019), mentions that the signal obtained by the electrocardiograph explores the knowledge of the degree of performance of cardiac function. Monitoring technologies such as multiparametric monitors, extremely common in health centers, also monitor ECG information that provides heart rate, which comprises a vital sign.

Research has been carried out worldwide for medical devices using the technology known as the " *Internet of Things*" (IoT) or Internet of Things. In the context of the

2020 pandemic, IoT was applied to patient monitoring systems in order to track high-risk cases through biometric measurements. In addition, capturing and managing health data from infected patients through the use of apps has also been widely adopted (Zorkot, 2021).

Therefore, the "internet of things" mechanism plays a vital role in the generation of facilitating systems for health monitoring. This technology implemented in diagnostic tools for heart problems plays a very important role since it has the purpose of continuously monitoring a vital sign (XU, 2020).

Through real-time monitoring technology systems; that have a less robust data acquisition system than the technologies used for diagnostic purposes in health environments; It is currently possible to detect electrocardiogram waves that reflect the pattern of regular heartbeats (SZEZEPAŃSKI; SAEED, 2014).

According to Zhang and Zhai (2021), obtaining the electrocardiographic signal through systems, in contrast to detection via manual methods, raises the data accuracy rate. A high level of accuracy contributes to the technological security of an ECG device. According to Tieppo (2021), the clinical methods commonly used in the detection of Cardiovascular Diseases (CVD), in addition to electrocardiograms, require high-cost equipment and qualified professionals, such as blood tests through which observation is carried out of biomarkers, computed tomography exams and angiograms.

This way, low-cost remote monitoring technologies accompany both the advancement of the increased use of smartphones and the needs for economically viable monitoring of health parameters outside the conventional clinical environment. Therefore, the present work proposed the development of a system for capturing and remotely monitoring the ECG parameter, so that its visualization is possible through a free platform in the cloud and its acquisition, through an easy-to-acquire sensor module. in the market.

THEORETICAL REFERENCE

The theoretical framework addresses the physiological and technical principles of the electrocardiogram, the presentation of the characteristics of the "Internet of Medical Things" and standards that involve the manufacture and operation of this type of solution. In addition, the concepts of devices known as *Point-of-Care (POC)* and examples of remote cardiac monitoring technologies proposed by the market are discussed.

PHYSIOLOGY OF THE HEART AS A BASIS FOR THE FUNCTIONING OF THE ELECTROCARDIOGRAM

The heart is an essential organ for life to exist, since, having its functionality exercised from electrical impulses produced within it, it makes the fluidity of an entire circulatory system capable (MINISTRY OF HEALTH 2021), thus requiring periodic monitoring specific for analysis of its functioning (EINTHOVEN, 1901 apud BURDON ; PAGE, 1878). In order to understand the basic functioning of the electrocardiogram, knowledge about the physiology of the cardiac organ becomes essential.

The heart consists of four cavities: right atrium, right ventricle, left atrium and left ventricle, which interact with each other, being essential in the dynamics of contraction (systole) and relaxation (diastole) of the muscle. The contraction process occurs due to the depolarization of the cells, when there is the presence of some stimulus generated by the differentiation of the potentials of the salts, while the relaxation occurs due to the repolarization of the cells, and there may be no stimuli or their cessation (TEIXEIRA, 2021).

The stimulus starts in the Sinoatrial Node (SAN), due to the large presence of pacemaker cells, following throughout the atrial myocardial cavity and heading to the atrioventricular node, where there is a delay in the transmission of the stimulus, following to the HIS Bundle, also known as the atrioventricular fasciculus, and the *Purkinje* network, allowing the stimulus to be distributed throughout the ventricular myocardium cavity equally (TEIXEIRA, 2021).

Obtaining the result of the electrocardiogram is done precisely by reading the electromagnetic waves generated inside the heart, thus allowing the recording of the emitted electrical activity, and consequently, the flow of the patient's circulatory system. Such results are expressed in an ECG graph with the example of wave complexes (LAGERHOLM et al., 2000).

Electrocardiogram and its importance

The electrocardiogram is the test that the medical team uses it to analyze the electrical waves emitted by the heart and to obtaining data on the size of the atria, ventricles and the situation of the coronary arteries, has the function of monitoring the heart rhythm, capturing the emitted millivolts and separating them into peaks of contractions and relaxations (EINTHOVEN, 1901). In Figure 1, the demonstration of the heart contraction process can be observed.

The electrocardiogram is an exam performed to measure the process of systole and diastole of the heart. For this, superficial electrodes are positioned in the pectoral region, with the aid of a gel and with the patient at rest, the electrocardiograph is turned on, starting to record the impulses emitted by the heart (MINISTÉRIO DA SAÚDE 2016).

The interpretation of the waves obtained through the electrocardiograph makes it possible to identify heart diseases that act on the myocardial beats, such as bradycardias responsible for causing an irregular or slow heart rhythm, normally with less than 60 beats per minute, and arrhythmias, responsible for fast and disordered heart beats, these diseases cause ventricular tachycardia, ventricular fibrillation and asystole (HUNTER et al., 2003). In figure 2, there is a visual example of cardiac rhythms.

INTERNET OF THINGS (IOT)

The ability to evolve is what differentiates humans from other animal species. Such ability allowed us to move from a harried experience in the midst of nature to a modest, comfortable everyday life that enjoys many technological aspects, but which made constant reinvention necessary within human knowledge and in the technological world (WOLPOFF; CASPARI, 1996).

What we know today as computer technology had a tangible beginning in 1946 with the creation of the first large-scale electronic digital computer, called ENIAC, created by the Americans John Eckert and John Mauchly. From then on, with the constant development of human knowledge and the discovery of new natural components, the existence of what we know today as IoT became possible, whose acronym means *Internet of Things* (RICKMAN; TODD, 2003).

The idea of the IoT came up in 1999 with the British Kevin Ashton, who during his studies on radio frequency identification noticed a singularity in ubiquitous sensors, as they were able to interact by connecting the physical world to the internet. From then on, the machine-to-machine connection began to be studied, in order to speed up processes automatically without human intervention (RAHMAN; ASYHARI, 2019).

In view of the growing development and technological structure of IoT, there was the

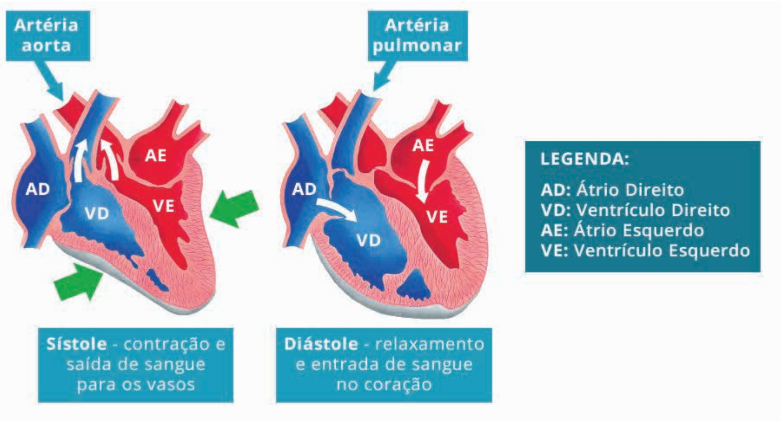

Figure 1 – Process of contraction (systole) and relaxation (diastole).

Source: Med Simple (2020)

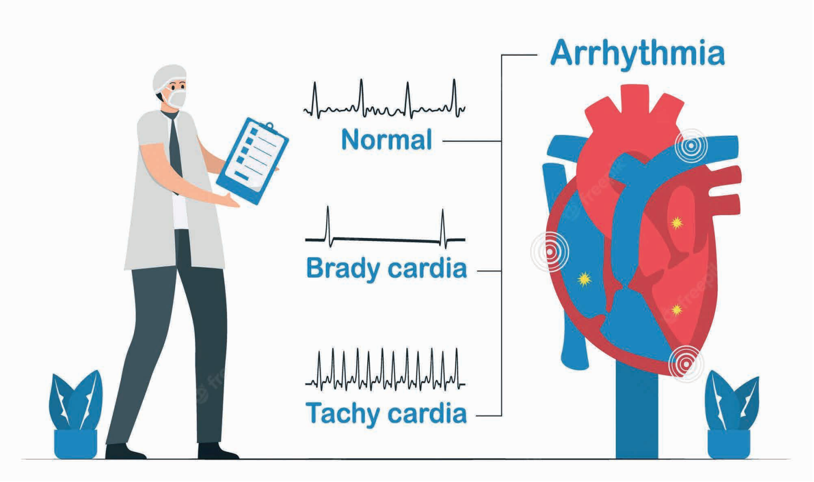

Figure 2 – Example of cardiac rhythms.

Source: Freepik (2020)

possibility of building equipment capable of detecting, processing and communicating data, associating sensors with multiple items of human daily life to help understand the behavior of these items or the environment. in which they are inserted (XU, 2020).

The implementation of technology in hospital routine is one of the most requested, among all areas of modern society, since the facilities that come from it make the routine activities of health professionals easier, more agile and profitable, in terms of quality and reliability in the which refers to the treatment of the patient and also the management of their information in real time, even if these professionals are not all the time next to their patients (HODGINS et al, 2008).

As a consequence of such technologies in the health area, a wide variety of machines and devices with greater connectivity and advanced applicability have been generated, which are extremely important in hospital environments, mainly because, based on such tools, it is possible to diagnose or treat patients with greater efficacy (HODGINS et al., 2008).

REGULATIONS RELATED TO THE EFFECTIVENESS AND SAFETY OF CARDIAC MONITORING DEVICES

Cardiac monitoring technologies, such as hospital electrocardiographs or systems that implement real-time acquisition of electrocardiographic signals, through mobile applications, must comply with requirements established by national and international standards that cover both manufacturing processes and the need for ensure electrical safety for users and operators (SARRACINI, 2021).

Because medical equipment is directly related to people's lives, it is a complex process where any failure can be very costly, in the sense of resulting in economic losses, injuries and more serious fatalities. Therefore, the guarantee of safety, effectiveness and reliability is essential to this process (ROSA apud LIN et al., 2014).

According to Vendramini and Sarracini (2020), medical electrical equipment, according to the ABNT NBR IEC 60601-1:2010 Standard (Brazilian Association of Technical Standards / *International Electrotechnical Commission*), is an electrical device that has an applied part, that is, a part that necessarily comes into physical contact with the patient, when in use, or transfers energy to the patient through an electrical supply network. It may be intended by the manufacturer for diagnostic, treatment or monitoring purposes.

Electromedical equipment in general needs to comply with regulatory standards that seek to ensure effectiveness and safety in performance. The "General Standard" cited above as ABNT NBR IEC 6060-1-1 deals with general safety prescriptions, applicable to all Medical Electrical Equipment. It prescribes general conditions for tests, protection against risks of electric shock, mechanical, among others.

In addition, there are collateral standards that are not dealt with in the General Standard and encompass a group of specific equipment. In the case of electrocardiograph equipment, the norm that deals with particular prescriptions for this group is ABNT NBR IEC 60601-2-25. This standard defines terms used in electrocardiography and adds some tests for safety evaluation. One of its sections contains, for example, the protection of the equipment against the effects of the defibrillator, in addition to terms used for carrying out the performance analysis of the electrocardiograph.

MARKET TECHNOLOGIES

Solutions that meet the specificity of performing cardiac monitoring remotely have been studied for merely informative applications or as devices based on the *Point-Of-Care* (PoC) concept, which have higher costs.

Point-Of-Care technologies that, in particular, enable real-time applications to monitor multiple health parameters, without the need for many resources, comparable to a portable laboratory (TIEPPO, 2021 apud MERKOÇI, 2018).

This section presents remote cardiac monitoring devices that offer the practicality of viewing data through applications. In addition to functioning, the current costs of these solutions are discussed.

SMARTCARDIA - 7L PATH

The Swiss company SMARTCARDIA has developed an ECG platform for remote cardiac monitoring of patients. According to her, the device is dedicated to detecting atrial fibrillation with precision and low noise, therefore, it is a technology for diagnosis (SMARTCARDIA, 2022).

The solution relies on a machine learning system called "SmartNeuralNet" that integrates data in the cloud. As soon as the monitoring starts, the health professional is notified of any significant cardiac arrhythmias, when these are automatically detected, quickly allowing measures to be taken (SMARTCARDIA, 2022).

The basis of the solution's "Artificial Intelligence" platform makes use of the ECG segments classified by cardiologists and cardiac technicians and, in real time, the vital signs are sent to the cloud with the 7 ECG leads (SMARTCARDIA, 2022).

Therefore, through an application, the electrocardiographic data are analyzed by an artificial intelligence algorithm and stored continuously, alerting the existence of arrhythmias. In addition, through a report generator tool, cardiologists can view, edit and download reports. See the structure of the device and the application interface in figure 3.

The "patch" device that has contact with the patient is waterproof, can remain connected for up to 14 days and does not require charging, which greatly facilitates its application for "Holter" exams aimed at monitoring needs for 24 hours (SMARTCARDIA, 2022).

ALIVECOR KARDIAMOBILE (Wireless Personal ECG)

Alivecor is a company North American medical device and artificial intelligence company that focuses on the development of electrocardiogram *software* and *hardware for mobile devices. The company was the first to receive Food and Drug Administration (FDA)* authorization for a medical device accessory for the *Apple Watch.* Basically, through an advanced algorithm it analyzes common arrhythmias (MEDICAL DEVICE NETWORK, 2021).

The Kardia Mobile technology aims to record the personal electrocardiogram in 30 seconds at any place or time. Therefore, it proposes to perform the detection of atrial fibrillation, bradycardia, tachycardia or normal heart rhythm. Similar to the technology mentioned above, the application stores the records and provides the possibility of sending them by email for the doctor to evaluate and this with unlimited cloud storage capacity (ALIVECOR, 2022).

It can be seen in Figure 4 the application interface and the practicality incorporated in the *design* of the device that has a support to attach to the *smartphone.*

METHODS

For Gil (1999), the scientific method is a way to achieve knowledge, which uses a set of intellectual and technical procedures. This methods section describes the characteristics of the method used, identifying the necessary

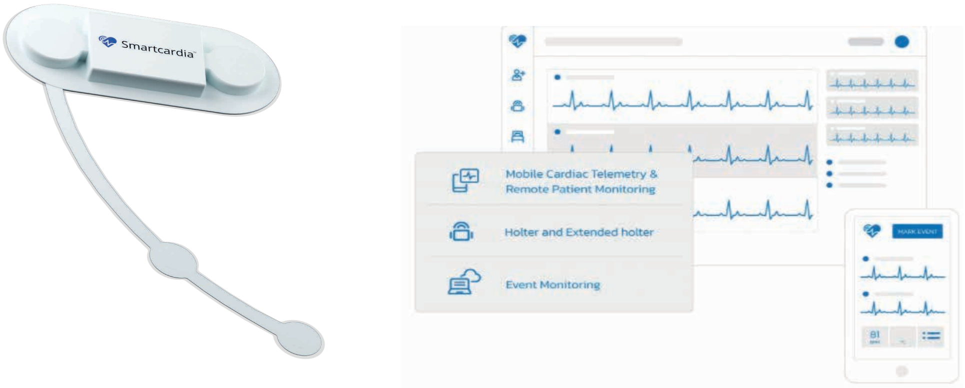

Figure 3 – Smart Cardia Device and Application Interface

Source: Smart Cardia (2022)

Figure 4 - AliveCor Device and Application Interface

Source: *Free Market (2021)*

COMPONENTS
ECG Module - AD8232
ESP32 microcontroller
Electrodes - 3
3.5mm electrode connector
Jumpers
Breadboard (400 holes)
3.5mm male to female connector
USB A male female connector
Arduino UNO

Table 1 - Survey of materials

Source: own elaboration (2022)

actions to arrive at knowledge.

LITERATURE REVIEW METHOD

With the objective of developing a project for an electrocardiograph capable of measuring signals for ECG remotely and accurately, helping in remote care, the methodology used is based on document analysis in an exploratory and deductive way. The "Google Academic" platform was used to obtain bibliographic material from the last five years, pertinent to the deepening of fundamental theories, already existing. With regard to the descriptors required for this research work, the following were used: "Internet of Things", Microcontrollers, Technology and Cardiac Monitoring. The acquired material enables a better understanding of the problems of the proposal so that, throughout the development, it is possible to implement the solution. For the development, the work of Savari (2022) was used for addressing the implementation of a remote electrocardiogram with "Internet of Things" applied.

Materials

For the development of the project, the materials for the assembly of the electronic circuit were raised. The selected materials were: AD8232 ECG module, ESP32 microcontroller, electrodes, 3.5mm connector, breadboard, jumpers, male to female USB connector and an Arduino UNO. In addition to surveying the necessary materials, a survey of their respective values was also carried out, which the sum results in values below the technologies present in the market that present the acquisition of ECG integrated to an application for mobile devices. Table 1 shows the survey carried out.

METHOD TO ANALYZE THE RELIABILITY RESULTS OF THE DATA OBTAINED BY ELECTROCARDIOGRAPHS BASED ON THE "INTERNET OF THINGS" TECHNOLOGY

Given the methodological approach used, the survey and collection of data on cardiac monitoring were carried out in a qualitative way, where the search for understanding and interpretation of these data was carried out from perceptions and comparison with the results of the analyzed articles and simulations graphics made during the development of the article with the help of online electronic *software tools.*

METHOD TO COMPARE TOOLS USED FOR THE DEVELOPMENT OF A LOW-COST CARDIAC MONITOR SYSTEM THAT INTEGRATES THE DATA IN AN APPLICATION

The method used as a study parameter that guided the development of a low-cost "Cardiac Monitor System", which integrates data into an application, was based on active research and observations of the day-to-day of modern society, as, understanding the way in which a society interacts with the world around it and at the same time with itself, it was possible to merge personal care of extreme importance for human health with a technological device that the vast majority of the population has access to, the cell phone. Thus, aiming at accessibility by health professionals and better monitoring of vital signs of the hearts in cardiac patients, and also in healthy patients.

METHOD FOR DESIGNING AN ELECTRONIC SIMULATION AND PROTOTYPE APPLICATION OF AN ELECTROCARDIOGRAM SYSTEM

In order to obtain data that confirm the effectiveness of the research and equipment, simulations were carried out, and for this, *online* simulation software tools were used, namely: PROTEUS for the simulation of the functionality of the electronic components, MULTISIM for the simulation of the reading electromagnetic waves coming from the heart, AUTOCAD to simulate the modeling of the finished equipment and finally the ARDUINO IDE and the ARDUINO CLOUD to simulate the programming and data transfer of the equipment, respectively.

Electronic simulation

The primary function of an ECG acquisition system is to amplify the electrical signal from the heart and reject artifacts and biological and environmental noise, normally using differential amplifiers. Mitigating these disturbing influences on the ECG signal is critical to improving its accuracy and reliability. The amplification of the electrical signal improves the interpretation of the exam.

Through the "Multisim" online circuit simulator, it was possible to design a basic circuit capable of producing the complete electrocardiogram signal at its output, as can be seen in Figure 6.

For the simulation of acquisition of heart beats in addition to the ECG waves, it was possible to develop a circuit in the PROTEUS *software,* in which, through a library called "Heart Beat Sensor", it is possible to acquire the BPM (heart beats per minute) which varies according to the change in resistance values connected to one of the sensor terminals. Through the use of an Arduino microcontroller available in PROTEUS and an LCD display, it is possible to program the visualization of heartbeats every 1 second. In Figure 7 follows the representation of the electrical diagram of the PROTEUS software.

For programming the Arduino Virtual of PROTEUS, the Arduino IDE software was used, in which it was possible to configure the Display or the Virtual Terminal, both places for viewing the BPM. In addition, through the Heart Beat sensor, it is possible to plot the output graph similar to that of the traditional ECG with the aid of an oscilloscope. Figure 8 shows the Arduino IDE programming code.

RESULTS AND DISCUSSION

RESULTS OF ELECTRONIC SIMULATION OF MONITOR OPERATION

Through the "Multisim" platform, the built circuit was able to generate complete signals from an electrocardiogram that reflects the representations of the ECG waves, such as the QRS complex stretch, the moment of activation of the ventricles and ejection of blood into the vessels, as well as in the recording of cardiac activity captured by electrodes, this activity can be seen in Figure 9.

The electrical scheme designed together with the Arduino IDE programming provides the projection of heartbeats on the PROTEUS terminal itself and the visualization of signals similar to the signals projected by electrocardiographs through the aid of an oscilloscope. The results obtained can be seen in Figure 10 and Figure 11.

Application interface

The proposed system consists of a set of *hardware and software* components that interact with each other. These components can be divided into four units: data collection which is responsible for reading the cardiac activity signals, the Wi-Fi ESP module which processes the data received from the ECG module and transmits information to the API application (Interface of Programming Application) and finally, the ARDUINO CLOUD application to display the received information on the cell phone screen. Therefore, in addition to reading, processing and sending data, the system proposes a

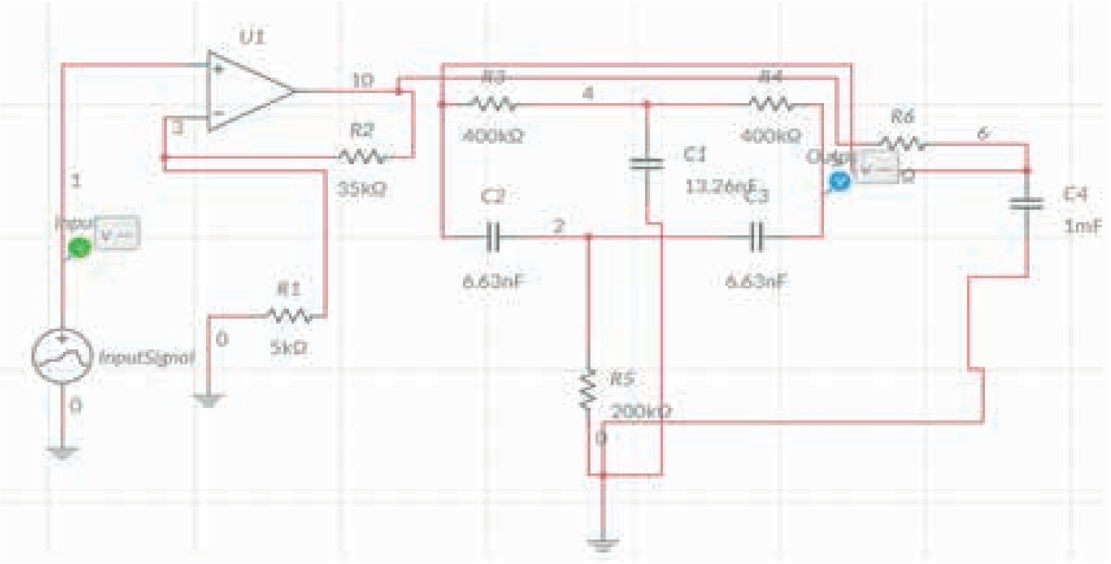

Figure 6 - Circuit representation of electrocardiogram signal projection

Source: own elaboration (2022)

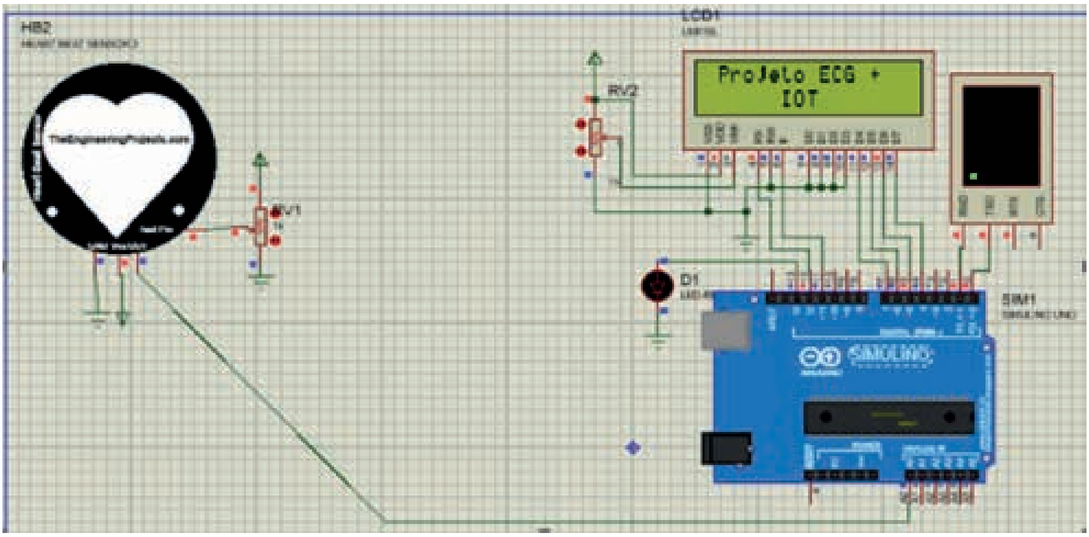

Figure 7 - Wiring diagram in the PROTEUS software

Source: own elaboration (2022)

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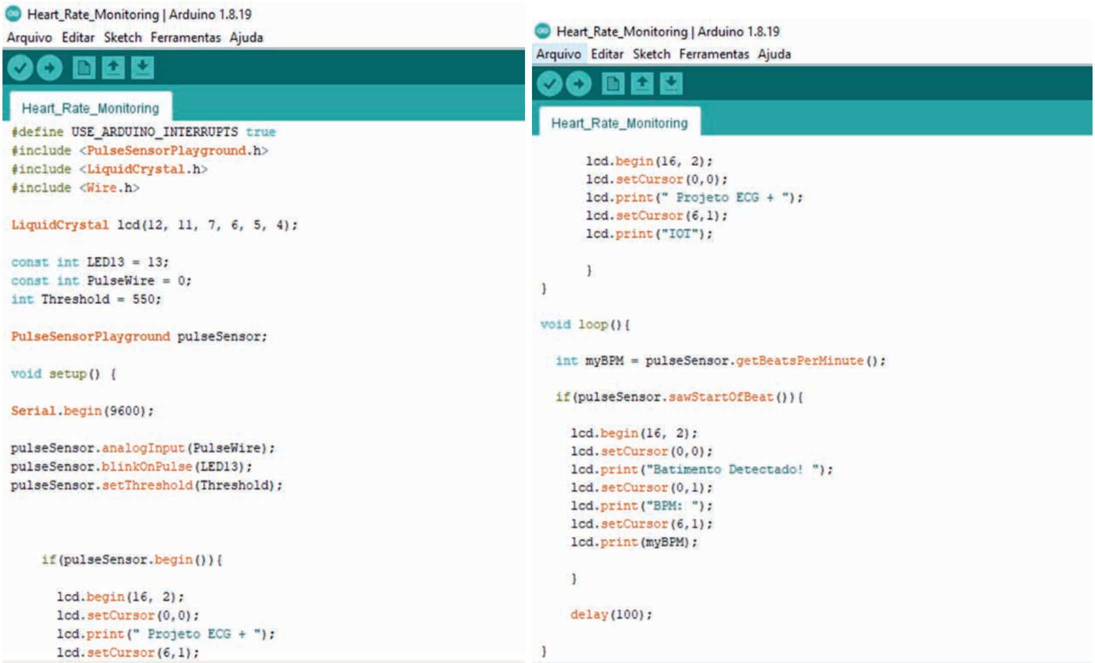

Figure 8 - Programming of the Virtual Arduino via ARDUINO IDE software

Source: own elaboration (2022)

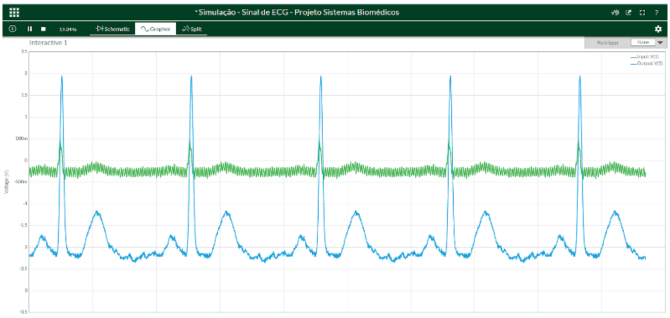

Figure 9 – Multisim output signal simulation

Source: The Own Elaboration (2022)

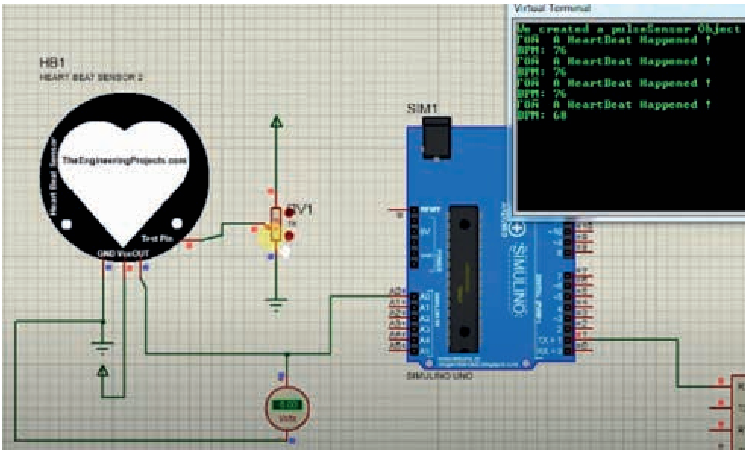

Figure 10 - Wiring diagram and simulation result

Source: own elaboration (2022)

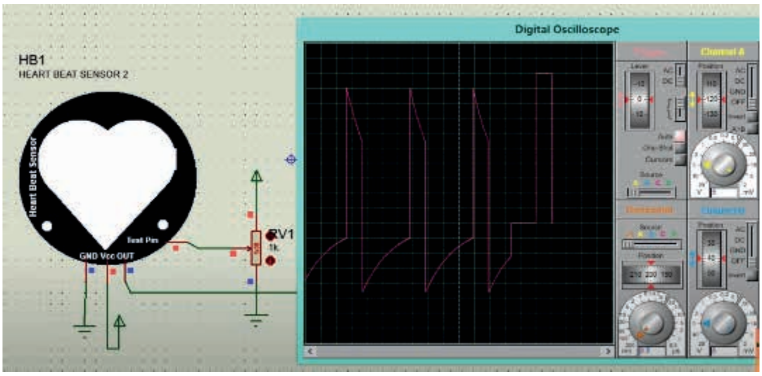

Figure 11 - Plotting the ECG signal on the oscilloscope

Source: own elaboration (2022)

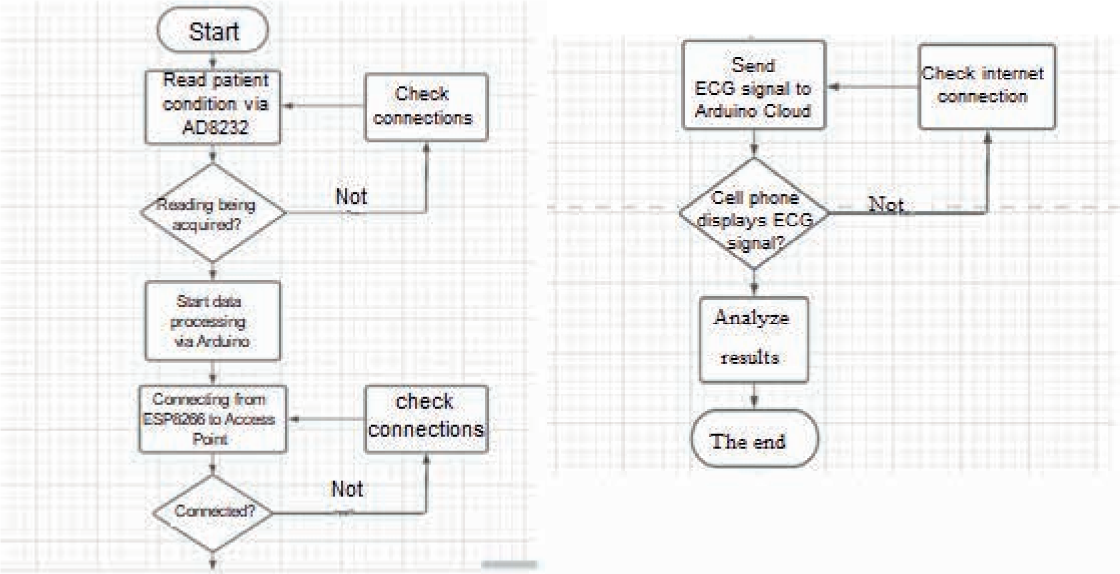

Figure 10 - Flowchart of the proposed architecture for the project

Source: own elaboration (2022)

graphic display according to the flowchart shown in Figure 10.

From the data acquisition, it is proposed the acquisition of a simple interface through the Arduino CLOUD, which allows the visualization of the ECG tracing. Figure 11 shows an interface for displaying data acquired by the AD8232 module in the Blynk application.

Prototype Modeling

For the elaboration of the prototype modeling, AUTOCAD *software was used.* For the development process, some points were taken into account, such as the easy understanding of the use of the equipment, its portability and the low cost of the project. With this, it is proposed a support for *mobile* devices in the electrocardiograph set, which has a 3.5mm input for connecting electrodes and a USB input for connecting a portable battery. In Figure 12 it is possible to observe the 3D modeling of the prototype.

FINAL CONSIDERATIONS

This work aimed to design an ECG system for health based on IoT for monitoring the cardiac activity of patients. The main strengths of the proposed system are the economically advantageous possibility of construction and connection, as well as the ease of use, since the device allows its operation anywhere.

The project has a console with structure to integrate data from an electronic simulation to a functional application. For a future perspective, it is proposed, with the assembly of the physical components, the visualization of the ECG tracing incorporated into an easy-to-execute application. The "case" can be prototyped in AUTOCAD in which there will be coupling of the entire circuit that will work together with a cell phone support. This allows the aid of a 3D printer, as a future perspective, in the manufacture of the device.

The project could be improved by increasing the number of electrodes for the ECG sensor in order to obtain more accurate results. In addition, the structure also allows the addition of more sensors for the measurement of other parameters, such as temperature and oxygen. Still for future works, the use of Arduino CLOUD allows the collection and storage of data for the elaboration of reports. Thus, a database of the results generated by the electronic circuit and displayed in the application can elevate the device to applications in diagnostic support contexts.

In addition, to validate proper functioning and data integrity, it is feasible for the device to undergo calibration steps using an ECG simulator that simulates heart rhythm and waveforms. Another issue would be understanding the limitation of remote technology, that is, the distance at which data can be acquired remotely, which will interfere with the methods of using technology and its effectiveness in relation to the accurate detection of data while the user is in movement, for example.

Finally, an extremely relevant point of improvement would be the integration of the entire system to the CEP technology, from the English "Complex Event Processing" to detect short- and long-term events in the patient's ECGs. Exploring detection algorithms, it is possible to identify the patient who is in a dangerous scenario. Thus, real-time professional analysis can be more targeted to the cases that deserve attention.

Figure 11 – ECG data acquisition interface prototype

Source: Blynk Community (2018)

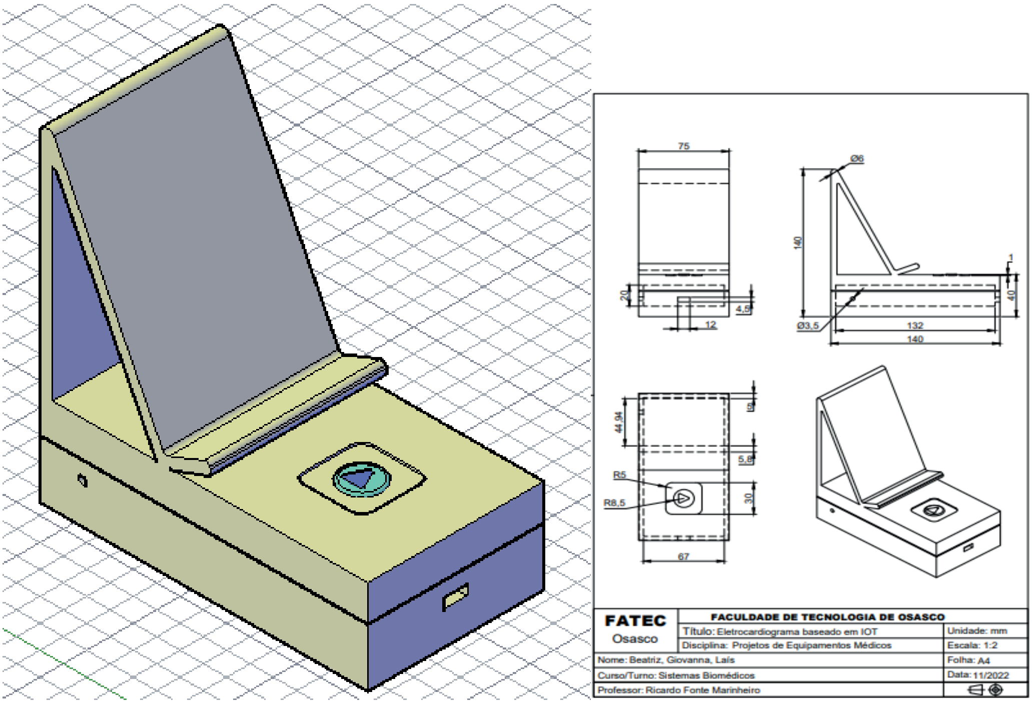

Figure 12 - 3D modeling of the project

Source: own elaboration (2022)

REFERENCES

CHAMLEY, Rebecca R; HOLDSWORTH, David A; RAJAPPAN, Kim; *et al*. ECG interpretation. **European Heart Journal**, v. 40, n. 32, p. 2663–2666, 2019.

CRONE, Bill. **Mitigation Strategies for ECG Design Challenges**. Analog.com. Disponível em: <https://www.analog.com/en/technical-articles/mitigation-strategies-for-ecg-design-challenges.html>.

DANIEL E. BECKER. **Ecg article**. Slideshare. Disponível em: <https://www.slideshare.net/ZakirHussain276/ecg-article-89747328>. Acesso em: 26 nov. 2022.

FELDMAN, José ; GOLDWASSER, Gerson P. Eletrocardiograma: recomendações para a sua interpretação. **Rev. SOCERJ**, n. 17(4): 251-256, p. 251–256, 2004. Disponível em: <https://pesquisa.bvsalud.org/portal/resource/pt/lil-398593>.

FERNANDES, Anamaria; NATÁLIA DINIZ DE MAGALHÃES, Isa; SOUZA, Alves; *et al*. **Sistema de aquisição de sinais ECG processado pelo LabVIEW com comunicação wi-fi por meio do módulo ESP8266**. [s.l.: s.n.], 2017. Disponível em: <https://periodicos.ifpb.edu.br/index.php/principia/article/download/1337/667>.

GADÊLHA, Manoel ; FAUSTINO, Francisco. Análise do desempenho de um eletrocardiógrafo interpretativo para utilização em um sistema computacional de auxílio diagnóstico em síndromes coronarianas agudas. **Revista Brasileira de Engenharia Biomédica**, v. 28, n. 2, 2012. Disponível em: <http://dx.doi.org/10.4322/rbeb.2012.019>. Acesso em: 17 mar. 2021.

GIFFONI, p>Rodrigo Tobias ; TORRES, Rosália Morais. Breve história da eletrocardiografia. **rmmg.org**, v. 20, n. 2, p. 263–270, 2009. Disponível em: <http://rmmg.org/artigo/detalhes/323>.

GIL, A. C. **Métodos e técnicas de pesquisa social.** 5.ed. São Paulo: Atlas, 1999.

GUILHERME TOGINHO, Dário. **ECG Gerado Por Microcontrolador**. [s.l.: s.n.], 2015. Disponível em: <http://www.uel.br/ctu/deel/TCC/TCC2015-DarioGuilhermeToguinho.pdf>. Acesso em: 26 nov. 2022.

HODGINS, Diana; BERTSCH, Arnaud; POST, Nils; *et al*. Healthy Aims: Developing New Medical Implants and Diagnostic Equipment. **IEEE Pervasive Computing**, v. 7, n. 1, p. 14–21, 2008. Disponível em: <https://ieeexplore.ieee.org/abstract/document/4431851>. Acesso em: 2022.

IKRAM; ABOORVA; HEEBASATHYA; *et al*. **Design of Op-Amp Based ECG Signal Acquisition Using MULTISIM**. Disponível em: <https://iopscience.iop.org/article/10.1088/1757-899X/1084/1/012129/pdf>. Acesso em: 5 out. 2022.

ISKANDAR, William Jerrel; ROIHAN, Ibnu ; KOESTOER, Raldi Artono. Prototype low-cost portable electrocardiogram (ECG) based on Arduino-Uno with Bluetooth feature. **AIP Conference Proceedings**, n. 2193 050019, 2019. Disponível em: <https://doi.org/10.1063/1.5139392>.

LI, Chao; HU, Xiangpei ; ZHANG, Lili. The IoT-based heart disease monitoring system for pervasive healthcare service. **Procedia Computer Science**, v. 112, n. KES2017, p. 2328–2334, 2017.

LI, Ren-Ke; JIA, Zhi-Qiang; WEISEL, Richard D.; *et al*. Cardiomyocyte Transplantation Improves Heart Function. **The Annals of Thoracic Surgery**, v. 62, n. 3, p. 654–661, 1996. Disponível em: <https://www.sciencedirect.com/science/article/abs/pii/S000349759600389X>. Acesso em: 2022.

LINHARES, Pedro ; MOREIRA, Tristão. **Protótipo de monitor cardíaco utilizando o módulo ESP32 e o sensor AD8232**. [s.l.: s.n.], 2020. Disponível em: <https://pettec.unifei.edu.br/wp-content/uploads/2021/04/Tutorial-prototipo-monitor-cardiaco.pdf>.

LIU, Hui; CHEN, Dan; CHEN, Da; *et al*. A large-scale multi-label 12-lead electrocardiogram database with standardized diagnostic statements. **Scientific Data**, v. 9, n. 1, 2022.

MACHADO, Alencar; LUIZ, Edson; SALVADORI, Fabiano; *et al*. **Utilização de Dispositivos Móveis, Web Services e Sotfware Livre no Monitoramento Remoto de Pacientes**. Disponível em: <https://www.researchgate.net/profile/Alencar-Machado/publication/242422641_Utilizacao_de_Dispositivos_Moveis_Web_Services_e_Sotfware_Livre_no_Monitoramento_Remoto_de_Pacientes/links/0c960537ce7cdb1520000000/Utilizacao-de-Dispositivos-Moveis-Web-Services-e-Sotfware-Livre-no-Monitoramento-Remoto-de-Pacientes.pdf>.

MACIEL, Rubens. **História da Cardiologia: História da Cirurgia Cardíaca Brasileira**. publicacoes.cardiol.br. Disponível em: <http://publicacoes.cardiol.br/caminhos/015/default.asp>. Acesso em: 26 nov. 2022.

MANSUR, Antonio de Padua ; FAVARATO, Desiderio. Taxas de Mortalidade por Doenças Cardiovasculares e Câncer na População Brasileira com Idade entre 35 e 74 Anos, 1996-2017. **Arquivos Brasileiros de Cardiologia**, v. 117, n. 2, p. 329–340, 2021.

MATHIAS, Thais Aidar de Freitas; JORGE, Maria Helena Prado de Mello ; LAURENTI, Ruy. Doenças cardiovasculares na população idosa: análise do comportamento da mortalidade em município da região Sul do Brasil no período de 1979 a 1998. **Arquivos Brasileiros de Cardiologia**, v. 82, n. 6, 2004.

MAXWELL, Marcio. **4 Confiabilidade metrológica de eletrocardiógrafos**. [s.l.: s.n., s.d.]. Disponível em: <https://www.maxwell.vrac.puc-rio.br/12402/12402_5.PDF>. Acesso em: 4 set. 2022.

PELLENSE, Márcia Cunha da Silva; AMORIM, Margareth Santos de; DANTAS, Eder Samuel Oliveira; *et al*. AVALIAÇÃO DA MORTALIDADE POR DOENÇAS CARDIOVASCULARES NO BRASIL: UMA SÉRIE TEMPORAL DE 2015 A 2019. **Revista Ciência Plural**, v. 7, n. 3, p. 202–219, 2021. Disponível em: <https://periodicos.ufrn.br/rcp/article/view/25186/14650>.

RAHMAN, Md Arafatur; ASYHARI, A. Taufiq. The Emergence of Internet of Things (IoT): Connecting Anything, Anywhere. **Computers**, v. 8, n. 2, p. 40, 2019.

RAJ, Nisha Rexline Rassal; PRIYA, Ebenezer; SAVARI, George Fernandez. Design and implementation of portable electrocardiogram recorder with field programmable gate arrays and IoT interface. **International Journal of Electrical and Computer Engineering (IJECE)**, v. 12, n. 5, p. 5176–5181, 2022. Disponível em: <https://ijece.iaescore.com/index.php/IJECE/article/view/25905>. Acesso em: 27 nov. 2022.

RICKMAN, Jon; TODD, Kim; VERBICK, Tabatha; *et al*. The evolution of the electronic campus. **Proceedings of the 31st annual ACM SIGUCCS conference on User services - SIGUCCS '03**, n. 1-58113-665-X/03/0009, 2003.

RODRIGO, Maycon; VENDRAMINI, Gabriel. **REQUISITOS DE SEGURANÇA EM EQUIPAMENTOS ELETROMÉDICOS**. [s.l.: s.n.], 2018. Disponível em: <https://semanaacademica.org.br/system/files/artigos/tcc_final_3.pdf>.

RODRÍGUEZ, R.; MEXICANO, A.; BILA, J.; *et al*. Feature Extraction of Electrocardiogram Signals by Applying Adaptive Threshold and Principal Component Analysis. **Journal of Applied Research and Technology**, v. 13, n. 2, p. 261–269, 2015.

SIQUEIRA, Suélia ; SANTOS, Andrea. **PROJETO PARA CONFIABILIDADE: APLICADO NO PROCESSO DE PROJETO DE EQUIPAMENTOS MÉDICOS**. Disponível em: <https://www.researchgate.net/publication/321232364_PROJETO_PARA_CONFIABILIDADE_APLICADO_NO_PROCESSO_DE_PROJETO_DE_EQUIPAMENTOS_MEDICOS>. Acesso em: 22 nov. 2022.

SPANO, Elisa; DI PASCOLI, Stefano ; IANNACCONE, Giuseppe. Low-Power Wearable ECG Monitoring System for Multiple-Patient Remote Monitoring. **IEEE Sensors Journal**, v. 16, n. 13, p. 5452–5462, 2016.

SZCZEPAŃSKI, Adam ; SAEED, Khalid. A Mobile Device System for Early Warning of ECG Anomalies. **Sensors**, v. 14, n. 6, p. 11031–11044, 2014.

VETOR, Rio ; GRANDE. Sistema para Aquisição de Sinais de Eletrocardiograma para Fins Acadêmicos System for Acquisition of Electrocardiogram Signals as a Tool for Academic Purposes. **VETOR**, v. 31, n. 1, p. 11–22, 2021. Disponível em: <https://periodicos.furg.br/vetor/article/download/13372/9548/44606>.

WOLPOFF, Milford H. ; CASPARI, Rachel. **Race and Human Evolution**. Library of Congress Cataloging-in-Publication-Data: Simon and Schuster, 1997. Disponível em: <https://books.google.com.br/books?hl=pt-BR&lr=&id=LyOvT1Kv2uoC&oi=fnd&pg=PA9&dq=human+evolution&ots=5vvkLUcS-F&sig=Y8G06zQj4fZt2rguBLNpM8isyuA#v=onepage&q=human%20evolution&f=false>. Acesso em: 2022.

WORLD HEALTH ORGANIZATION. **Cardiovascular diseases (CVDs)**. www.who.int. Disponível em: <https://www.who.int/news-room/fact-sheets/detail/cardiovascular-diseases-(cvds)#:~:text=Cardiovascular%20diseases%20(CVDs)%20are%20the>. Acesso em: 17 jun. 2022.

XU, Guangyu. IoT-Assisted ECG Monitoring Framework With Secure Data Transmission for Health Care Applications. **IEEE Access**, v. 8, n. 10.1109/ACCESS.2020.2988059, p. 74586–74594, 2020.

ZHANG, Meng; ZHAI, Yifei. A DETECTION SYSTEM OF EXERCISE ELECTROCARDIOGRAM. **Revista Brasileira de Medicina do Esporte**, v. 27, n. 4, p. 358–362, 2021.

ZIKRIA, Yousaf Bin; ALI, Rashid; AFZAL, Muhammad Khalil; *et al*. Next-Generation Internet of Things (IoT): Opportunities, Challenges, and Solutions. **Sensors**, v. 21, n. 4, p. 1174, 2021.

EINTHOVEN, W.; FAHR, G. ; DE WAART, A. On the direction and manifest size of the variations of potential in the human heart and on the influence of the position of the heart on the form of the electrocardiogram. **American Heart Journal**, v. 40, n. 2, p. 163–211, 1950.

HUNTER, Peter J.; PULLAN, Andrew J. ; SMAILL, Bruce H. Modeling Total Heart Function. **Annual Review of Biomedical Engineering**, v. 5, n. 1, p. 147–177, 2003.

LAGERHOLM, M.; PETERSON, C.; BRACCINI, G.; *et al*. Clustering ECG complexes using Hermite functions and self-organizing maps. **IEEE Transactions on Biomedical Engineering**, v. 47, n. 7, p. 838–848, 2000.

RAJ, Nisha Rexline Rassal; PRIYA, Ebenezer ; SAVARI, George Fernandez. Design and implementation of portable electrocardiogram recorder with field programmable gate arrays and IoT interface. **International Journal of Electrical and Computer Engineering (IJECE)**, v. 12, n. 5, p. 5176–5181, 2022. Disponível em: <https://ijece.iaescore.com/index.php/IJECE/article/view/25905>. Acesso em: 27 nov. 2022.

SZCZEPAŃSKI, Adam ; SAEED, Khalid. A Mobile Device System for Early Warning of ECG Anomalies. **Sensors**, v. 14, n. 6, p. 11031–11044, 2014.

TEIXEIRA, D. A. **FISIOLOGIA HUMANA**. [s.l.]: Núcleo de Investigação Científica e Extensão, 2021.

XU, Guangyu. IoT-Assisted ECG Monitoring Framework With Secure Data Transmission for Health Care Applications. **IEEE Access**, v. 8, n. 2169-3536, p. 74586–74594, 2020.

ZORKOT, Mouhamed; AQUINO DOS SANTOS, Alex; NETTO, Severino; *et al*. **Avanços da Internet das Coisas Médicas na Saúde e Neuroengenharia**. ResearchGate. Disponível em: <https://www.researchgate.net/publication/350568204_Avancos_da_Internet_das_Coisas_Medicas_na_Saude_e_Neuroengenharia>. Acesso em: out. 2022.

KAMBLE, Prachi ; BIRAJDAR, Ashish. IoT Based Portable ECG Monitoring Device for Smart Healthcare. **2019 Fifth International Conference on Science Technology Engineering and Mathematics (ICONSTEM)**, n. 19213040, 2019. Disponível em: <https://doi.org/10.1109/ICONSTEM.2019.8918776>.

TIEPPO, Bianca. **SISTEMA DE MONITORAMENTO REMOTO DE SINAIS ECG BASEADO EM DISPOSITIVOS DE POINT-OF-CARE ECG SIGNAL REMOTE MONITORING SYSTEM BASED ON POINT-OF-CARE DEVICES**. [s.l.: s.n.], 2021. Disponível em: <https://dspace.mackenzie.br/bitstream/handle/10899/29081/Bianca%20Tieppo%20-%20protegido.pdf?sequence=1&isAllowed=y>.