Assessing the AD8232 sensor's effectiveness on telemedicine kits: checking the AD8232 sensor

Avaliando a eficácia do sensor AD8232 em kits de telemedicina: checando a eficácia do sensor AD8232

Evaluación de la efectividad del sensor AD8232 en kits de telemedicina: comprobación del sensor AD8232

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Abstract
In pandemic times or due to patient's motor disabilities, the visit to health care centers can be difficult. Fortunately, multiple solutions have emerged in the last decades to provide remote medical care. In this scenario, the monitoring of vital signals is crucial for a number of diseases. Technologies of Internet of Things (IoT) are improving the collection, digitalization, transmission, and storage of such data. Some works in this field present measurement systems using of-the-shelf sensors and actuators. This paper aims to check the effectiveness, ease, and robustness of the AD8232 cardiac sensor for its use in telemedicine. Twenty experiments were performed using different devices and sensors and the results show that although it is an efficient sensor for studying or practicing with micro-controllers and sensors, it is not an effective solution for professional use. It presents problems with the position of the electrodes and the sensitivity of the sensor. Also, the device creates noise signals (impairing the collection of data), doesn't allow the control of multiple parameters, and has limitations in technology. Most of the graphs made by the AD8232 module did not form curves that would allow their interpretation. The conclusion, considering the difficulty in obtaining good graphics, is that this sensor cannot be applied professionally.
Keywords: eHealth; Tele medicine; Vital parameters; Electrocardiogram.

Resumo
Em tempos de pandemia ou devido a deficiências motoras do paciente, a visita a centros de saúde pode ser difícil. Felizmente, nas últimas décadas têm surgido múltiplas soluções para fornecer cuidados médicos à distância. Neste cenário, a monitorização de sinais vitais é crucial para uma série de doenças. As tecnologias da Internet das Coisas (IoT) estão a melhorar a recolha, digitalização, transmissão e armazenamento de tais dados. Alguns trabalhos neste campo apresentam sistemas de medição que utilizam sensores e atuadores. Este trabalho visa verificar a eficácia, facilidade e robustez do sensor cardíaco AD8232 para a sua utilização em telemedicina. Vinte experiências foram realizadas utilizando diferentes dispositivos e sensores e os resultados mostram que, embora seja um sensor eficiente para estudar ou praticar com micro-controladores e sensores, não é uma solução eficaz para uso profissional. Apresenta problemas com a posição dos eletrodos e a sensibilidade do sensor. Além disso, o dispositivo cria sinais de ruído (prejudicando o recolhimento de dados), não permite o controle de múltiplos parâmetros e tem limitações na tecnologia. A maioria dos gráficos feitos pelo módulo AD8232 não formaram curvas que permitissem a sua interpretação. A conclusão, considerando a dificuldade em obter bons gráficos, é que este sensor não pode ser aplicado de forma profissional.
Palavras-chave: eHealth; Telemedicina; Parâmetros vitais; Eletrocardiograma.

Resumen
En épocas de pandemia o debido a las discapacidades motrices de los pacientes, la visita a los centros sanitarios puede resultar difícil. Afortunadamente, en las últimas décadas han surgido múltiples soluciones para proporcionar atención

médica a distancia. En este escenario, la monitorización de las señales vitales es crucial para varias enfermedades. Las tecnologías del Internet de las Cosas (IoT) están mejorando la recogida, digitalización, transmisión y almacenamiento de dichos datos. Algunos trabajos en este campo presentan sistemas de medición que utilizan sensores y actuadores estándar. Este trabajo pretende comprobar la eficacia, facilidad y robustez del sensor cardíaco AD8232 para su uso en telemedicina. Se han realizado 20 experimentos utilizando diferentes dispositivos y sensores y los resultados muestran que, aunque es un sensor eficiente para estudiar o practicar con microcontroladores y sensores, no es una solución eficaz para el uso profesional. Presenta problemas con la posición de los electrodos y la sensibilidad del sensor. Además, el dispositivo crea señales de ruido (perjudicando la recogida de datos), no permite el control de múltiples parámetros y tiene limitaciones en la tecnología. La mayoría de los gráficos realizados por el módulo AD8232 no formaban curvas que permitieran su interpretación. La conclusión, teniendo en cuenta la dificultad para obtener buenas gráficas, es que este sensor no puede aplicarse profesionalmente.
Palabras clave: eHealt; Telemedicina; Parámetros vitales; Electrocardiograma.

1. Introduction

Residential health care, or Home Care, began in the United States to treat the ill veterans in the period after the War of Independence and started in 1796, aiming to treat these patients at home instead of hospitalizing them. The hospital was seen as an unhealthy place, where plague-stricken and the poor awaited death. This promoted the training of specialized professionals (NEAD Saúde 2021). With technological developments, this practice has become online home care in the 21st century.

This practice intensified during the pandemic of the new coronavirus caused by SARS-CoV-2. One of the measures to contain transmission of the virus is the Lockdown, when people stay at home and only essential services continue to operate, to reduce spreading the disease. This measure turned face-to-face meetings into "screen-to-screen" meetings, and medical appointments were no different.

The advance needed for better remote diagnosis motivates the following study. The measurement of vital parameters is one of the main aspects of online medicine and the possibility to monitor changes in those, so that even without live communication, alerts can be sent to the health professional. In IoT-based healthcare, distributed devices aggregate, analyze and communicate real time medical information to the cloud, to collect, store and analyze the large amount of data in several alternative forms and activate context-based alarms (Kodali P.K. et al 2015).

Among the existing exams in the medical field today, one that enables a wide range of diagnoses related to electrolyte disturbances and heart diseases, is the Electrocardiogram (ECG), which is the record of the electrical phenomena originated from cardiac activity. This exam follows the same principle since the last century due to its quality in obtaining electrical signals. Today the exam technology has improved and is even more dependable (Morsch J. A. 2017).

The device analyzed in this work is a sensor module called AD8232, which has the function of obtaining a derivation of electrical signals from the heart with three electrodes, which can be attached to the limbs or the thorax. This equipment is small and easy to carry, which would work as a portable solution for checking the heart function of patients with heart problems. The correct use of eHealth equipment should prevent false alerts and facilitate the communication of users with multiple backgrounds. Thus, it is necessary to verify the proper use of this equipment for usage on a broad scale.

The study addressed here seeks to present how technology can collaborate with health, especially with the implementation of IoT devices. Based on this, the central objective is to judge the use of the AD8232 sensor regarding its commercial viability, taking into account the required level of knowledge of the equipment and cardiac functioning. Moreover, variables that can collaborate negatively in obtaining data, such as the use of the ideal type of electrodes, variations in the device's power supply, and incorrect positioning of the electrodes are also addressed. All of these are points of easy variation and that can greatly contribute to not obtaining the desired parameters in their best form.

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2. Methodology

This study is an experience report that used as method the analysis of the studied sensor data supposed to different situations in order to better understand its behavior for its checking, the data collection is direct and qualitative (Pereira A. S. et al. 2018). Sensors and microcontrollers were chosen to obtain and analyze data. From this, we evaluate the feasibility of use on a commercial scale of the proposed system based on the AD8232 sensor module. Various conditions and different devices were used, to isolate manufacturing or assembly problems. The equipment used to perform the experiments with the sensors are described in Table 1.

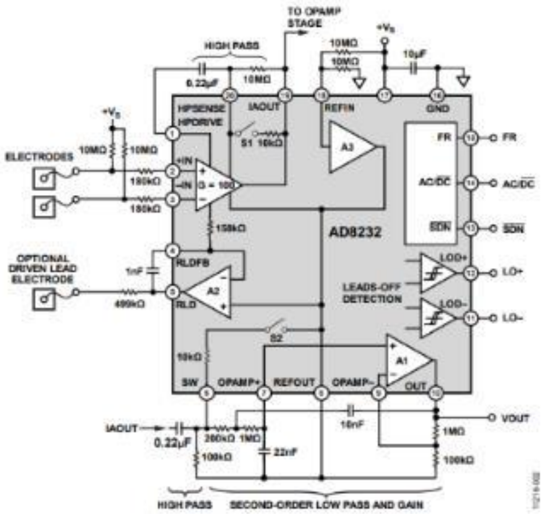
Table 1: Table with the equipment used to make the study.

Equipment	Description	Quantity
AD8232	Module sensor studied in this work.	3
ESP8266	Microcontroller with internet access.	1
Arduino UNO	Microcontroller with no internet access.	1
Disposable electrodes	To adhere the electrodes to the thorax.	200
Jumpers	To make the connections of the circuit.	50
USB cable	Data transmission cables.	1
Power supply	Adjustable. To power the protoboard.	1
Protoboard	To assemble the circuit.	1
Smartphone	To see the data using Blynk app	1

Source: the authors.

With the equipment shown in Table 1, it's possible to assemble a device capable of measuring cardiac parameters, sending them via cables to a computer, or wirelessly to a mobile phone application. AD8232 is a heart rate monitor front-end conveniently assembled with the necessary components for initial evaluation in fitness applications. A schematic of this module is presented in the Figure 1.

Figure 1: Schematic of Default configuration AD8232.



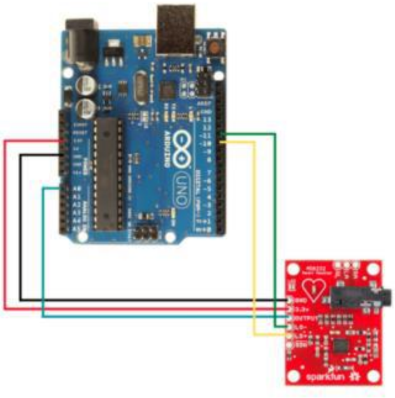
Source: Analog Devices (https://www.analog.com/en/products/ad8232.html).

In this schematic you can see the inputs of this sensor, both the power supply inputs for sensor operation, as well as the inputs responsible for connecting the electrodes that pick up the heart signals. The outputs are captured by the microcontroller, which in turn can display them with the help of a computer or smartphone.

2.1 Assembly of the systems

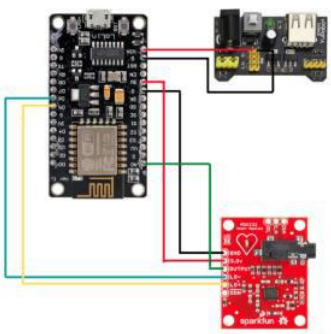
The tests were made on different microcontrollers. The first uses a Arduino, and is possible to assess quality of the data obtained, and the second using the ESP8232. This last one, has Wi-Fi connectivity and corresponds to the prototype system that would be used for remote use in telemedicine. Furthermore, three AD8232 modules were used to reduce the chances of isolated manufacturing errors. We can see the systems used to get the data below on the Figure 2.a and 2.b.

Figure 2.a: Assembly of the system circuit using Arduino UNO.



Source: the authors.

Figure 2.b: System circuit assembly using Esp8232 and Adjustable Source for protoboard.



Source: the authors.

This first system is assembled to test the acquisition of data from the sensor and check the feasibility of this module. Simpler components are used, without making these data available to the network, to limit reading errors or data availability only to the microcontroller. The Figure 2.a shows how the connections were made to get this data.

In this system, a more independent device is proposed, since it is implemented one source that can be plugged into any outlet. This independence is achieved because this system allows the microcontroller to connect to local Wi-Fi and provide data from a mobile application. Thus, making it non-dependent on a computer and auxiliary cables for connection, as shown in Figure 2.b.

2.2 Prototype and architecture

The algorithm captures the data and create graphs. Two types of systems with two different microcontrollers are proposed and the code for both is similar. The first used the Arduino system, and this is the simplest system. The other used the

ESP8266 controller, which has Wi-Fi connectivity and allows the creation of a device that makes the data obtained by the microcontroller available in the cloud. This way the data can is available through other devices, such as smartphones. And this would be the central goal of the telemedicine prototype.

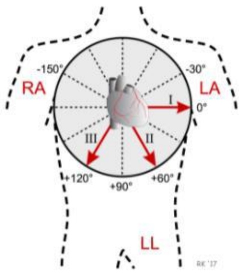
To mediate the availability of data we used the Blynk platform (Blynk 2017). It permits the user to observe in real time the graph formed by the data collected according to the electrical signals. This is possible from any mobile device using the login registered for the project linked to the sensors.

For each project created in Blynk, a token is generated. This token corresponds to a link that connects the system to the Blynk platform network, and it is loaded into the microcontroller. In other words, the data captured by the sensor is read by the microcontroller, sent to the network, and displayed on your mobile device with no computer. A project is created through Blynk and through a dashboard created by the user to visualize the data.

2.3 Ideal Position of the electrodes

The most recommended way to place the electrodes is according to Figure 3.a. This position is also based on Einthoven's triangle, which is based upon universally accepted ECG rules (Klabunde, R. 2011).

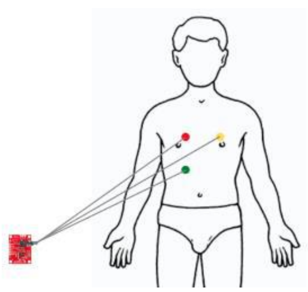
Figure 3.a: Einthoven's triangle, references of the electrodes in degrees.



Source: CV Physiology (http://www.cvphysiology.com/Arrhythmias/A013a).

The measurement is performed on the thorax because it is closer to the heart and thus it captures the electrical signals of the heart more easily and with less noise. Therefore, the position of the electrodes adopted for this study is shown in Figure 3.b.

Figure 3.b: Electrode positions on the chest.



Source: the authors.

3. Results, Analysis and Discussion

IoT is an approach in which "things" such as objects, places and environments are interconnected through the Internet, ranging from a global network of computers to a global network of objects (Koreshoff T. L. et al 2013) and its main goal is that objects present in people's daily lives become able to capture their needs and act without explicit instructions.

To apply IoT and computer network technology in telemedicine, it is necessary to understand the subject addressed in this research, which is the electrocardiogram exam. For this, we describe it´s evolution since the invention until the current technology available. Luigi Galvani, in his 1791 work "Commentarius", describes his discovery about the existence of electrical phenomena in animals (Piccolino, M. 1997). Since then, it was discovered the electrical signals in the human body, allowing the evaluation of heartbeats and their synchrony.

The parts of the heart normally beat in an orderly sequence. Contraction of the ventricles (ventricular systole follows contraction of the atria (atrial systole)), during diastole; all four chambers are relaxed (Piccolino, M. 1997). And these movements of the heart are determined by the sinoatrial node, responsible for the rate of these movements, which are triggered by electrical signals, which can be measured to verify the functioning of the heart. For this verification of the heart's electrical signals, Eithoven, physician and scientist, in 1901, invented the ECG by connecting wires in the foot and hands of the volunteer in a bucket with an electrolyte solution, connecting these three derivations to a huge machine, which weighed almost 300 kilos, occupied two rooms and required five people to operate it (Figuinha F. 2018).

With the advancement of technology, devices to measure these electrical signals have become smaller and easier to handle. Nowadays there are cheap kits of sensors available to the public. Based on this evolution, we evaluate the AD8232 sensor, composed of a small module and three electrodes, which guarantees the measurement of electrical signals using only one more microprocessor board. This sensor was be used during this work to check its effectiveness for clinical diagnosis.

According to the manufacturer of the AD8232 Analog Devices, the sensor module is a conditioning block capable of extracting, amplifying and filtering small biopotential signals in the presence of noisy conditions, such as those created by movement or remote placement of the electrodes (Analog Devices, 2012).

To support this study is important to know that other authors made similar works, and the result for the comparison between a traditional ECG and the AD8232 made by Sugunakar M. is that there is a strong positive correlation between them. However, the AD8232 module can be used instead of standard ECG device for basic monitoring, and the author shows pros and cons about using AD8232 module, and we will look some of them:

Pros: AD8232 versatile device, easily available for purchase through online. The device run on 3V to 5V (most common USB voltage). The detection QRS complex has a great significance in the development of automated intelligent ECG signal detection. Cons: only basic monitoring can be achieved. For analysis of axis deviation, a real time 12 channel ECG is required. Most recent ECG monitors have advanced signal processors and patent information storage capabilities. Scope of further development: the more compact sound recording software can be developed which can run on mobile devices since audacity software is open source (Sugunakar, M. B. S. 2021).

3.1 Cardiac Physiology

According to Koeppen and Stanton, the heart is a muscular organ formed by two distinct pumps that pump blood into the pulmonary circulation and into the systemic circulation. It is composed of four chambers, two atria and two ventricles; and four valves; two atrioventricular valves and two semilunar valves.

During the heartbeat, the heart undergoes three events: electrical activities, sound activities, and mechanical activities. I composed the electrical activities of the depolarization and repolarization of muscle cells. This type of activity enables the muscle to contract or relax, respectively (Figuinha F. 2018). The sound activities that the heart emits, called heart sounds correspond to the closing of the atrioventricular valves and semilunar valves.

3.2 Electrocardiogram

In the ECG, one can observe distinct traces called waves. The first one is called P wave, it is recorded in any derivation of the electrocardiogram and represents the depolarization of the atrium; it needs to be a rounded wave, symmetrical, small amplitude. Every P wave must be followed by the QRS, atrioventricular relationship. Absence of the P wave makes up arrhythmias, as examples, atrioventricular blocks (BAV) of 2nd and 3rd degrees, atrial flutter or fibrillation and junctional rhythm. P waves with increased amplitude should be analyzed in the context of the clinical picture, because it may correspond to atrial growth (Schwarz L. 2009).

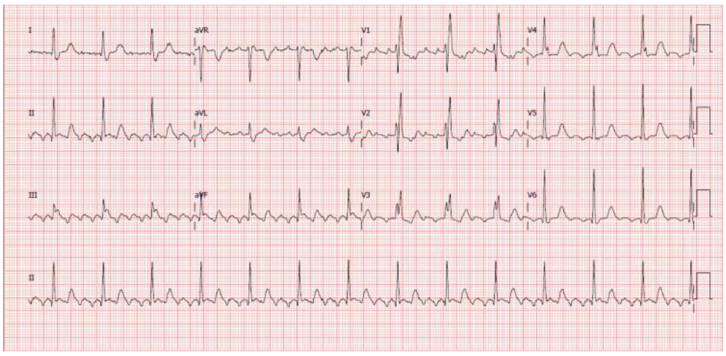
Then there is the second wave, called QRS complex. It represents the ventricular depolarization and has a pointed morphology, unlike the rounded P and T. It occurs at the onset of ventricular systole, at the ventricular apex. Abnormal or pathological Q wave has increased duration and increased amplitude, correlating with a possible ventricular necrosis. Morphological alterations of the QRS allow for the identification of ventricular hypertrophies and branch blocks. QRS with increased amplitude may correspond to LV hypertrophy (Schwarz L. 2009).

Finally, the last wave corresponds to the T wave. It represents the ventricular repolarization, rounded and asymmetric wave, with variable amplitude, smaller than the QRS. Changes in its shape and polarity can be observed in a series of situations: in children and adolescents, it can be negative in V1 to V4; in obese or brief adults, or in women or black race, it can be negative in V1 and V2; in athletes it can be negative in several derivations. In smokers, or after alcohol ingestion or hyperventilation, the T wave may become flattened, small amplitude or even slightly negative, setting the nonspecific changes of ventricular repolarization (Schwarz L. 2009).

Thus, it is possible to realize that variations in different waves suggest different cardiac dysfunctions, and that some details such as voltage, morphology and duration of the wave may somehow alter the subsequent diagnosis. Likewise, it is possible to observe that some alterations can only be visualized in certain leads. This shows the importance of an intense analysis in each particularity of the wave and in each of the exposed leads.

To begin the presentation of the results, it is important to understand what an electrocardiogram used professionally by doctors looks like.

Figure 4: Example of a traditional electrocardiogram exam and its leads.



Source: Cardio Papers (https://cardiopapers.com.br/curso-basico-de-eletrocardiograma-parte-07-frequencia-cardiaca/).

The Figure 4 shows a test performed in a traditional clinic. It’s important to present this traditional test to serve as a form of comparison with the images from the experiments that will be presented.

Knowing this, several tests were made to approximate the graphs presented above. Since the experiments required a person to measure the parameters, there is the expense of electrodes, and it is not something so simple and fast, twenty experiments were done to bring reliability to the study. The tests were performed in various situations with the three modules available for this study. In addition, the cables that connect to the electrodes and jumpers used in the circuit were also replaced to isolate manufacturing errors in this equipment.

Table 2: Experiment design.

Variable	Condition
Quantity of sensors	3
Electrodes	Original
	Non-Original
Position	Standing
	Sitting
	Lying
Presence of hair	Yes
	No
Sensor supply	Adjustable Source
	Computer USB port

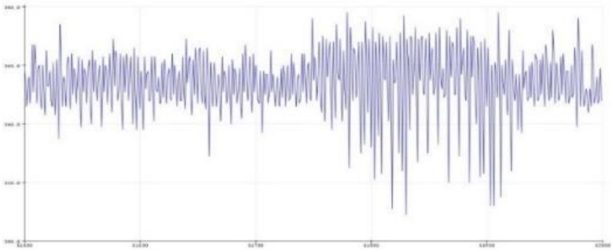
Source: the authors.

The variables observed in this acquisition of data are these shown in Table 2, and itt was a important factor to understand how the sensor works in different situations.

3.3 Data collection with Arduino UNO

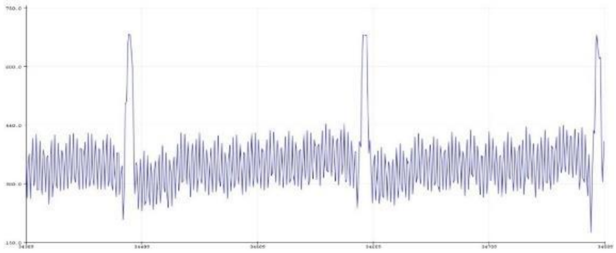
At first, most of the graphs obtained did not even form curves close to an electrocardiogram. The results were established at value zero of the sensor or at the maximum value. After variations in body position, it was noticed that this occurred when the feet were in contact with the ground. Experiments showing this was performed and presented in the Figure 5.a and 5.b.

Figure 5.a: Demonstration of how the first experiments with the sensor showing only noise.



Source: the authors.

Figure 5.b: Better format of the waves but still with a much noise.



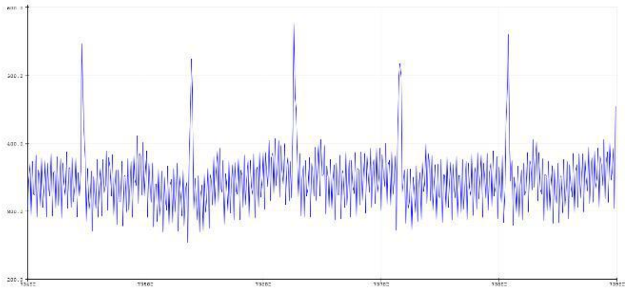
Source: the authors.

That said, the positions standing and sitting with the feet on the ground were discarded. The next tests were performed either with the feet elevated or with the volunteer lying down. After this, the graphics obtained were like the following presentation in Figure 5.a.

After learning more about how the sensor works, the ideal positions of the electrodes and what is the bests conditions of the variables already cited, graphics got a little closer to the desired, cleaner and with less noise as can see in Figure 5.b.

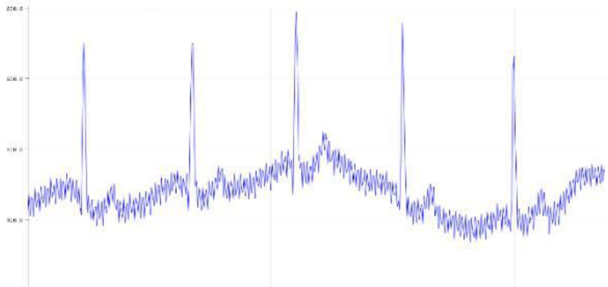
Another information noticed during the experiments is that using the original electrodes of the module produces graphs with less noise and disturbances. The electrodes were positioned at the same points had different behaviors, as shown in Figure 6.

Figure 6.a: Non-original electrodes.



Source: the authors.

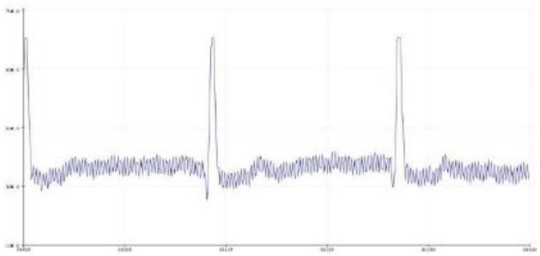
Figure 6.b: Original electrodes.



Source: the authors.

As observed, the difference between the graphs obtained in Figure 6.a and 6.b is clear, since the latter presents a much smaller amount of noise. Thus, for better effectiveness of the study, only the electrodes in the original kit of the AD8232 module were used. And after many tests to obtain graphs with less noise, the following graphs were obtained, as we can see in the Figure 7.

Figure 7: Example of graph obtained with the lowest amount of noise among the experiments performed.



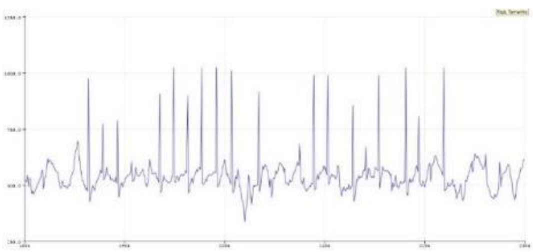
Source: the authors.

Finally, as far as data collection is concerned, the above graph in Figure 7 was achieved, with the noise level low and with an appearance similar to that seen in traditional examinations, such as those in Figure 4.

3.4 Testing the prototype of the suggested system for Telemedicine

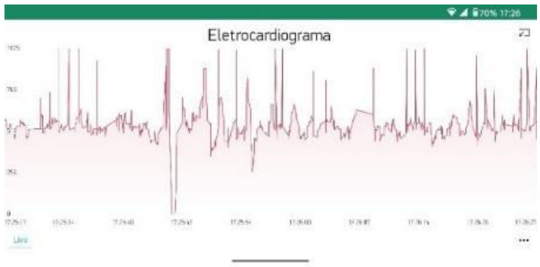
When the prototype proposed in this article was used for remote use, a graph was seen that was visually different from the one got with the previous microcontroller. But the quick response of sending the data to the smartphone was noticed, as well as the fidelity of the data from the similarity of the graphs displayed on the computer screen (using a data cable) and those seen on the smartphone. To present the results, graphs are presented that were got using a computer and using the mobile phone as seen in Figure 8.a and 8.b.

Figure 8.a: Graphics visualized by the computer.



Source: the authors.

Figure 8.b: Graphics visualized by the smartphone.



Source: the authors.

The curve that was formed in the Figure 8.a and 8.b have the level of noise very representative, in this way is possible to affirm that it's not similar to the curves seen at professional ECG Figure 8. On the right image we see the graphs obtained with the ESP8266 microcontroller visualized by smartphone, and we see that the curves are similar to the previous one.

3.5 Discussion of results

Our experience was that the AD8232 sensor module has easy construction and programming. The module prepares the output signal, and the software job is to capture and present data. The three sensors assessed didn't present physical failures, have general good quality and deliver similar results.

On the unsatisfactory aspects, the difficulty in obtaining graphics with little noise was the most noted. This problem was persistent throughout the study and the following factor can be to blame:

- Wrong position of the electrodes.
- Position of the patient under exam.
- Use of the electrodes present in the original sensor kit.
- Presence of hair on the electrode adhesion area.

These problems deteriorate the quality of the sensor. For large-scale use, with several people of different levels of technical knowledge, it can be impractical. In addition, the differences in the graphs obtained when using original and non-original electrodes show poor standard, since the electrodes are disposable and drastically decrease the quality obtained data if reused. Another problem happened with the position of the monitored patient, since when in a sitting position with the feet on the floor, the sensor reads zero or maximum value.

For the medicine this sensor might not be very effective in diagnosing or checking the functioning of the heart by a health professional. The ECG requires high precision - small distortions could represent serious diseases - and with the amount of noise obtained makes diagnosis impossible.

As seen above in the Figure 8, the electrocardiogram performed in medical laboratories has no noise and must have several derivations. As mentioned earlier, these derivations perform different functions and together can diagnose many diseases and problems in cardiac functioning. As seen in the results, this sensor AD8232 corresponds to only one of these derivations.

As mentioned above, several variations were performed in the experiment besides a satisfactory number of repetitions. As this is an experiment to visualize the results, the data produced were the images already presented, and thus no value or parameter was used to measure the noise.

With the observation of these images, it could be seen that even if standards were adopted for the experiment to make it cleaner, following the manufacturer's recommendations for use, it is still seen that the use of this equipment for diagnosis of patients is not appropriate.

4. Conclusion

Health home care has grown over the years. Allied to this, measurement of vital parameters is more available, specially using IoT devices. However, this use has not yet reached an elevated level of comprehensiveness for every type of exam.

This research evaluates the AD8232 module, a kit destined to assemble an ECG monitoring device. It was tested to obtain ECG data in several situations, considering different products, and variate uses. The evaluations presented compromised results, as most of the data results collected noise with the signals. That impaired the evaluation for the diagnosis of cardiac problems, since small oscillations in the graph could already indicate a disease.

According to our results, the AD8232 module should not be used on a professional scale because it does not provide satisfactory results to diagnose patients. It is recommended that this equipment be used only for academic purposes. Better devices must use more electrodes to allow other derivations of the traditional ECG and a simpler use, delivering results with less noise. In addition, it is necessary to improve the electronics of the AD8232 module by improving the noise filter.

For our future work, we will conduct research with healthcare professionals, presenting the data obtained in this study to confirm that this sensor module cannot be trusted on a professional scale. This verification with professionals is important to have a practical basis besides the theoretical one already studied in this analysis. It would be interesting to develop a sensor with a higher quality in obtaining data. Another factor of foremost importance is the number of leads seen in the exam, and for a diagnosis, it is essential to visualize more electrical signals. In this way, for future works, a technological development study is proposed for a device or software that could deliver a data collection without noise and with more derivations of the heart's electrical signals.

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