Design of a low-cost portable electrocardiograph for telemedicine application

Diseño de un electrocardiógrafo portátil de bajo coste para su aplicación en telemedicina

Conceção de um eletrocardiógrafo portátil de baixo custo para aplicação em telemedicina

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Summary. - This paper presents the design of a portable electrocardiograph designed to provide community health care. The AD8232 main sensor has multiple options for displaying cardiac activity. The first option uses the serial plotter in the Arduino IDE, while the second employs LabVIEW, allowing additional observation of the patient's blood pressure via block coding. In addition, the Arduino cloud is integrated to process the information captured by the ESP32, enabling visualization on any device with internet access. Through this platform, it is possible to download the studies performed in different periods (1 hour, 1 day, 7 days, and 15 days), with an efficiency percentage of 4.11%.

Keywords: Portable Electrocardiograph; Healthcare; IoT; Community; Cardiac Activity.

Resumen. - *El presente trabajo presenta el diseño de un electrocardiógrafo portátil diseñado para proporcionar asistencia médica comunitaria. Se emplea el sensor principal AD8232, con múltiples opciones de visualización de la actividad cardíaca. La primera opción utiliza el serial plotter en el IDE de Arduino, mientras que la segunda emplea LabVIEW, permitiendo la observación adicional de la presión arterial del paciente mediante codificación de bloques. Además, se integra la nube de Arduino para procesar la información capturada por el ESP32, lo que posibilita la visualización en cualquier dispositivo con acceso a internet. A través de esta plataforma, se pueden descargar los estudios realizados en distintos lapsos de tiempo (1 hora, 1 día, 7 días y 15 días), con un porcentaje de eficacia del 4.11%.*

Palabras clave: *Electrocardiógrafo portátil; Asistencia Sanitaria; IoT; Comunidad; Actividad Cardiaca.*

Resumo. - *Este artigo apresenta o projeto de um eletrocardiógrafo portátil projetado para prestar cuidados de saúde comunitários. O sensor principal AD8232 possui múltiplas opções para exibir a atividade cardíaca. A primeira opção utiliza o plotter serial no Arduino IDE, enquanto a segunda utiliza o LabVIEW, permitindo observação adicional da pressão arterial do paciente por meio de codificação em bloco. Além disso, a nuvem Arduino está integrada para processar as informações captadas pelo ESP32, possibilitando a visualização em qualquer dispositivo com acesso à internet. Através desta plataforma é possível baixar os estudos realizados em diferentes períodos (1 hora, 1 dia, 7 dias e 15 dias), com percentual de eficiência de 4,11%.*

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Palavras-chave: *Eletrocardiógrafo Portátil; Assistência médica; IoT; Comunidade; Atividade Cardíaca.*

1. Introduction. - The electrocardiogram is known as a non-invasive medical test that records the electrical activity of the patient's heart. It is used to evaluate the health of the most important organ, the heart, and to detect possible cardiovascular problems. During an electrocardiogram, electrodes are attached to the skin at different locations on the human body, such as the chest and upper and lower extremities [1], [2].

During the pandemic or situations in which it has been difficult for patients to approach a medical center to review the information or know the status of the study has been a limiting factor either physical, personal, or environmental conditions and this has severely affected humanity during this health crisis [3], [4].

At present, there is a solution to this problem, which consists of the use of medical equipment capable of connecting to the network and sending the information obtained in real time, which will be stored in a cloud and can be viewed by anyone who requires it [5], [6].

The use of the IoT (Internet of Things) connection in medical equipment has the purpose of improving the quality of service both to better process the studies and to provide the doctor with the facility to visualize the information to perform an analysis anywhere on the planet. This has represented a great improvement in the field of health, allowing Telecommunications and Medicine to work together [7], [8].

IoT communication is based on a device that acts as a transmitting antenna, in our case the ESP32, which receives the processed signal through its ports and proceeds to send it to the Arduino cloud. This device is one of the main options to consider when making an IoT connection due to its advantages over other components that do not have this capability [9], [10].

In the design of this article, Arduino Uno is used as the receiver and will be the one to process the information from the AD8232 sensor which captures the cardiac signal in analog form. The Arduino transforms the analog signal to digital for easy reading and sends the data to the other stages of the design, sending the COM port to the LabVIEW software which through the LINX library helps to make the connection of the system [11], [12].

At this stage the LabVIEW software provides a plus to the design since the blood pressure is displayed along with the graph of the cardiac activity of the heart, normally in other mostly analog equipment this result is displayed every minute, but through the formula for the prediction of blood pressure (equation 1), the prediction is obtained every 15 seconds which provides a much faster response to conventional [13], [14].

The final and most important step of this design is to send the information to the Arduino ESP32 Wi-Fi module which is previously linked to the Arduino cloud where, through its interface, the cardiac activity can be observed in real-time and this collection of information can be downloaded through an Excel file in comma delimited format for processing [15], [16].

The tracing shown in Figure I is the result of a simulation performed using BTL Cardiopoint software. This software is used as an electrocardiogram (ECG) simulator, allowing various clinical conditions and scenarios to be accurately recreated. The graphical representation provides detailed information about the electrical activity of the heart and is useful for medical education and cardiovascular research. This tracing, generated using the aforementioned software, provides a valuable tool for the analysis and interpretation of cardiac activity in controlled settings. In addition, it facilitates the practice of ECG interpretation, helping to improve the diagnostic and patient management skills of healthcare professionals [17], [18].

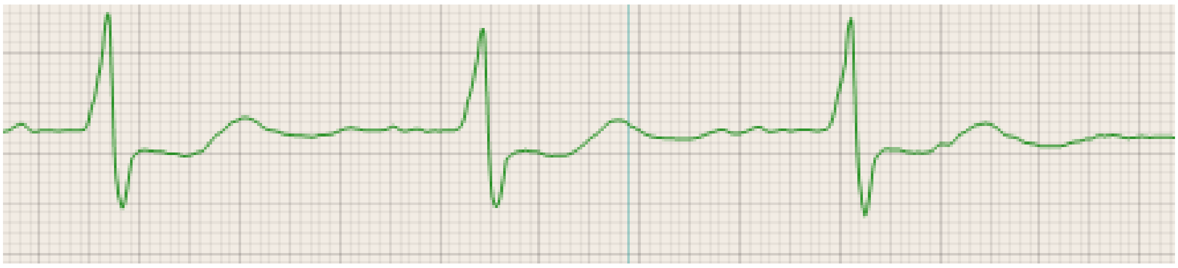

Figure I. Simulation of an ECG using Cardiopoint software.

1.1 Related Work. - The authors of the article [16] mention that currently, many people die of cardiac arrest, due to a poor check and control of the state of their cardiovascular system. They propose a solution to this problem through their design, which is based on the realization of a cardiac activity monitor using the AD8232 sensor and an ESP32 that serves as a microprocessor and the device responsible for the connection to the cloud using Ubidots and Thingspeak [19], [20].

The authors of the article [5] designed an ECG that focuses on making the cost as low as possible, and at the same time they implemented a system to detect any anomaly in the outlets, in the case of any, they will send an alert message to the doctor or the person in charge. The design has a Bluetooth connection system that covers a distance of 100 meters. It is concluded that its design is a great advance for society and a great alternative for people or entities that need to start in the cardiovascular care of their patients because the manufacturing cost of the proposed design is significantly lower than other models previously considered [21], [22].

The authors of the article [3] state that cardiovascular care awareness has now increased due to the emergence of COVID-19, since during the pandemic period, the number of deaths due to cardiac arrest increased considerably. They point out that the speed of detection time is crucial to avoid irreparable damage to human life.

They concluded that the design will be very useful because it can accommodate the information collected through unique record codes that will facilitate the search of the records [23], [24].

The authors mention that about 30% of the population in rural areas of Bangladesh lives in poverty. Due to the lack of modern medical technology in these areas, medical care and diagnostic services are limited for rural residents. As a result, adequate medical care is inaccessible to the rural population. In this context, modern technology could be implemented to address their health problems. For example, electrocardiogram (ECG) sensing tools connected to the human body can be used to collect essential cardiovascular data through Internet of Things (IoT) devices [22].

The authors of the article mention that, in recent times, several researchers have explored the connection between emotions and people's physical well-being. This research interest has intensified due to the rapid progress of computer technology, especially in the biomedical field. In the field of engineering, there is a focus on understanding how emotions affect the human body, which motivates researchers to conduct studies in this area. It should be noted that this design does not have an information storage system, nor does it have the function of sending the information to the cloud, it only focuses on the analysis and visualization during the ECG [1].

The aforementioned authors presented their devices to the world, some of them stand out in some particular quality depending on the case. But they all fulfill their general purpose, to provide a tool for the care and prevention of cardiovascular problems in humans, these articles were of great help in guiding which direction could focus the analysis of this study and what other issues to innovate as evidenced in the implementation of the pressure gauge in LabVIEW, therefore this article has great advantages to take into consideration as shown in the results section.

1.2 **Arterial prediction formula implemented in LabVIEW. -** The equation for blood pressure prediction (1) used in LabVIEW is as follows:

$$W = \left(\frac{P}{4}\right) * t \quad (1)$$

Where:

$$W \rightarrow Pulse\ prediction\ every\ (t)\ time \quad [bpm]$$
$$P \rightarrow Arterial\ pulses\ captured\ by\ the\ sensor \quad [bpm]$$
$$t \rightarrow Time\ at\ which\ data\ will\ be\ predicted\ [s]$$

Equation 1 is used to calculate blood pressure using radial pulse-taking techniques, whereby, if the pulse during the first 15 seconds is continuous, the value obtained is multiplied by 4, resulting in an accurate prediction of the value that would be obtained if the pulse were taken for a full minute. One of the great advantages of using this method is that physicians can know in advance the blood pressure coming from the individual under study.

2. Method. - For the design of the electrocardiograph, first of all, the placement of the electrodes and the type of data obtained through the AD8232 sensor are identified and coded using Arduino. The information obtained is analyzed locally using the Serial plotter in the Arduino IDE. Then, using LabVIEW, a graphical interface is created to visualize the electrical activity of the heart and make a blood pressure prediction, which is obtained every 15 seconds as opposed to the manual method, which is obtained every minute. Finally, the Arduino cloud is used to open the doors to the world of IoT, it is observed by any device with internet access and as an additional benefit, the report of the data received is downloaded as a text file [25], [26].

The advantage of using the AD8232 sensor is its ease concerning its size, which allows it to make cases, thus facilitating its portability with the patient. This sensor handles 3.3 volts, obtained through the Arduino, which is powered with 5V. This also facilitates the use of portable batteries with which the portability of the prototype is enhanced [27], [28].

It is important to mention the advantage of downloading the information containing the studies performed on each patient in a comma delimited file that can be opened by Excel and obtain the details every second of the reading of the data of the electrical activity of the heart, this information needs to be processed as shown below. With the information already processed, a more in-depth analysis is performed in the cardiovascular area.

Below, in Figure II, a scheme is presented to explain more simply the stages of processing and analysis of the prototype.

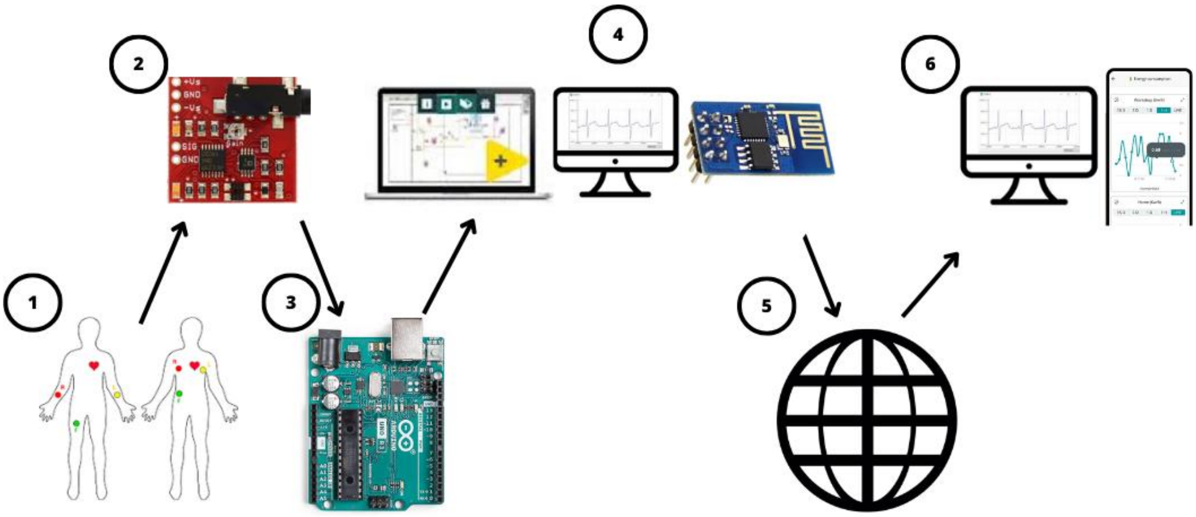

Figure II. Outline of the proposed design.

Where:

1. Placement of the electrodes on the patient.
2. Recording of electrical measurements of the heart using the AD8232 module.
3. Processing of the measurements taken by the Arduino.
4. Visualization of the cardiac activity on the monitor through Arduino and LabVIEW.
5. Sending the data of the measurements to the cloud.
6. Remote viewing of the analysis performed.

The most important materials used in the development of this design are the following:

-Arduino UNO.

-AD8232 sensor.

-ESP32.

-Cables to interconnect the devices with each other.

Figure III shows the physically assembled prototype circuit, which represents the design of a portable electrocardiograph intended to provide medical assistance to the community. The circuit incorporates the use of the AD8232 as the primary sensor for accurate detection of cardiac activity. In addition, it offers three options for displaying the heart rate graph, allowing for versatile monitoring that is adaptable to the user's needs. This innovative design seeks to provide an affordable and effective solution for cardiac monitoring in medical and community settings, thus contributing to improving cardiovascular health and quality of life.

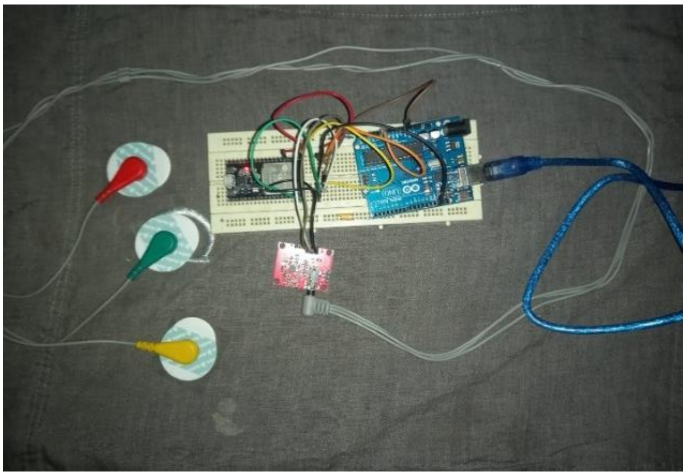

Figure III. Physically assembled circuit.

Figure IV shows the torso of a patient with the electrode arrangement of the prototype circuit of a portable electrocardiograph. These electrodes, essential for accurate detection of the heart rhythm, are strategically placed following standard medical guidelines as follows.

- Red electrode: located on the right side of the right torso on the lateral side (1).
- Yellow electrode: located on the left side of the torso at the level of the heart (2).
- Green electrode (Neutral): located under the last rib on the right side of the torso (3).

This innovative approach to electrocardiograph design reflects a significant advance in medical technologies, as it enables effective, noninvasive cardiac rhythm monitoring in clinical and community settings. The correct arrangement of the electrodes on the patient's torso ensures accurate and reliable measurements, which is critical for informed medical decision-making and cardiovascular health care.

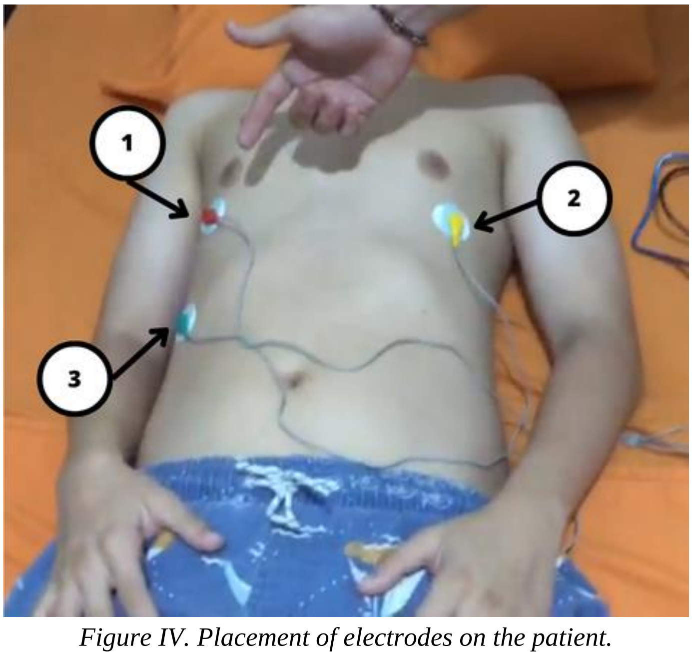

Figure IV. Placement of electrodes on the patient.

2.1 LabVIEW Block Diagram Configuration. - Next, each of the steps related to the configuration of the block diagram used in LabVIEW, as shown in Figure V, are detailed. In this comprehensive analysis, each of the components and connections of the diagram are addressed, explaining their function and their contribution to the overall system operation. In addition, the design decisions made during the creation of the block diagram are described, highlighting their relevance to the success of the project.

This detailed approach provides a thorough understanding of the configuration process in LabVIEW, allowing readers to become familiar with the techniques used and their application in the specific context of the project. This detailed explanation seeks to provide clarity and facilitate replication of the process by other researchers or practitioners interested in using LabVIEW for similar projects.

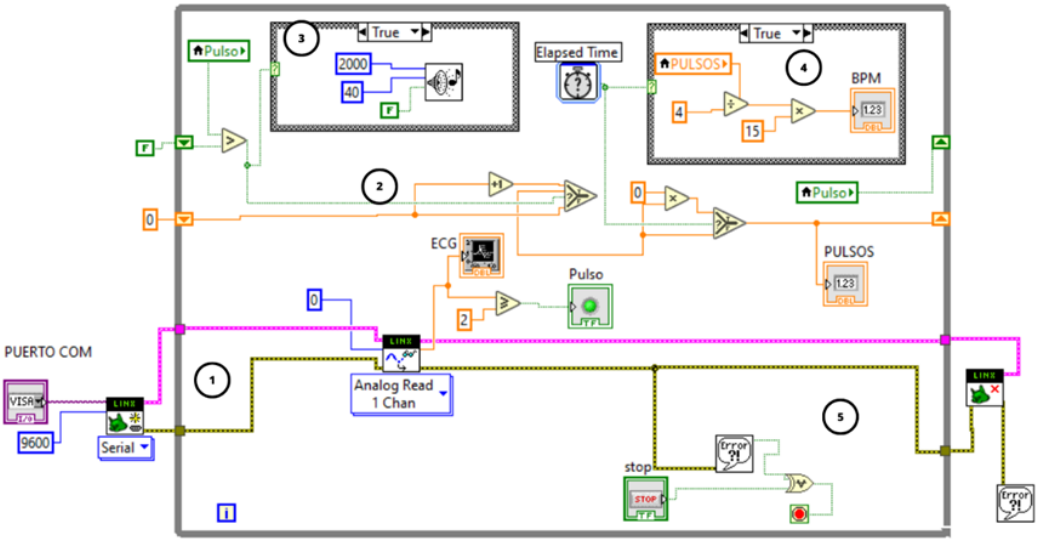

Figure IV. Configure Design in LabVIEW.

2.2 Configuration LabVIEW with Arduino. - In Figure VI, we initially present the COM port block, which is in charge of reading the information through the COM ports of our PC. This information is sent to the Linx Open. vi file, where the baud rate is set to 9600 to ensure optimal data transmission speed to the system.

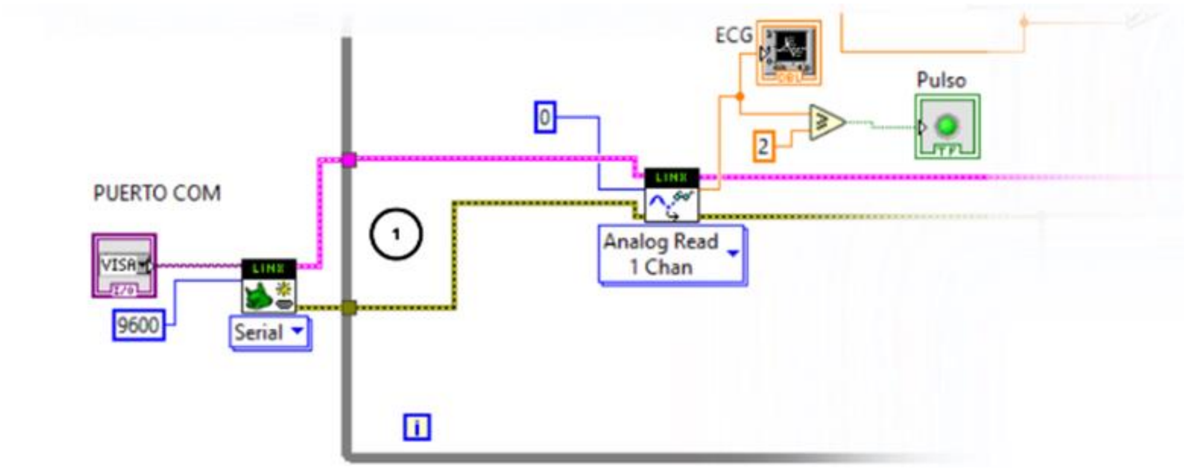

Figure VI. Arduino communication block.

After establishing communication with the Arduino, an analog reading is made, because the information processed by the sensor is of this type. It is established that the pin of the Arduino to which the reading is being made will be the A0, after this process the acquired data is sent to be displayed on a display, which will also trigger an LED that will show the heartbeat obtained.

2.2 Comparator Processing. - Figure VII shows the comparator process, highlighting a gradual increment to reach the set value. Once this requirement is met, a multiplication by zero is performed to reset the counter and return to the initial loop. This cycle continues iteratively to ensure consistent and efficient operation of the system. The visual representation provides a clear understanding of how the comparators are managed in the process, making it easy to optimize and adjust parameters appropriately as needed.

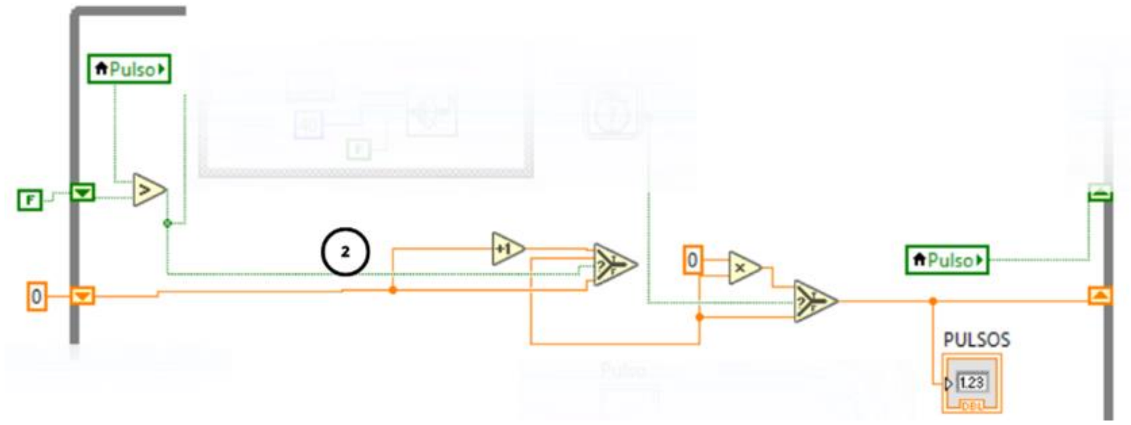

Figure VII. Data Processing Block.

2.3 Audible Heartbeat Indicator. - In this section, the implementation of a horn to notify the detection of a heartbeat by the proposed prototype is incorporated. Figure VIII clearly shows how this component is integrated into the heart rate measurement system. The addition of the horn enables instant audible feedback, which improves usability and user experience during cardiac monitoring. This additional functionality is critical for alerting the user to the detection of a heartbeat and can be useful in a variety of clinical and personal care settings.

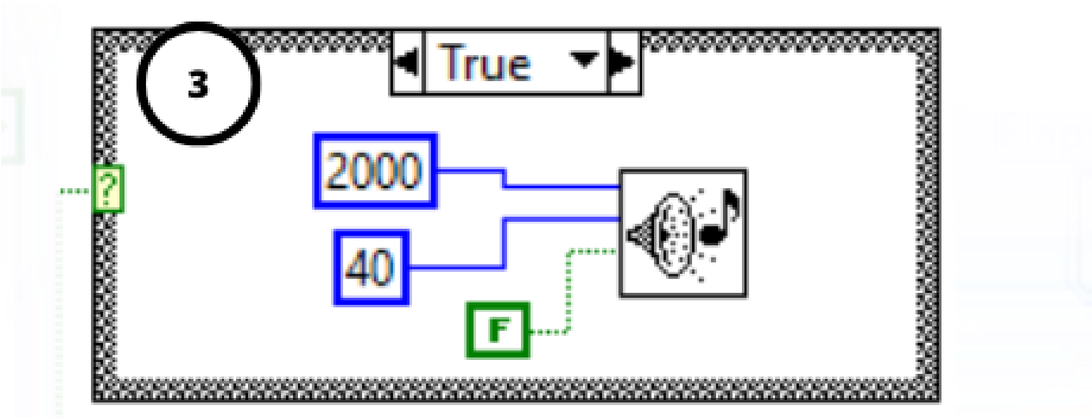

Figure VIII. Beats the sound indicator block.

2.4 Blood Pressure Prediction Programming. - In this section, there is an "Elapsed Time" which will act as the equipment clock and allows to set the time unit in milliseconds. The coding of the pressure prediction system is located inside the loop. The formula for the calculation of the blood pressure prediction is used, to know the cardiac pressure data the pulsations must be taken during one minute, but with this formula, it will be able to make a prediction in only 15 seconds and show it more efficiently as shown in Figure IX.

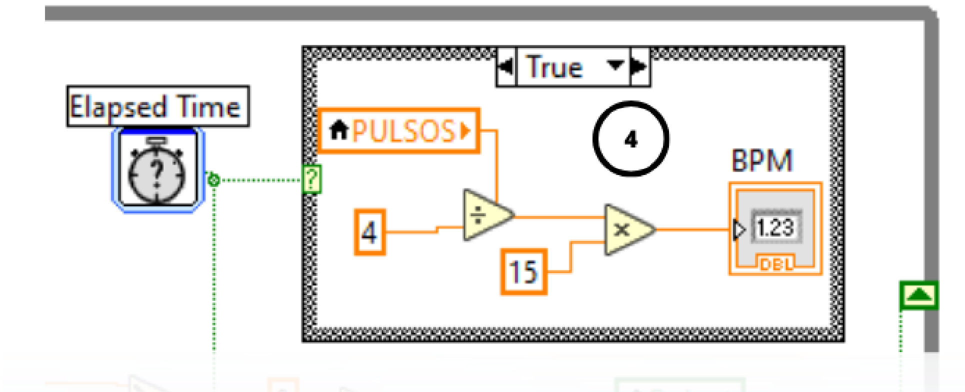

Figure IX. Heartbeat prediction block.

2.5 Stop Configuration. - In Figure X, you can see the section corresponding to the stop button, which is designed to initiate the block that completes the communication between LabVIEW and Arduino. This function is crucial to ensure proper and controlled termination of the data exchange process between the devices. The inclusion of this button provides the user with a convenient means to stop communication quickly and safely when necessary. In addition, its integration into the overall system interface makes it easy to access and use during the operation of the control system.

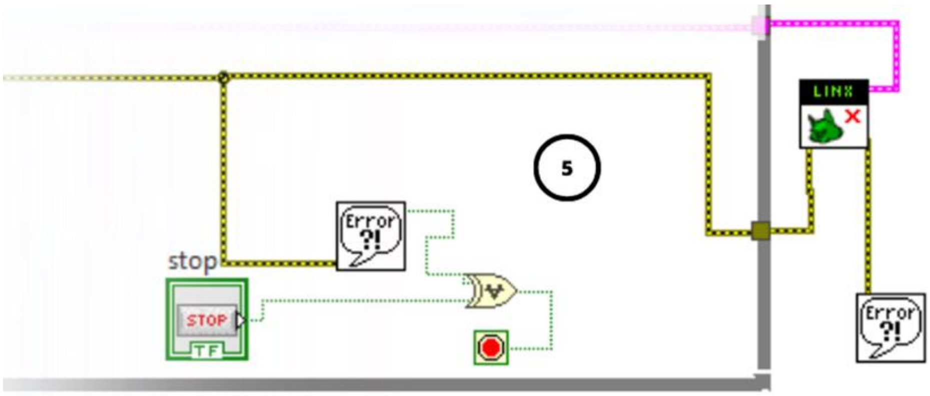

Figure VIII. Stop Configuration Block.

The code used to perform the processing through the ESP32 and its subsequent sending to the Arduino cloud is presented below:

```
#include "thingProperties.h"
void setup() {
  Serial.begin(9600);
  delay(1500);
  initProperties();
  // Connect to Arduino IoT Cloud
  ArduinoCloud.begin(ArduinoIoTPreferredConnection);
  setDebugMessageLevel(2);
  ArduinoCloud.printDebugInfo();
}

void loop() {
  ArduinoCloud.update();
  analogData();
}
void analogData() {
pulso_cardiaco= analogRead(34);
Serial.println(pulso_cardiaco);
delay(200);
}
```

2.6 Cloud Configuration. - Regarding the creation of an Arduino cloud user for real-time monitoring of a portable electrocardiograph system, designed to provide medical assistance to the community, a specific process is followed. This process involves the use of the AD8232 as the main sensor and provides real-time cardiac activity display options. To create a user in the Arduino cloud, the user must provide information such as email, username, and password. This process is shown in detail in Figure XI.

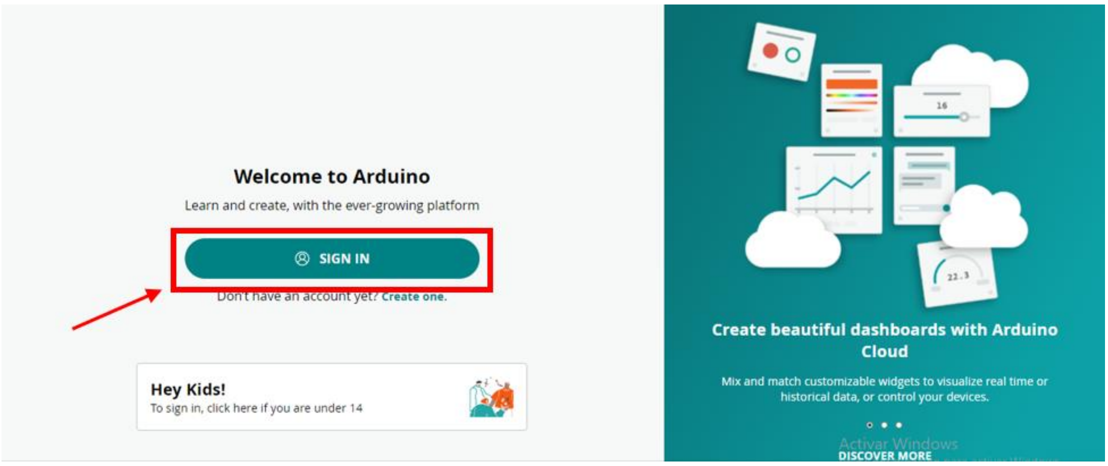

Figure XI. Account Registration on Arduino.

In addition, the appropriate boxes must be checked according to the privacy preferences and acceptance of terms. Once these steps are completed, click "Sign Up" to finalize the Arduino cloud registration. Creating a user in the Arduino cloud allows access to additional functionalities, such as data storage and analysis in the cloud, which facilitates remote monitoring and efficient management of the electrocardiography system.

Once the measurement information from the portable electrocardiograph circuit has been successfully sent, users can access it in real-time from the "Dashboard" section. To do so, they should click on the specific control panel created for this purpose, as shown in detail in Figure XII below.

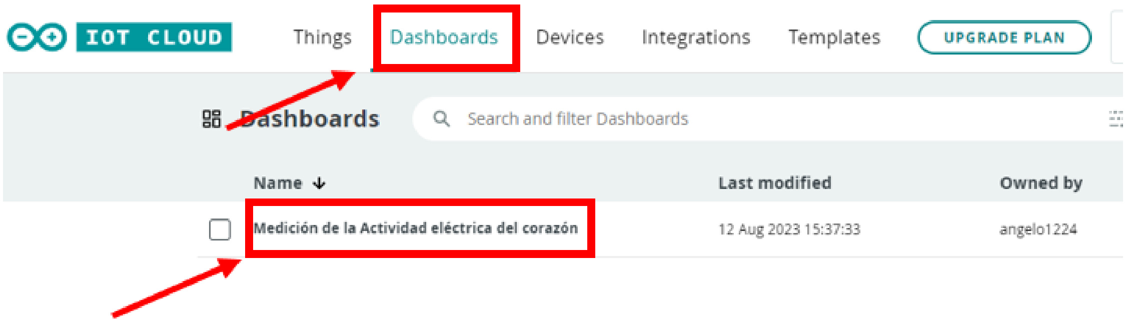

Figure XII. Accessing the Dashboard on Arduino IoT Cloud.

Real-time visualization of the data facilitates the tracking and continuous monitoring of the heart rhythm, which is crucial for the early detection of any irregularity or medical emergency. In addition, access to this real-time information from any location provides greater flexibility and responsiveness for medical professionals and caregivers, enabling them to make informed decisions and provide more timely and effective medical care to patients.

2.7 Equipment Cost. - The estimated cost of the system is $74, broken down as follows: Arduino Uno $20, Arduino AD8283 Module $19, Arduino Wifi Module $15, and other consumables totaling $20.
However, it is important to note that this cost could increase significantly if a desktop computer and the necessary software licenses are not available. The acquisition of these additional items could add approximately $800 to the total cost of the project, resulting in a final value of $874.

Considering the importance of cost minimization as one of the main design parameters, the idea of mass-producing the electrocardiograph is encouraged. This not only benefits educational institutions but also private or public companies looking for cost-effective solutions for cardiac monitoring.

Thanks to this cost-effective approach, our design can successfully compete with other similar products on the market. In addition, by offering an easily accessible portable electrocardiograph at an affordable price, we are contributing to improving the accessibility of medical care and cardiovascular health monitoring for a wide range of users from interested parties.

3. Results. - Table I below compares the data collected from the proposed prototype with the data simulated in the simulator. This analysis provides a comparative contrast between the two data sets, revealing that, on average, there is a margin of error of 5.81%. This level of discrepancy is considered considerably low, indicating a satisfactory correspondence between the data obtained in practice and the simulated data.

This result reinforces the validity and accuracy of the proposed prototype for heart rate measurement. Furthermore, it suggests that the simulation model used is effective in predicting the behavior of the system under real conditions. This finding is encouraging as it demonstrates the reliability of the prototype in practical settings, supporting its potential application in medical and health monitoring applications.

Sensed data (R) mV	Simulated data (S) mV	% error
1210	1180	2,5
1120	1215	7,8
1300	1195	8,8
1120	1205	7,1
1520	1180	11,9
1210	1165	3,9
1180	1195	1,3
1163	1185	1,9
1012	1170	13,5
1201	1190	0,9
1321	1160	13,9
1210	1195	1,3
1150	1175	2,1
1310	1180	11,0
1180	1205	2,1
1050	1195	12,1
1210	1180	2,5
1186	1200	1,2
1283	1215	5,6
1112	1195	6,9
1090	1200	9,2
1123	1175	4,4
1168	1190	1,8
Average error %		5,813

Table I. Sensed data compared with simulation.

As was carried out in the analysis presented in Table I above, a scenario study was performed with 53 additional patients under similar test conditions. The results obtained were averaged and contrasted with the simulated data, thus calculating the error of the proposed prototype.

The purpose of this scenario was to analyze the level of discrepancy present in the measurement of the electrical activity of the heart. Table II, which contains the information collected from these 53 additional patients, is presented below.

Table II shows three columns with information, the first column is the average value of the patient's 2-hour ECG study, and the second column contains the average value of a simulated ECG with the patient's data (age, weight, height, etc.) using Cardiopoint software, and the third column corresponds to the average value of the two columns mentioned above [29], [30].

	ECG (R) mV	ECG (S) mV	% error
Patient 1	1192,56	1188,91	5.81
Patient 2	1245,70	1190,65	8,10
Patient 3	1271,87	1196,87	9,01
Patient 4	1251,30	1191,04	5,63
Patient 5	1248,74	1188,83	5,54
Patient 6	1230,13	1174,57	4,75
Patient 7	1229,13	1174,22	4,70
Patient 8	1224,22	1173,22	4,37
Patient 9	1236,30	1174,35	5,31
Patient 10	1172,43	1190,61	2,36
Patient 11	1172,65	1123,48	5,60
Patient 12	1173,00	1137,43	4,73
Patient 13	1173,83	1115,65	6,44
Patient 14	1168,57	1151,96	8,83
Patient 15	1157,87	1133,91	8,48
Patient 16	1160,74	1127,83	9,46
Patient 17	1142,39	1120,22	8,11
Patient 18	1155,91	1098,91	6,31
Patient 19	1163,48	1128,04	4,70
Patient 20	1151,26	1130,00	4,23
Patient 21	1174,35	1138,04	4,95
Patient 22	1147,57	1133,48	2,70
Patient 23	1166,04	1130,43	4,17
Patient 24	1144,87	1134,78	3,62
Patient 25	1159,00	1132,83	4,43
Patient 26	1130,22	1188,91	4,93
Patient 27	1216,13	1133,70	7,29
Patient 28	1134,26	1175,87	4,02
Patient 29	1306,52	1244,13	5,07
Patient 30	1098,30	1112,17	3,81
Patient 31	1230,43	1265,00	3,50
Patient 32	1344,39	1410,43	4,83
Patient 33	1353,91	1370,87	2,77
Patient 34	1113,04	1102,83	1,97

Patient 35	1410,43	1370,87	3,00
Patient 36	1095,17	1116,96	1,97
Patient 37	1261,13	1278,87	1,97
Patient 38	1095,48	1114,96	1,91
Patient 39	1111,39	1127,83	1,65
Patient 40	1259,52	1266,00	1,67
Patient 41	1183,52	1214,17	2,87
Patient 42	1235,17	1253,57	1,75
Patient 43	1207,87	1201,35	1,77
Patient 44	1214,87	1231,26	1,91
Patient 45	1171,48	1191,39	2,05
Patient 46	1192,09	1225,74	2,81
Patient 47	1159,65	1179,17	2,21
Patient 48	1227,48	1237,83	1,45
Patient 49	1309,22	1320,17	1,04
Patient 50	1124,35	1135,48	1,44
Patient 51	1196,48	1215,57	1,60
Patient 52	1311,91	1269,30	3,37
Patient 53	1341,43	1373,04	2,57
Average	1202,83	1190,71	4,11

Table II. Table of results from conducted studies.

This extended analysis provides a more comprehensive evaluation of the prototype's accuracy and reliability in a variety of clinical scenarios. The results obtained will help to further validate the clinical utility of the proposed device and provide valuable information for future improvements and refinements of the system.

Table III presents the average value obtained from each of the studies performed. These data were collected over 2 hours using the proposed prototype for cardiac measurement of the Patients in the test scenarios. Subsequently, this set of values is downloaded from the cloud in .csv format for further processing.

	ECG (R) mV
Patient 1	1192,56
Patient 2	1245,70
Patient 3	1271,87
Patient 4	1251,30
Patient 5	1248,74
Patient 6	1230,13
Patient 7	1229,13
Patient 8	1224,22
Patient 9	1236,30
Patient 10	1172,43

Patient 11	1172,65
Patient 12	1173,00
Patient 13	1173,83
Patient 14	1168,57
Patient 15	1157,87
Patient 16	1160,74
Patient 17	1142,39
Patient 18	1155,91
Patient 19	1163,48
Patient 20	1151,26
Patient 21	1174,35
Patient 22	1147,57
Patient 23	1166,04
Patient 24	1144,87
Patient 25	1159,00
Patient 26	1130,22
Patient 27	1216,13
Patient 28	1134,26
Patient 29	1306,52
Patient 30	1098,30
Patient 31	1230,43
Patient 32	1344,39
Patient 33	1353,91
Patient 34	1113,04
Patient 35	1410,43
Patient 36	1095,17
Patient 37	1261,13
Patient 38	1095,48
Patient 39	1111,39
Patient 40	1259,52
Patient 41	1183,52
Patient 42	1235,17
Patient 43	1207,87
Patient 44	1214,87
Patient 45	1171,48
Patient 46	1192,09
Patient 47	1159,65
Patient 48	1227,48

Patient 49	1309,22
Patient 50	1124,35
Patient 51	1196,48
Patient 52	1311,91
Patient 53	1341,43
Averages	1202,83

Table III. Summary of simulations.

The collected data are subjected to a conversion process using the table hosted in Table IV. This table is used to subtract 1800 from the value extracted from the .csv file, followed by a multiplication by 1.8 conversion necessary to express it in millivolts.

This method allows us to obtain a standard measure of cardiac activity, thus providing a clearer picture of the reliability of the proposed design. The calculation of the average of these samples is essential to assess the consistency of the data obtained and to ensure the accuracy of the device as a whole.

In addition, the presentation of these effectively processed data facilitates communication with the professionals responsible for the diagnosis and analysis of the cardiac studies performed.

Conversion factors		
Obtained data	Data – 1800	x1.8 (mV)
2500	700	1260
2400	600	1080
2450	650	1170
2491	691	1243,8
2501	701	1261,8
2486	686	1234,8
2512	712	1281,6
2502	702	1263,6
2415	615	1107

Table IV. Conversion table.

The integration of the Arduino cloud with the help of the ESP32 allows the establishment of an IoT connection that makes it possible to view the data collected by the heart rate monitoring prototype from any location. This solution offers the advantage of accessing the information received at predefined time intervals, such as hourly, daily, weekly, and fortnightly.

Additionally, the facility is provided to download this data into a comma-delimited Excel (.csv) file, as shown in Figure XIII. This ability to remotely view and download data in Excel format offers additional flexibility in the analysis and management of the information obtained from cardiac monitoring, which is especially useful for medical professionals and research teams.

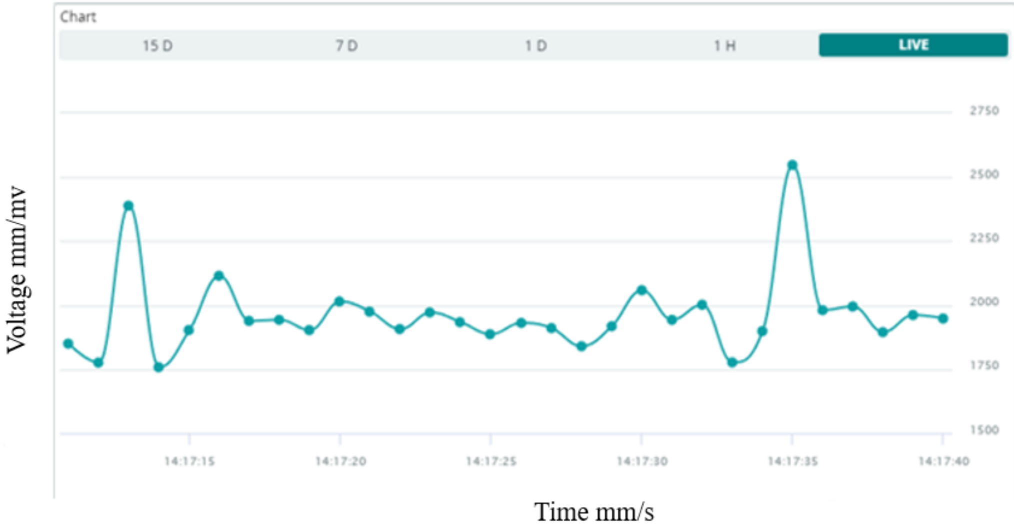

Figure IXIII. Real-time visualization of collected data.

The graphs generated locally using the Arduino serial plotter are presented below. These plots visually display the data collected by the heart rate monitoring prototype and are detailed in Figure XIV. The graphical representation of this data provides a clear and detailed visualization of the heart rate over time, making it easy to identify patterns and anomalies in the Patient's cardiac activity. These graphs provide an invaluable tool for the analysis and interpretation of the results obtained, both for healthcare professionals and researchers in the field of cardiology.

Figure XIV. Graphs were obtained using the Arduino Serial Plotter.

Figure XV shows the measurements collected over one hour in the system, obtained from the data recorded by the heart rate monitoring prototype and linked to the IoT platform. This visual representation provides a detailed snapshot of the heart rate over a specific period, allowing an accurate assessment of the Patient's cardiac activity over that interval.

These measurements provide valuable information about heart rate variability and can help identify potential irregularities or patterns of interest for clinical analysis. Analysis of these measurements can provide meaningful insights for the assessment of the Patient's cardiovascular health and contribute to informed medical decision-making.

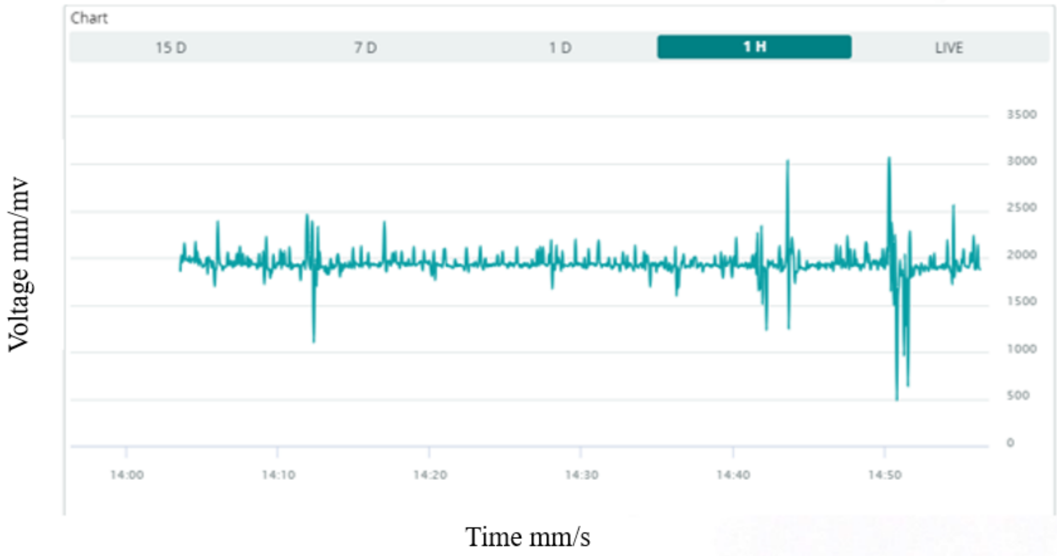

Figure XIV. Displaying measurements in real time over a 1-hour period.

4. Discussion. - The authors of the article [16], made a design of a remote monitoring of heartbeat and ECG signal using the SP32 with which they obtained graphs using the Arduino serial plotter.
The results obtained for comparison are determined by analyzing the graphs obtained, it is considered that the metric used in that design is performed every 60 seconds (1 minute), unlike our design in which every 15 seconds a prediction is made which allows obtaining a much faster and reliable measurement.

The authors performed an electrocardiogram that hosts the information in the cloud through MySQL which allows it to manage display screens much more friendly to the end user, thus allowing the characteristic ease and accessibility, in that aspect presents an improvement with the design presented in this article, a clear particularity that can be polished and added in subsequent works to enhance the present design.
Something notorious in the article is the lack of a margin of error study of the values obtained by the AD8232, which is necessary to evaluate the reliability of the data presented [3].

In [5] made a similar design to the one presented in this thesis, although they use the same sensors, they do not contemplate obtaining the blood pressure, they only focus on obtaining the ECG graphs, they use the Ubidots cloud to visualize the information sent by the ESP32. In addition, they make a comparison between the different forms of connection either by Bluetooth, wifi, or ZigBee but do not present a comparison of the quality of the transmitted data, which marks a notable difference compared to the present article.

The development of this design provides a very accurate analysis of the electrical activity of the heart, facilitating the study and analysis of cardiovascular patterns in patients. A great advantage compared to the design of the researchers in the article [16] is the improvement and implementation of the predictive analysis of blood pressure no longer every 60 seconds but every 15 seconds, providing an advantage for the prediction of possible tachycardias or bradycardias, which can be correctly detected by health professionals, providing a very valuable tool for those who use this design.

The following Table V compares the related works, showing the strengths of each one of them, and showing which one's present improvements compared to others. It is concluded that the proposed design, despite the 4.11% error rate, offers a wider range of characteristics compared to other designs, reducing the error rate may be the objective to be achieved in future research from already established bases.

	ECG	Cloud	ABPM	Census info	% Error
Proposed	✓	✓	✓	✓	4.11
Art. [16]	✓	✓	✓	✓	X
Art. [5]	✓	✓	X	✓	X
Art. [3]	✓	✓	X	X	X

Art. [22]	✓	✓	✓	X	0.41
Art. [1]	✓	X	X	X	X

Table V. Comparison table of related items

The design of the portable electrocardiograph system outlined in this paper presents several notable advantages. Firstly, the system offers detailed blood pressure information, enhancing the comprehensive assessment of a patient's cardiovascular health. Additionally, it features a visual indicator that records each detected heartbeat, facilitating precise monitoring of cardiac activity.

A standout feature of the system is its capability to transmit collected information to the cloud. This functionality allows users to access data from any internet-connected device, providing increased flexibility and accessibility in monitoring heart health. Furthermore, the system offers the option to download information as an XML file, streamlining further processing for analysis and storage purposes.

Measured values, such as an Average ECG (R) of 1202.83 mV and simulated Average ECG (S) values of 1190.71 mV, reveal a margin of error of 4.11%. Despite this small margin, the prototype demonstrates acceptable reliability in measuring cardiac activity. These results underscore the effectiveness and practicality of the developed portable electrocardiograph system, underscoring its potential for integration into clinical and community settings.

5. Conclusions. - After a thorough evaluation of the performance of the portable electrocardiograph designed to provide community healthcare, 1-3 hour study scenarios were conducted to verify the reliability of the information captured and transmitted through our cloud platform. During this process, a margin of error of 4.11% was observed.

However, the presence of a certain level of noise was detected in the measurements shared with the Arduino cloud, suggesting that this interference could explain part of the error and the slight distortion in the received signal. These findings highlight areas of improvement for future research, where techniques could be implemented to mitigate the noise and thereby improve the quality of the transmitted signal.

The design of the portable electrocardiograph system makes a valuable contribution to community medical knowledge, opening the door for further exploration in this field through additional research. This design lays the foundation for the future development of devices aimed at improving the quality of life of both students and society in general, representing a significant advance for human welfare. In this sense, the ability to provide quality medical care at the community level is strengthened with the implementation of this innovative technology.

Furthermore, it is important to highlight that the successful implementation of this portable electrocardiograph in community settings could have a significant impact on the early detection of cardiac problems and the prevention of serious complications. By facilitating more accessible and continuous monitoring of patients' cardiac health, it could improve preventive medical care and reduce the burden on healthcare systems, especially in remote or underserved areas. This would not only benefit individuals at risk for heart disease but would also contribute to health promotion and overall community well-being. Ultimately, the portable electrocardiograph represents not only a technological advance in the medical field, but also a vital tool for improving quality of life and public health at the community level.

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References

[1] L. Dioren Rumpa, S. Suluh, I. Hendrika Ramopoly, and W. Jefriyanto, “Development of ECG sensor using Arduino uno and e-health sensor platform: Mood detection from heartbeat,” in Journal of Physics: Conference Series, Institute of Physics Publishing, Jun. 2020. https://doi.org/10.1088/1742-6596/1528/1/012043

[2] M. Bansal and B. Gandhi, “IoT Big Data in Smart Healthcare (ECG Monitoring),” in Proceedings of the International Conference on Machine Learning, Big Data, Cloud and Parallel Computing: Trends, Perspectives and Prospects, COMITCon 2019, 2019. https://doi.org/10.1109/COMITCon.2019.8862197

[3] A. Qtaish and A. Al-Shrouf, “A Portable IoT-cloud ECG Monitoring System for Healthcare,” IJCSNS International Journal of Computer Science and Network Security, vol. 22, no. 1, 2022

[4] P. Kamble and A. Birajdar, “IoT Based Portable ECG Monitoring Device for Smart Healthcare,” in 5th International Conference on Science Technology Engineering and Mathematics, ICONSTEM 2019, 2019. https://doi.org/10.1109/ICONSTEM.2019.8918776

[5] P. Singh and A. Jasuja, "IoT-based low-cost distant patient ECG monitoring system" 2017 International Conference on Computing, Communication and Automation (ICCCA), Greater Noida, India, 2017, pp. 1330-1334, https://doi.org/10.1109/CCAA.2017.8230003

[6] E. Kim, J. Kim, J. Park, H. Ko, and Y. Kyung, “TinyML-Based Classification in an ECG Monitoring Embedded System,” Computers, Materials and Continua, vol. 75, no. 1, 2023, https://doi.org/10.32604/cmc.2023.031663

[7] N. Misran, M. S. Islam, G. K. Beng, N. Amin, and M. T. Islam, “IoT Based Health Monitoring System with LoRa Communication Technology,” in Proceedings of the International Conference on Electrical Engineering and Informatics, 2019. https://doi.org/10.1109/ICEEI47359.2019.8988869

[8] A. D. Acharya and S. N. Patil, “IoT based Health Care Monitoring Kit,” in Proceedings of the 4th International Conference on Computing Methodologies and Communication, ICCMC 2020, 2020 https://doi.org/10.1109/ICCMC48092.2020.ICCMC-00068

[9] H. Santillán, M. Suárez, and D. Cárdenas, “Desarrollo de una herramienta IoT para optimizar el control de la humedad en el cultivo de cacao,” Memoria Investigaciones en Ingeniería, vol. 25, Dec. 2023, https://doi.org/10.36561/ING.25.14

[10] H. Santillán Carranza, J. O. Enríquez Sandoval, y J. F. Bonilla Castro, «Development of a Raspberry Pi-Based Wireless Educational Tool», INGENIO, vol. 7, n.º 1, pp. 13–22, feb. 2024. https://doi.org/10.29166/ingenio.v7i1.5630

[11] Y. He, B. Fu, J. Yu, R. Li, and R. Jiang, “Efficient learning of healthcare data from IoT devices by edge convolution neural networks,” Applied Sciences (Switzerland), vol. 10, no. 24, 2020, https://doi.org/10.3390/app10248934

[12] E. G. Bertogna, F. M. Machado, and M. A. Sovierzoski, “An optimized ECG android system using data compression scheme for cloud storage,” Health Technol (Berl), vol. 10, no. 5, 2020, https://doi.org/10.1007/s12553-020-00464-z

[13] Md. O. F. et al. Altaf C., “Low Power IoT based Implementation ECG & Health Monitoring System.,” Proceeding International Conference on Science and Engineering, vol. 11, no. 1, 2023, https://doi.org/10.52783/cienceng.v11i1.319

[14] Q. N. and A. F., “Design Health care system using Raspberry Pi and ESP32,” Int J Comput Appl, vol. 177, no. 36, 2020, https://doi.org/10.5120/ijca2020919863

[15] J. Lakshmi Prasanna, S. V. Aswin Kumer, M. Ravi Kumar, M. Sangeetha Lakshmi, P. Srilaxmi, and C. Santhosh, “Low-cost ECG and Heart Monitoring System Using Ubidot Platform,” in Lecture Notes in Networks and Systems, 2022. https://doi.org/10.1007/978-981-19-0976-4_19

[16] M. A. Rahman, Y. Li, T. Nabeed, and M. T. Rahman, “Remote monitoring of heart rate and ECG signal using ESP32,” in Proceedings - 2021 4th International Conference on Advanced Electronic Materials, Computers and

Software Engineering, AEMCSE 2021, 2021. https://doi.org/10.1109/AEMCSE51986.2021.00127

[17] B. Sugandi, M. H. Satria, H. Arif, N. Nelmiawati, and I. H. Mulyadi, "LOW COST WIRELESS ECG PATCH USING ESP32," JURNAL INTEGRASI, vol. 12, no. 1, 2020, https://doi.org/10.30871/ji.v12i1.1764

[18] V. K. Patil, V. R. Pawar, S. P. Kulkarni, T. A. Mehta, and N. R. Kharea, "Real Time Emotion Recognition with AD8232 ECG Sensor for Classwise Performance Evaluation of Machine Learning Methods," International Journal of Engineering, Transactions B: Applications, vol. 36, no. 6, 2023, https://doi.org/10.5829/ije.2023.36.06c.02

[19] A. Bushnag, "A Wireless ECG Monitoring and Analysis System Using the IoT Cloud," Intelligent Automation and Soft Computing, vol. 33, no. 1, 2022, https://doi.org/10.32604/iasc.2022.024005

[20] K. J. P. Ortiz, J. P. O. Davalos, E. S. Eusebio, and D. M. Tucay, "IoT: Electrocardiogram (ECG) monitoring system," Indonesian Journal of Electrical Engineering and Computer Science, vol. 10, no. 2, 2018, https://doi.org/10.11591/ijeecs.v10.i2.pp480-489

[21] L. R. Yeh et al., "Integrating ECG monitoring and classification via iot and deep neural networks," Biosensors (Basel), vol. 11, no. 6, 2021, https://doi.org/10.3390/bios11060188

[22] M. O. Rahman et al., "Internet of Things (IoT) based ECG System for Rural Health Care," International Journal of Advanced Computer Science and Applications, vol. 12, no. 6, 2021, https://doi.org/10.14569/IJACSA.2021.0120653

[23] G. Xu, "IoT-Assisted ECG Monitoring Framework with Secure Data Transmission for Health Care Applications," IEEE Access, vol. 8, 2020, https://doi.org/10.1109/ACCESS.2020.2988059

[24] P. W. Rusimamto, Endryansyah, L. Anifah, R. Harimurti, and Y. Anistyasari, "Implementation of arduino pro mini and ESP32 cam for temperature monitoring on automatic thermogun IoT-based," Indonesian Journal of Electrical Engineering and Computer Science, vol. 23, no. 3, 2021, https://doi.org/10.11591/ijeecs.v23.i3.pp1366-1375

[25] Y. Liu, "Artificial intelligence-based neural network for the diagnosis of diabetes: Model development," JMIR Med Inform, vol. 8, no. 5, 2020, https://doi.org/10.2196/18682

[26] H. Hamil et al., "Design of a secured telehealth system based on multiple biosignals diagnosis and classification for IoT application," Expert Syst, vol. 39, no. 4, 2022, https://doi.org/10.1111/exsy.12765

[27] A. Mishra, B. Chakraborty, D. Das, and P. Bose, "AD8232 based Smart Healthcare System using Internet of Things (IoT)," International Journal of Engineering Research & Technology (IJERT), vol. 7, no. April, 2018.

[28] Z. Annisa, P. C. Nugraha, and M. R. Makruf, "An Advanced Holter Monitor Using AD8232 and MEGA 2560," Jurnal Teknokes, vol. 14, no. 2, 2021, https://doi.org/10.35882/teknokes.v14i2.6

[29] L. I. Skora, J. J. A. Livermore, and K. Roelofs, "The functional role of cardiac activity in perception and action," Neuroscience and Biobehavioral Reviews, vol. 137. 2022. https://doi.org/10.1016/j.neubiorev.2022.104655

[30] S. Villamil, C. Hernández, and G. Tarazona, "An overview of internet of things," Telkomnika (Telecommunication Computing Electronics and Control), vol. 18, no. 5, pp. 2320–2327, Oct. 2020, https://doi.org/10.12928/TELKOMNIKA.v18i5.15911

Nota contribución de los autores:

1. Concepción y diseño del estudio
2. Adquisición de datos
3. Análisis de datos
4. Discusión de los resultados
5. Redacción del manuscrito
6. Aprobación de la versión final del manuscrito

HS ha contribuido en: 1, 2, 3, 4, 5 y 6.
AM ha contribuido en: 1, 2, 3, 4, 5 y 6.
DC ha contribuido en: 1, 2, 3, 4, 5 y 6.
PW ha contribuido en: 1, 2, 3, 4, 5 y 6.

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