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Theme:

Embedded system for chronic disease patient monitoring using IoT

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- *To all our teachers.*
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- *To all those who have helped us directly or indirectly in shaping this work.*

DEDICATION

We dedicate this work to:

- *Our grand parents*
- *Our families*
- *Our friends*

Abstract

This project aims to develop an embedded system that monitors chronic disease patients who need frequent medical check-ups.

This embedded system uses a Raspberry Pi 4b to gather data from several sensors installed in patients' bodies, and their data is constantly saved, analyzed and processed to extract vital details about their health and transfer it safely with the help of security encryption to the IoT cloud where it is organized into an interface making it easier to use and understand, which allows users like doctors to easily access patients’ data and observing their health state from any place in the world.

To enhance the functionality of the system, a warning system has been integrated into the IoT platform, which warns the doctor when the patient enters an abnormal state.

Key words: Embedded system, Chronic Disease, Health, patients, Security Encryption, IoT Platform, Sensors.

ملخص

يهدف هذا المشروع إلى تطوير نظام مدمج يراقب المرضى المصابين بالأمراض المزمنة الذين يحتاجون إلى فحوصات طبية متكررة.

يستخدم هذا النظام المضمن Raspberry Pi 4b لجمع البيانات من عدة أجهزة استشعار مثبتة في أجسام المرضى، ويتم حفظ بياناتهم وتحليلها ومعالجتها باستمرار لاستخراج التفاصيل الحيوية حول صحتهم ونقلها بأمان بمساعدة التشفير الأمني إلى منصة إنترنت الأشياء السحابية حيث يتم تنظيمها في واجهة تسهل استخدامها وفهمها، مما يسمح للمستخدمين مثل الأطباء بالوصول بسهولة إلى بيانات المرضى ومراقبة حالتهم الصحية من أي مكان في العالم.

لتعزيز وظائف النظام، تم دمج نظام تحذيري في منصة إنترنت الأشياء، والذي يحذر الطبيب عند دخول المريض في حالة خطيرة أو غير طبيعية.

الكلمات المفتاحية: نظام مضمن، الأمراض المزمنة، صحة، مرضى، التشفير أمني، منصة إنترنت الأشياء، أجهزة استشعار.

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List of Abbreviations:

BPM	Beats per minute
IBI	Interval Beat Interval
RMSSD	Root Mean Square of Successive Differences
CBT	Core body temperature
ECG	Electrocardiograph
PPG	Photoplethysmography
GPIO	General Purpose Input/output
HR	Heart Rate
HM	Health Monitoring
RPI	Raspberry Pi
PR	Pulse Rate
BP	Blood Pressure
IoT	Internet of Things
USB	Universal Serial Bus
ADC	Analog to Digital Converter
LPDDR	Low-Power Double Data Rate
SDRAM	Synchronous dynamic random-access memory
SPI	Serial Peripheral Interface
VDD	Voltage Drain Drain
GND	Ground
OS	Operating System
API	Application Programming Interface

General Introduction:

In this modern time, a concept known as Patient monitoring was widely spread, which is the Continuous measurement of patient parameters such as heart rate and rhythm, respiratory rate, blood pressure, blood oxygen saturation, and many other parameters , But today, it is difficult for patients to go to hospitals, either because of their old age and deteriorating health, or the inability to approach patients to avoid infection, as is currently happening with the Coronavirus, which necessitated the creation of systems for remote patient care.

The big question is Can we monitor patients remotely? If we take the healthcare systems technology of the last decade as a basis, it will not be completely impossible, but will be somewhat crude, but what about now?

These days, the healthcare and technology industries have been highly interlinked for a long time. However, the intelligent Internet of Things (IoT) tsunami is taking increasingly a giant leap in almost all healthcare processes [1], and with the help of information and communication technologies in the healthcare domain (i.e., eHealth), a variety of monitoring applications can be realized using real-time data such as accelerometer and biomedical signals like an electrocardiogram (ECG), electroencephalogram (EEG) and blood pressure to help with diagnoses and decision-making [2]. Because monitoring tasks must be conducted on-site, eHealth devices are battery-powered embedded systems. From a technical perspective, applications must be processed in real-time (i.e., before the deadline specified by an individual application) on small and low-power IoT devices.

In this research, we created a remote care system based on Internet of Things technology and assigned it to a specific category of patients with chronic diseases. This system took data from certain sensors, processed it, and saved it in a cloud server where doctors can access it via a website, and it issue a warning if an abnormal situation occurs.

After this general introduction, our master thesis will be organized into 4 chapters:

In the first chapter, we introduced some work related to our subject and gave some details on chronic diseases in Algeria.

In chapter 2, we gave details on the Software and hardware components used and we presented a synoptic of the overall system.

In chapter 3, we implemented our experimentations tests on the designed embedded system which were performed and discussed.

Finally, in chapter 4, we conducted a study on the main IoT platform which was done to select the best for our application, then the development of the IoT interface was done and experimental tests were performed on the ThingsBoard IoT platform. In the end, a conclusion for the master thesis is presented with perspectives.

Chapter 1 : Generalities

1.1. State of the Art (SOTA):

Remote Patient Monitoring systems are designed to collect data from patients and monitor their physiological status without needing them to have direct contact with doctors or anybody else associated with them and made it accessible by internet. What we did was gather prior projects analyze, describe and compare them to get a clear picture of what we needed to include in our project.

1.1.1. IoT Based Health Monitoring System using Raspberry Pi:

This system aims to use IoT devices to monitor the health of elderly people and store the acquired data on an IoT server using the RPi. the system starts by collecting data from patients through low power sensors periodically, this data will be processed and then forwarded to the IoT server for storage from where it is accessible to desired clients in the system, which gives the ability to observe the patient's condition and recommend the required prescriptions. In the healthcare area, these functions can be used to gather patient data on the local system as well as dispatch it to remote machines.

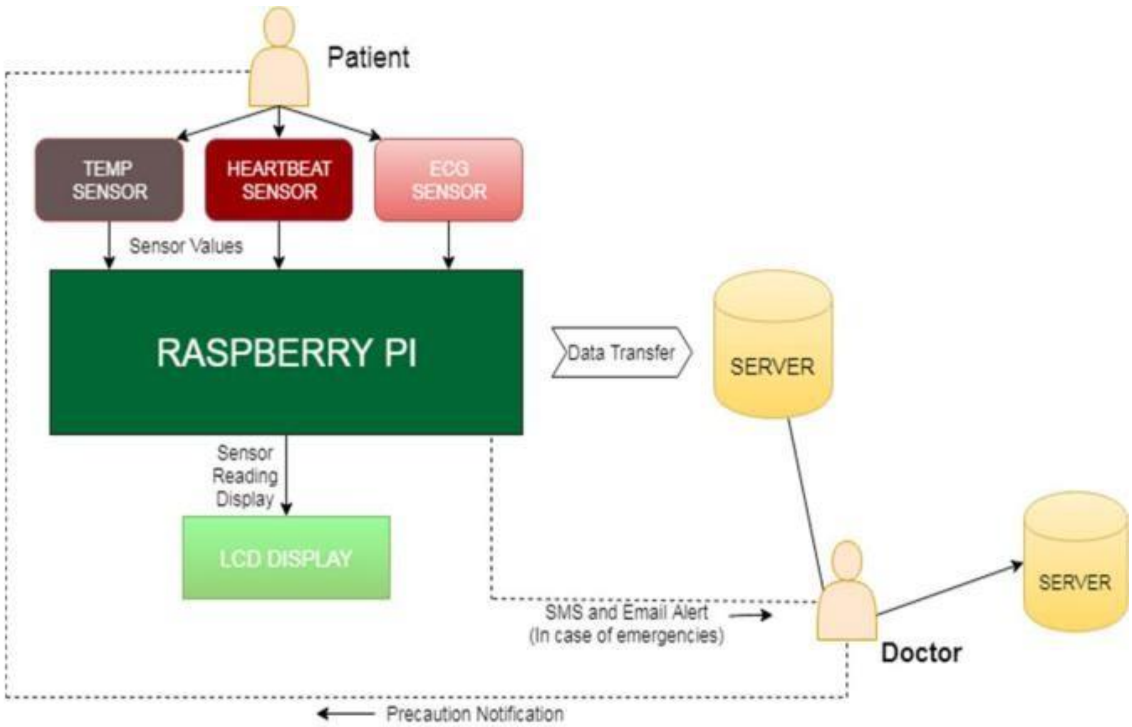

Figure 1.1: Proposed System architecture of an IOT based HM system

1.1.2. Remote Cardiovascular Health Monitoring System with Auto-diagnosis:

This project can be used as a significant tool for doctors and healthcare organizations in predicting certain critical cases in the practice and advising patients accordingly. The system contains various health sensors for detecting heart rate, blood pressure (BP), electrocardiogram (ECG), body mass index (BMI), body temperature, and basic medical interviews performed by a chatbot. The classification model will be able to answer more complex inquiries in the prediction of heart attack disorders.

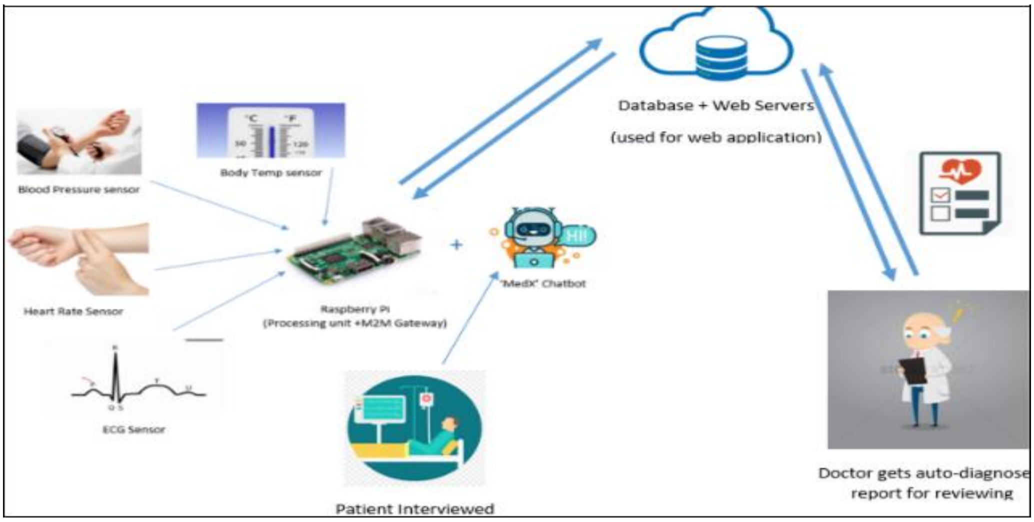

Figure 1.2: The overall architecture of a Remote cardiovascular health monitoring system

1.1.3. Health Monitoring System:

The system will take physical parameters using different on-body sensors which are blood pressure, spo2, adxl345 MEMS, by using these biosensors including the GPS & GSM module we can detect high/low Blood pressure, anemia and the position of the person. When the abnormality of a person’s condition is detected, a message will be sent to the hospital, emergency staff, or caretaker, simultaneously with the diagnosis by displaying the medicine names.

1.1.4. IOT Monitoring System for Patients with Cardiac Disease:

This system receives data from the host, such as temperature, heartbeat, and ECG data, and then organizes, displays, and makes decisions based on that data to perform the appropriate measures and first aid for the patient if needed. The information is then uploaded to the cloud.

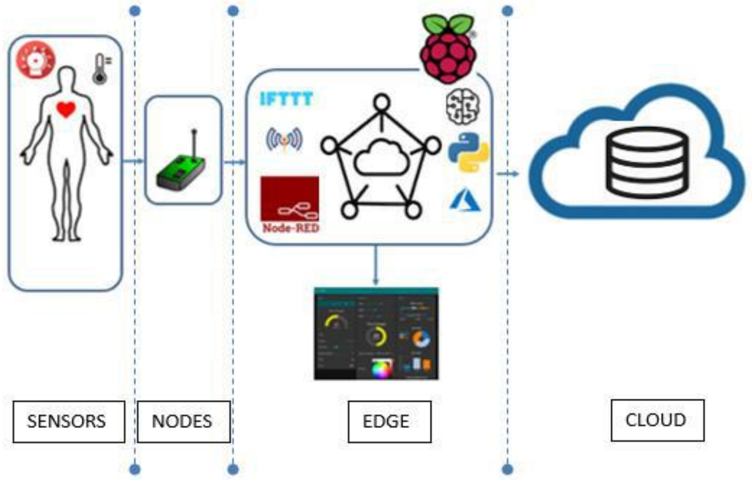

Figure 1.3: System architecture of an IOT Monitoring System for Cardiac Patients

1.1.5. IoT Based Health Monitoring System for Elderly People:

Is a system that uses several sensors to observe the daily basic activities of elderly people, and the system decides how serious the situation is, based on the data saved from the sensors. If it is indeed that critical, a message will be sent to the patient's concerned relatives informing them of the patient's current state.

1.1.6. IoT Blood Pressure Monitoring System:

The Raspberry Pi is in charge of this system, which detects data from the blood pressure sensor and delivers it over the internet for users to observe through Telegram and email. This platform can also be viewed by anybody with permission to access the server’s data and information.

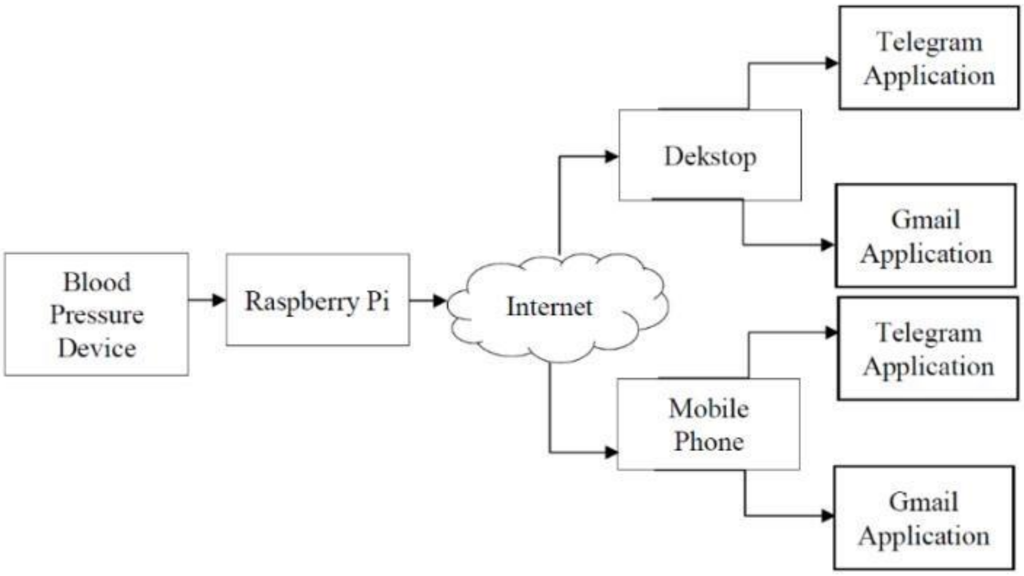

Figure 1.4: System block diagram of an IoT BP monitoring system

Project	MC	Sensors	Software	Result	Date
[3] IoT Based Health Monitoring System using Raspberry Pi	Raspberry pi 3 model B	– LM35 Temperature sensor – Pulse-Rate Sensor – ECG Sensor	– MQTT, HTTP or CoAP protocol – IoT server	- Provide a reliable Remote patient monitoring system for various parameters: Temperature, ECG, heartbeat.	2018
[4] Remote cardiovascular health monitoring system with auto-diagnosis	Raspberry Pi	– DS18B20 Temperature sensor – AD8232 ECG sensor – Blood Pressure Sensor – Heart Rate sensor	– MedX' Chatbot – Neural Networks (NN) and FuzzyKNN – Python 3 – Data base & Web Servers	- A system which provides the ability to remotely monitor the health of CVD patients using machine-to-machine (M2M) technology.	2019
[5] Health Monitoring System	Raspberry Pi	– ADXL345 MEMS (Accelerometer) – SPO2 SENSOR – PRESSURE SENSOR – GPS Module – GSM Module – SPEAKER	– Python3 – Raspbian OS	- Provide a quick rescue procedure by using specialized sensings elements to observe the patient's health rate.	2019
[6] IoT based Health Monitoring System for Elderly People	Arduino Uno	– Temperature Sensor – Pulse Sensor – Ultra-Sonic Sonar Sensor – Pressure Pad – Wi-Fi Module	– Arduino IDE – Thingspeak	- Monitor host remotely - Alarm system can send messages. - Remote monitor the temperature, pulse, and counting bowel discharge. - Analyzing the collected data.	2019
[7] IoT blood pressure monitoring system	Raspberry Pi	– Blood pressure Device mode CK101 – Universal Serial Cable (USB)	– H-term software – Putty software – Raspbian OS	- Detect 3 stats of blood pressure (systolic, diastolic, pulse). - Send the result via Gmail and telegram. - Shows Accuracy of blood pressure based on user's position.	2020
[8] IOT MONITORING SYSTEM FOR PATIENTS WITH CARDIAC DISEASE	Raspberry Pi model 3B+	– The temperature sensor – Electrocardiogra m (ECG) – Heart parameters sensors	– Mosquitto broker – Bash commands – Azure Cloud IOT	- Collect the data from the host. - Analyze the data and decide if is the stats of the host are abnormal. - Shows the data on the web platform.	2019

Table 1.1: Different IoT systems

1.2. Problematic:

The remote monitoring system was designed to assist specific groups in our community who require it the most. In our project, we chose patients with chronic diseases because chronic diseases are the cause of nearly 57 percent of deaths in Algeria, 66 percent of them are aged 30 to 69 (as revealed by the National Institute of Public Health (INSP) in 2021 [9]), which puts them the most at risk. What complicates the decision is that patients with chronic diseases fall into several categories. In the Multiple Indicator Cluster Survey (MICS6) 2019 [10], they asked each sample household member aged 15 or over if they had a chronic ailment, and the most three answers were:

1) Hypertension.
2) Diabetes.
3) Cardiovascular disease.

The difference between the symptoms of these three diseases puts us in imperative to pick the most suitable one for our system, so we need to discuss the information of each one of them and make a final decision based on that.

1.2.1. Definitions:

1.2.1.1 High Blood Pressure (hypertension):

Hypertension is defined as a constant or episodic rise in blood vessel tension, which increases the effort of the heart pump and promotes vessel hardening [11].

In other words, it is a condition in which the blood pressure in arteries and veins is persistently too high, causing the heart to work harder to circulate blood throughout the body which impacts all organs. Over time, Hypertension can damage and block the arteries that provide blood to the heart and brain, which leads to raising the possibility of getting a heart attack or stroke.

(Note: Blood pressure is the pressure that carries blood in arteries and the vessels from the heart to the brain and the rest of the body.)

Types of hypertensions:

There are 2 types of High Blood Pressure:

- **Primary Hypertension:** This is often referred to as essential hypertension. It is referred to it like this when there is no recognized cause for high blood pressure. This is the most common type of hypertension, which usually develops over a long period of time. It is probably a result of the lifestyle, environment, and how the body changes as we age.

- **Secondary Hypertension:** This is when your High Blood Pressure is caused by a health problem or medication. Secondary Hypertension can be caused by the following factors:
    - Kidney problems.
    - Sleep apnea.
    - Thyroid or adrenal gland problems.
    - The sides effects of Some medicines.
    - Alcohol.

Complications caused by Hypertension:

The excessive pressure on the artery walls caused by High Blood Pressure can damage the blood vessels as well as organs. The higher the blood pressure and the longer it goes uncontrolled, the greater the damage.

The Uncontrolled High Blood Pressure can lead to:

- Heart attack or stroke.
- Heart failure.
- Weakened and narrowed blood vessels in the kidneys.
- Thickened, narrowed, or torn blood vessels in the eyes. This can result in vision loss.
- Metabolic syndrome.
- Troubles with memory or understanding.
- Dementia.

1.2.1.2 Diabetes:

Diabetes is a disease that develops when the pancreas stops producing insulin or when the body’s insulin isn’t effectively used.

Insulin is a hormone produced by the pancreas that acts as a key to allowing glucose from our food to pass from the bloodstream into our cells for energy production. In the blood, all carbohydrate meals are broken down into glucose, thus Insulin aids glucose absorption into cells.

As a result of not being able to generate or utilize insulin efficiently, blood glucose levels rise (known as hyperglycemia) and over time it causes catastrophic damage to the heart, blood vessels, eyes, kidneys, and nerves.

The types of diabetes:

This disease has three main types: type 1, type 2, and gestational diabetes (diabetes while pregnant).

Type 1: diabetes can develop at any age but occurs most frequently in children and adolescents. When a person has type 1 diabetes, his body produces very little or no insulin, which means that he needs daily insulin injections to maintain blood glucose levels under control.

Type 2: diabetes is more common in adults and accounts for around 90% of all diabetes cases. When a person has type 2 diabetes, his body does not make good use of the insulin that it produces. The cornerstone of type 2 diabetes treatment is a healthy lifestyle, including increased physical activity and a healthy diet. However, over time most people with type 2 diabetes will require oral drugs and/or insulin to keep their blood glucose levels under control.

Gestational diabetes (GDM): is a type of diabetes that consists of high blood glucose during pregnancy and is associated with complications to both mother and child. GDM usually disappears after pregnancy but women affected and their children are at increased risk of developing type 2 diabetes later in life.

Some of the long-term consequences of diabetes:

- Adults with diabetes have a two to three-fold increased risk of heart attacks and strokes.
- Combined with reduced blood flow, neuropathy (nerve damage) in the feet increases the chance of foot ulcers, infection, and the eventual need for limb amputation.
- Diabetic retinopathy is an important cause of blindness and occurs as a result of long-term accumulated damage to the small blood vessels in the retina.
- Diabetes is among the leading causes of kidney failure.

1.2.1.3 Cardiovascular disease:

Cardiovascular disease (CVD) is a general term for conditions affecting the heart or blood vessels. It’s usually associated with a build-up of fatty deposits inside the arteries (atherosclerosis) and an increased risk of blood clots [12], you can describe it as a disease that is created When one of the cardiovascular system’s organs stops working, which blocks or obstructs the transport of nutrients and oxygen-rich blood to other parts of the body and, stops the return of deoxygenated blood to the lungs.

Types of cardiovascular diseases:

The cardiovascular system is composed of a number of organs, which is why cardiovascular illness comes in so many different forms, each one with its unique effect on the heart.

Some types of cardiovascular disease:

- **Coronary artery disease (CAD),** is caused by the buildup of plaque in the heart's arteries.
- **Arrhythmia**, which is a heart rhythm abnormality.
- **Atherosclerosis**, which means the hardening of the arteries.
- **Dilated cardiomyopathy**, caused by a narrowing or blockage in the coronary arteries.
- **Cardiomyopathy**, this condition causes the heart's muscles to harden, abnormally thick or grow weak.
- **Congenital heart defects**, are heart irregularities that are present at birth.
- **Heart infections**, may be caused by bacteria, viruses, or even parasites.
- **Not to mention other types including:** mitral valve regurgitation, mitral valve prolapses, aortic stenosis, myocardial infarction, heart failure, and hypertrophic.

The relation between heart disease and other chronic diseases:

- **Diabetes:**

  Over time, high blood sugar levels from diabetes can damage the blood vessels in your heart, making them more likely to develop fatty deposits. The longer you have diabetes, the higher the chances are that you will develop heart disease.

- **Hypertension:**

  High blood pressure damages arteries and veins of the body which increases the risk for a variety of cardiovascular diseases including stroke, coronary artery disease, heart failure, atrial fibrillation, and peripheral vascular disease.

Some risk factors:

Factors that can raise the risk for heart disease are:

- Smoking.
- Being overweight or having obesity.
- Not getting enough physical activity.
- Eating a diet high in saturated fat, trans fat, cholesterol, and sodium (salt).
- Drinking too much alcohol.
- old age.

1.2.2. Prevalence Rate: (Based on The Multiple Indicator Cluster Survey (MICS6) 2019):

	Hypertension	Diabetes	Cardiovascular
Sexe:			
Male	5.1%	4.6%	1.1%
Feminine	10.0%	5.4%	1.3%
Age:			
15 – 49 years old	from 0.0% to 5.0%	from 0.6% to 4.6%	from 0.1% to 0.8%
50 – 80 years old & +	from 13,5% to 38,9%	from 10,3% to 12,9%	from 1.8% to 7.4%
Place of residence:			
Urban	8.1%	5.6%	1.3%
Rural	6.5%	3.9%	1.0%
Territorial Programming Space:			
North Center	8.1%	5.5%	1.3%
Northeast	7.4%	5.4%	1.4%
North West	8.3%	5.0%	1.3%
High Plateau Center	7.0%	3.7%	0.9%
Eastern High Plateau	6.2%	4.6%	1.4%
High West Plateau	7.0%	3.7%	0.9%
South	6.5%	4.7%	0.5%
Economic well-being index:			
The poorest	6.2%	3.5%	0.9%
Second	6.8%	4.4%	1.2%
Average	7.3%	5.0%	1.2%
Fourth	8.3%	5.6%	1.2%
The richest	8.9%	6.4%	1.4%

Table 1.2: Percentage of population aged 15 and over with chronic diseases in Algeria [10]

1.2.2.1 The Analysis:

Hypertension, diabetes and cardiovascular diseases, which have a very high prevalence in the world, are considered the most major public health problems in developed and emerging countries, especially Algeria.

Firstly, when it comes to the proportion of the population that has one of these illnesses, Hypertension has the highest rate for both sexes compared to Diabetes and Cardiovascular diseases, which have substantially lower percentages for both men and women.

In terms of age differences, the difference was five times bigger in the other two illnesses than in cardiovascular disease between the ages of 15 and 49. However, there has been a remarkable growth in the proportion of Hypertension disease from ages 50 to 80&+, which will keep increasing until it constitutes three times greater than the percentages of both other diseases combined.

By considering the residential environment side, we surprisingly see that urban places are rife with chronic diseases compared to rural places, although the statistics are slightly spaced, hypertension was the most disease that showed high prevalence rates compared to others.

For the territorial programming space side, we clearly notice that all percentages of the 3 diseases differ in each territory Where diabetes and cardiovascular disease record their highest rates in the Northeast and the Eastern High Plateau, even though the hypertension rates are clearly superior in all territories, reaching the highest prevalence rates by 8.1% and 8.3% in the North Center and North West, respectively.

In terms of the economic well-being index, we note that the rates of hypertension, diabetes, cardiovascular are dramatically increasing, reaching their apex in the rich layers by 8.9%, 6.4% and 1,4% respectively, despite the fact that Hypertension still remains dominant across all social strata without exceptions (according to The Multiple Indicator Cluster Survey (MICS6) 2019).

1.2.3. Death Rate:

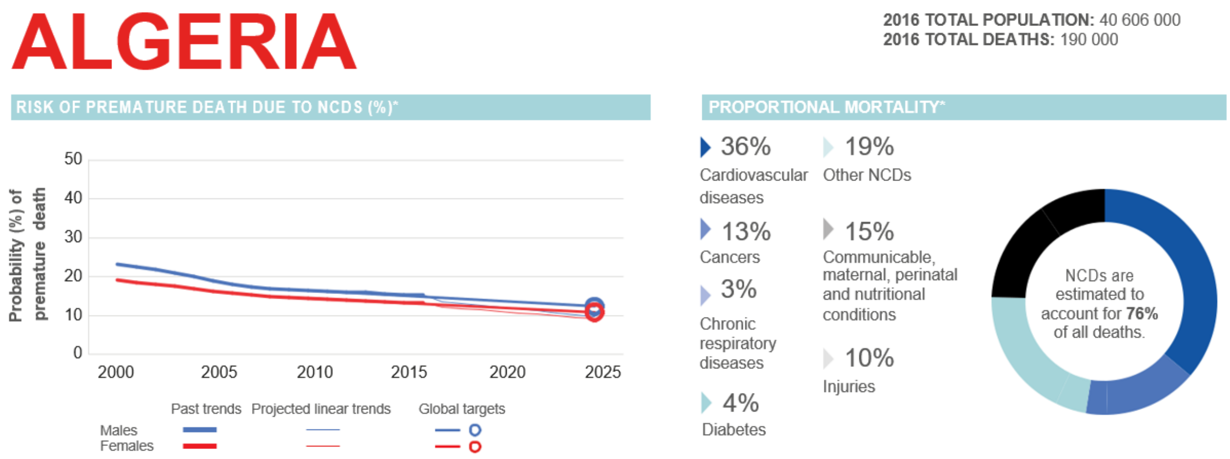

Figure 1.5: RISK OF PREMATURE DEATH DUE TO NCDS (%) AND PROPORTIONAL MORTALIT (%) (World Health Organization - Noncommunicable Diseases (NCD) [13])

DISEASE	Deaths	Percentage %	Deaths Rate per 100,000
Coronary Heart Disease	44,336	26.02	141.69
Diabetes Mellitus	8,390	4.92	26.79
Hypertension	2,171	1.27	6.94

Table 1.3: Latest published death rate data for Algeria in 2018 [14]

According to the graph and table data, we can clearly see that cardiovascular disease is the leading cause of death, accounting for 36% of deaths in 2016 and 26.02% in 2018, and the highest rate with 141.69, compared to Diabetes and Hypertension rates, which combined didn’t even approach half of the previous one, making Patients with Coronary Heart Disease the most categories of people risk to death in Algerian society

1.2.4. The Decision:

After examining and evaluating the above, we concluded that patients with heart diseases are the category most in need of the so-called remote care system. Despite the small number of heart patients compared to patients with diabetes and hypertension, who account for a larger proportion of the patients, heart diseases have the highest death rate in Algeria, which is estimated at 36% of total deaths (according to 2016 statistics), making it the most vulnerable category to death, and there is also the fact that both diabetics and blood pressure patients have a high probability of developing heart disease by 25.0% and 39.5% respectively [15]. So, we focused on heart disease patients in order to reduce the pressure on them as much as possible, perhaps our work will provide them some relief, and why not? maybe it will save their lives if they are in danger.

Chapter 2 : System Components; Hardware description and design

2.1. Introduction:

This chapter is divided into two parts:

- The first part demonstrates the Hardware Synoptic, electronic schema, and explains the hardware being used in our project: a definition of the Raspberry Pi 4b and its general-purpose input-output (GPIO), The Ad8232 ECG heart rate sensor, LM35 temperature sensor, and MCP3008 ADC converter along with their characteristics [ANNEX A, B, C].
- The second part explains the software tool and libraries being used in our system along with the flowchart of the overall system.

2.2. Synoptic diagram of the overall system:

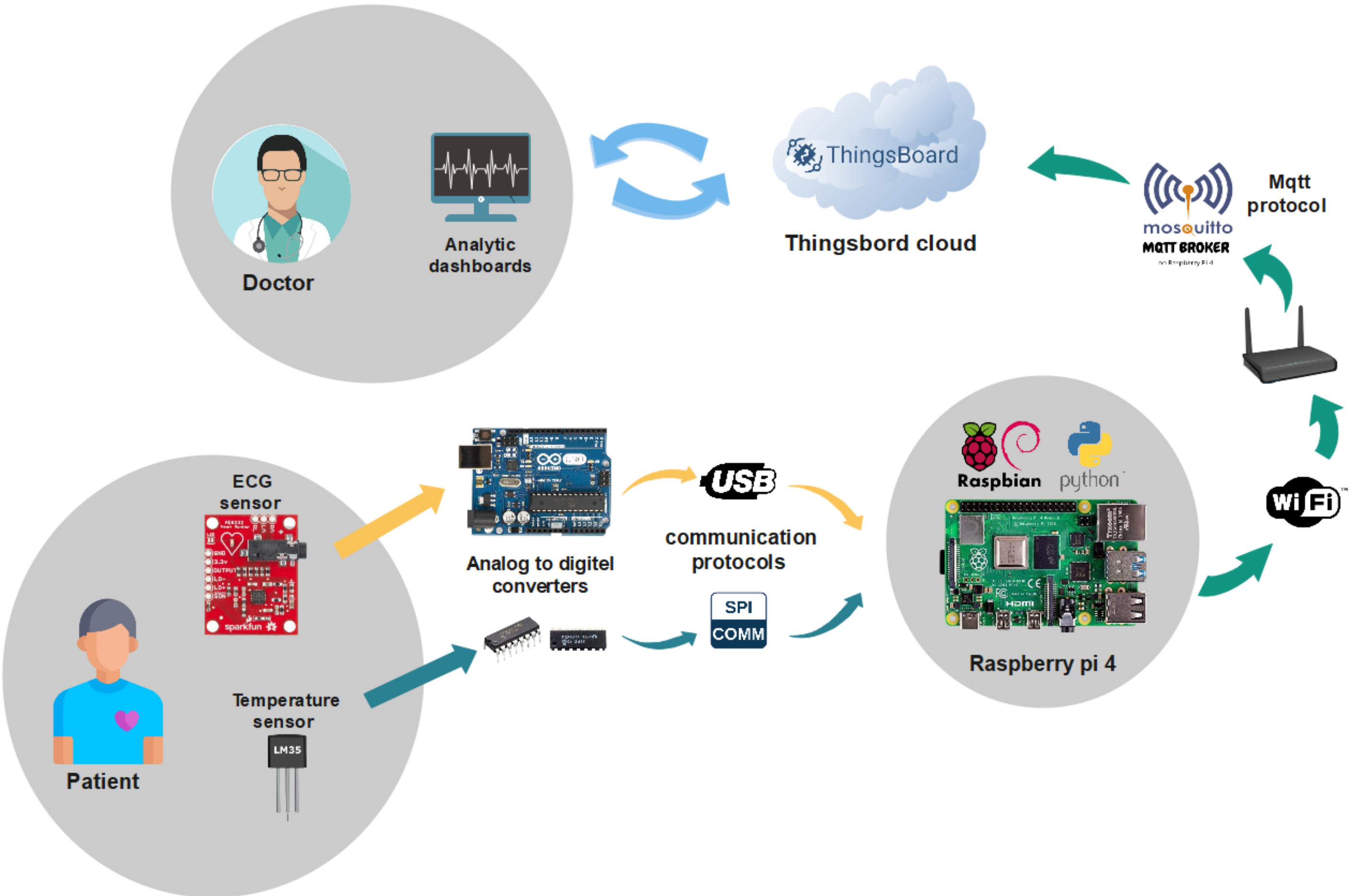

Figure 2.1: The Synoptic diagram of the overall system

2.3. Electronic circuit schema:

This is our system's schema; however, it's not a finished product that can be deployed in the field; rather, it's an experiment schema. Yes, it functions perfectly; it's just that some components aren't necessary for this schema.

At first, we were supposed to utilize a single ADC that connected to sensors, and the chosen one was the MCP3008 ADC, but it wasn't available at the time, and we had to wait for a long time to receive it. As the Raspberry Pi lacks an Analog to Digital converter, we utilized Arduino instead, which has an ADC with the same capabilities as the MCP3008. After we had made significant progress on the project and just as we finished our work with Arduino, the MCP3008 became available. Of course, it was too late to remake the whole work from scratch, so we utilized the LM35 with MCP3008 to overcome the problem of the Arduino being overloaded by delivering numerous data through USB communication which allowed us to add more components to our system without affecting the ECG signal.

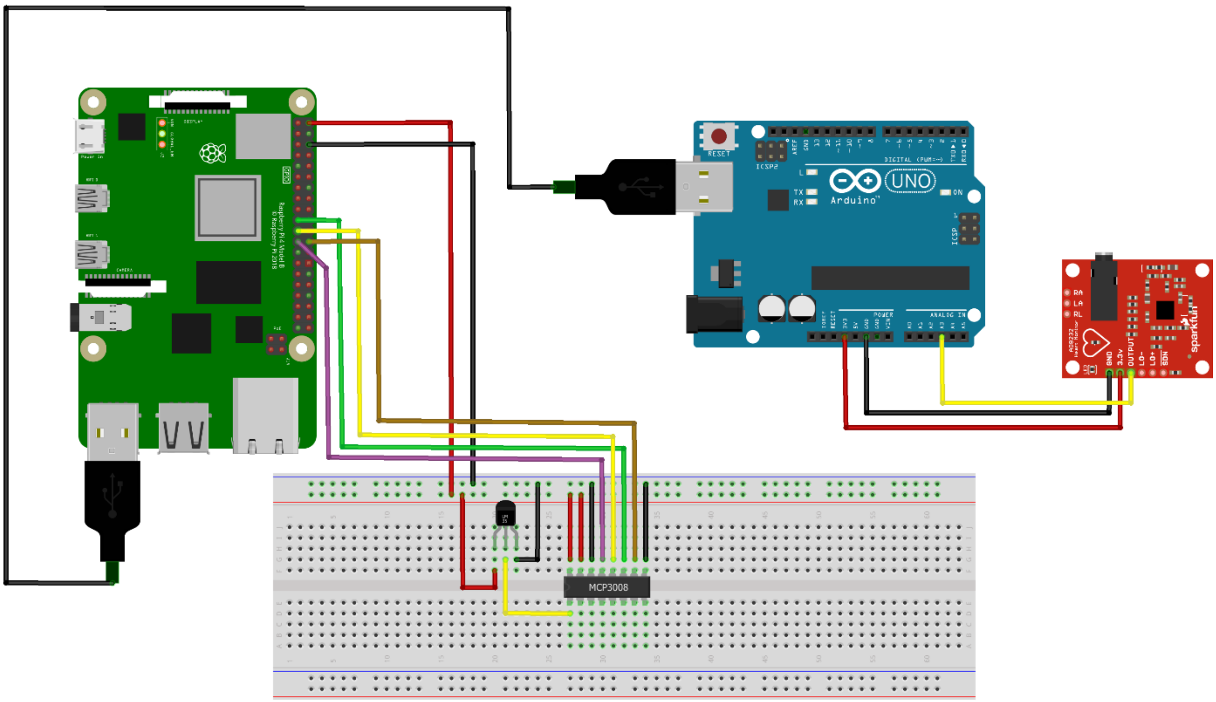

Figure 2.2: The Project's Electronic circuit schema

2.4. Hardware Description:

2.4.1. The Raspberry Pi 4 Model B:

2.4.1.1 Definition:

The Raspberry Pi 4 Model B is the most recent addition to the popular Raspberry Pi computer range. It outperforms the previous-generation Raspberry Pi 3 Model B+ in terms of CPU speed, multimedia performance, memory, and connection while maintaining backwards compatibility and power efficiency. The Raspberry Pi 4 Model B offers desktop performance equivalent to entry-level x86 PC systems to the end user.

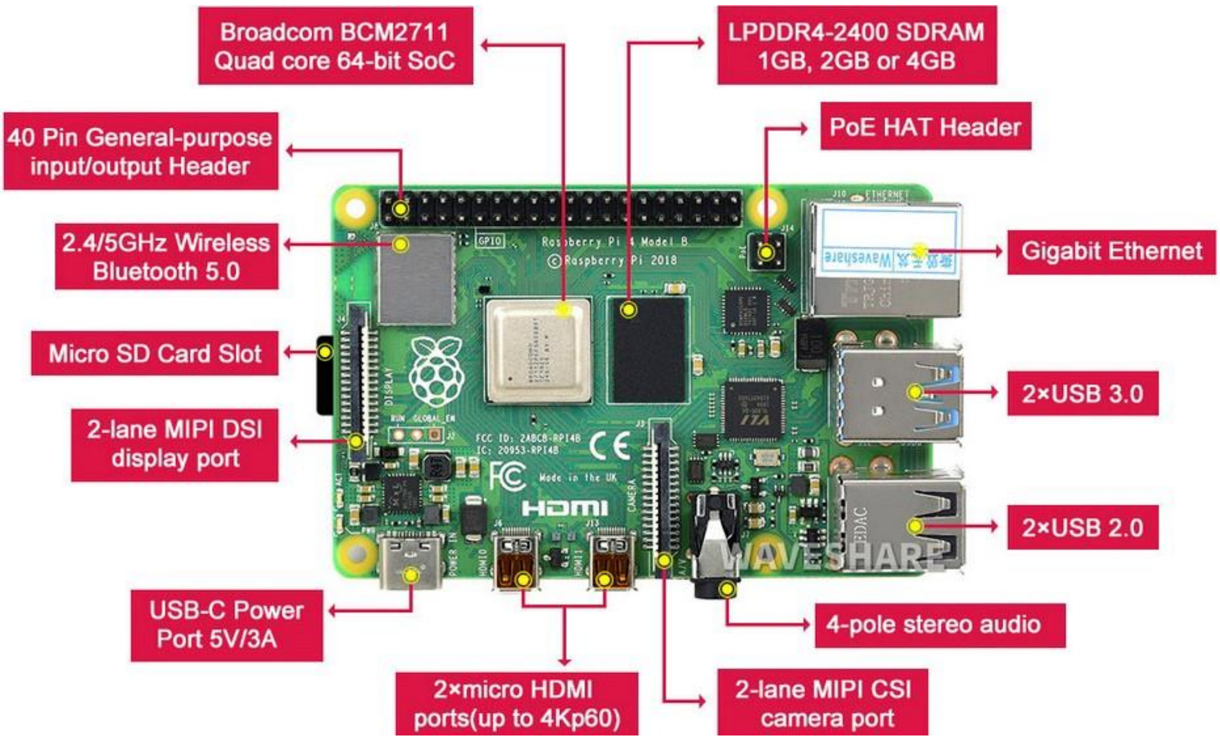

Figure 2.3: The Raspberry Pi 4b board

This product’s key features include a high-performance 64-bit 1.5GHZ quad-core processor, dual-display support at resolutions up to 4K 60FPS via a pair of micro-HDMI ports, hardware video decode at up to 4Kp60, Video Core VI graphics supporting OpenGL, up to 8GB of LPDDR4 SDRAM, dual-band 2.4/5.0 GHz wireless LAN, Bluetooth 5.0, full-throughput Gigabit Ethernet, USB 3.0, two USB 2.0 ports and PoE capability (via a separate PoE HAT add-on).

2.4.1.2 General Purpose Input Output (GPIO):

There are two rows of pins on the Raspberry Pi's side. These pins are referred to as the GPIO connector. The GPIO connector of the Raspberry Pi allows users to attach electronic devices to it. All GPIO pins can be utilized as general-purpose input/output pins. This implies they can function as input or output pins.

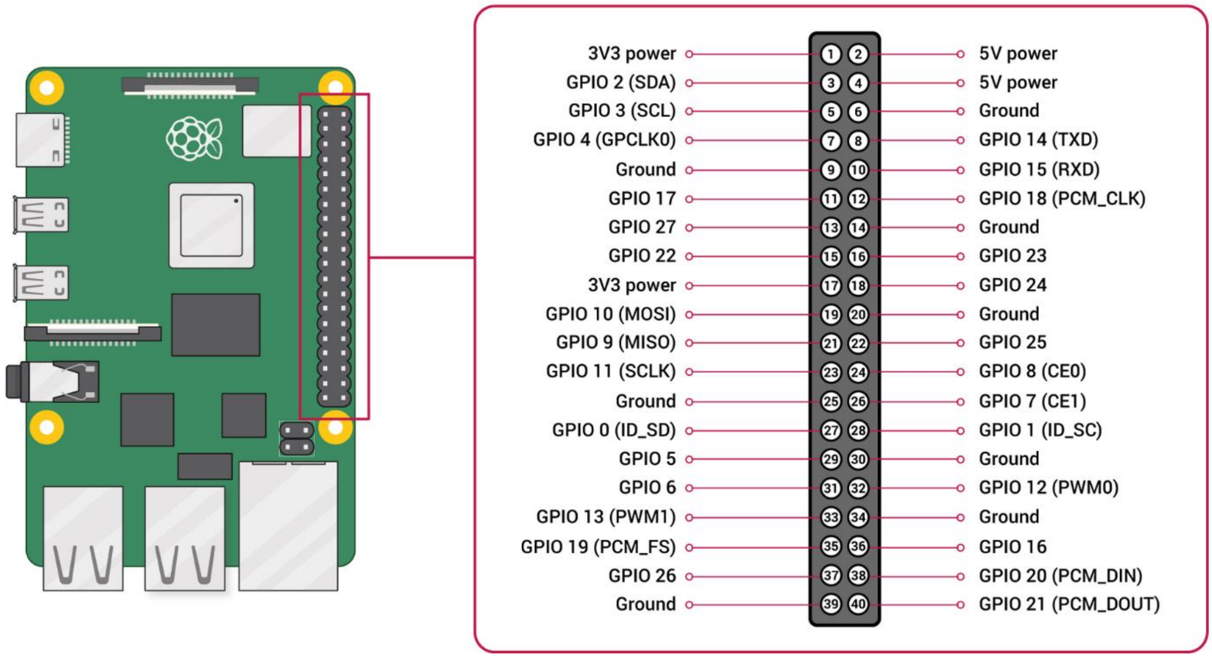

Figure 2.4: GPIO connector's pin layout on Raspberry Pi 4b

The pins are numbered from the top left corner, with odd numbers on the left and even numbers on the right. Some GPIO connector pins have extra labels following the pin name. They serve as identifying markers for distinct characteristics. SDA and SCL are the labels for GPIO 2 and GPIO 3, respectively. These pins are being used to represent the data and clock lines on a serial bus. I2C is a serial bus that is often used to interface with peripherals such as temperature sensors and LCD displays.

2.4.2. The Arduino Uno (The Microcontroller (MCU)):

The ATmega328P-based Arduino Uno is a microcontroller board. It contains 14 digital input/output pins (of which 6 may be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator (CSTCE16M0V53-R0), a USB connection, a power jack, an ICSP header, and a reset button. It comes with everything needed to support the microcontroller; it simply needs to be connected it to a computer through USB or power it using an AC-to-DC converter or battery to get started [16].

We used this microcontroller purposely in our project to read the ECG analog data from our sensor (Ad8232) since Arduino Uno has 6 0n-board 10-bit ADC channels which can be used to read analog signals in the range 0-5V means it gives digital values in the range of 0 – 1023 that provided us with quantifiable data, that makes it easier to process and store, as well as provides more accurate and reliable conversion by minimizing errors.

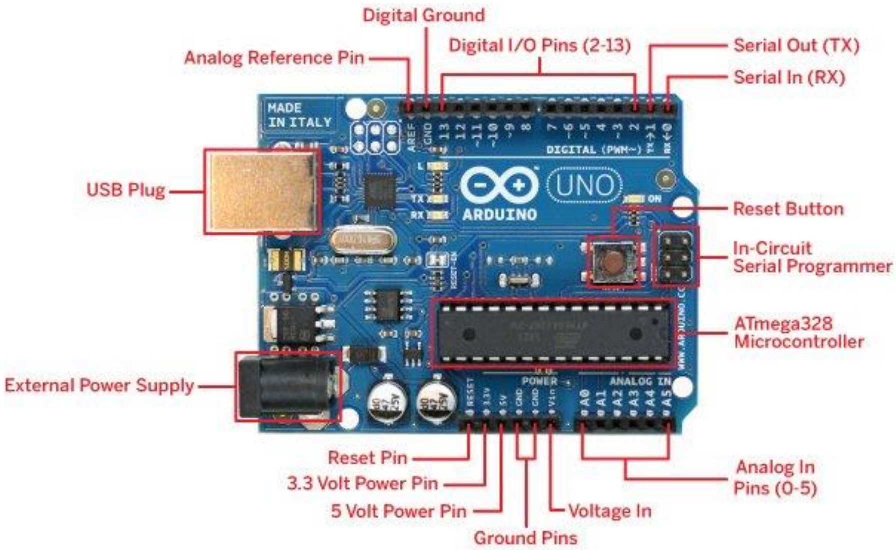

Figure 2.5: The Arduino Uno (MCU)

2.4.3. MCP3008 (The ADC converter):

The MCP3008 is a low-cost 8 single-ended input channels with a successive approximation 10-bit analogue-to-digital converter. It has a 4-wire serial SPI-compatible interface that is used to get digital output for all channels. It has an onboard sample and holds circuitry as well as providing both analog and digital ground connections which help in noise reduction. This device is capable of conversion rates of up to 200 ksps for a 5V power supply.

2.4.3.1 How To Use the MCP3008 IC:

The MCP3008 can measure analog voltage values ranging from 0 to 1023 and send them to a microcontroller or microprocessor via SPI communication. It can run on both 3.3V and 5V, so it can be used with both 5V and 3.3V microcontrollers, such as the Raspberry Pi. Because the ADC employs the SAR method, a reference voltage is necessitated for it to determine the unknown voltage. This reference voltage should always be less than the operating voltage, but in most cases, it was the same. In our case, we used a 5V reference voltage in conjunction with the VCC pin [17].

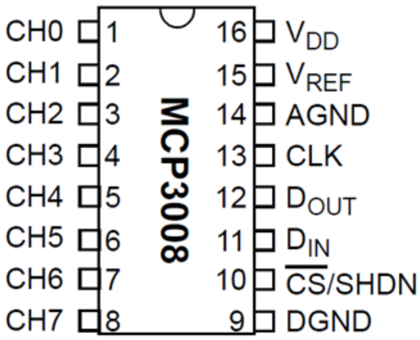

Figure 2.6: The MCP3008 A/D converter [18]

The channel pins CH0 to CH7 can be used to feed in the analog voltage which needs to be measured, and the maximum voltage level that each pin can measure is equivalent to the reference voltage (5V). Each pin measures voltage with a 10-bit resolution, which means that an input voltage of 0-5V is converted to 0-1023 digital data. This digital data can be converted back to voltage using the following formula [17]:

$$\textbf{Analog Voltage Measured} = \textbf{ADC Reading} * \frac{\textbf{System Voltage}}{\textbf{Resolution of ADC}}$$

Following the measurement of the analog voltage by the IC, the microcontroller or microprocessor can obtain its value via SPI communication. To accomplish this, the IC's CS, Din, Dout, and Clock pins are connected to the SPI pins of the microcontroller or microprocessor. Thereafter, using the SPI communication protocol, we sent the control bit data for selecting the channel number from which to obtain the ADC value, and then the IC responded to us with the value.

The calculation of the output reference voltage can be done using the following formula [19]:

$$\textbf{Digital output} = \mathbf{1024} * \frac{\textbf{Vin}}{\textbf{Vref}}$$

2.5. sensors:

2.5.1. LM35 Temperature Sensor:

The LM35 is a precision integrated-circuit temperature sensor with an output voltage linearly proportional to the Centigrade temperature. It shows high voltage values than thermocouples and may not require the output voltage to be amplified. The output voltage can easily be interpreted to obtain a temperature reading in Celsius. The coating also prevents it from self-heating, and because of its low cost and high precision, it is becoming increasingly popular with manufacturers and students in general.

In addition, The LM35 device has an advantage over linear temperature sensors calibrated in Kelvin, as the user is not required to subtract a large constant voltage from the output to obtain convenient Centigrade scaling. The LM35 device does not require any external calibration or trimming which makes it advantageous over thermocouples, and gives the ability to provide typical accuracies of ±¼°C at room temperature and ±¾°Cover a full −55°C to 150°C temperature range.

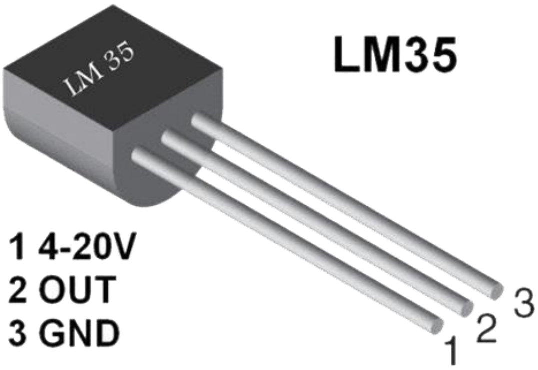

Figure 2.7: The LM35 Temperature sensor

2.5.1.1 LM35 Working Principle:

The LM35 has a linear scale factor of +10 millivolt per degree centigrade, which means that for every 10 millivolts rise in output from the sensor Vout pin, the temperature value increases by one. For example, if the sensor outputs 100 millivolts at the Vout pin, the temperature in degrees Celsius is $\frac{100mv}{10mv/°c} = 10$ degrees Celsius. The same goes for the negative temperature reading. The temperature is -10 degrees Celsius if the sensor outputs -100 millivolts [20].

For the LM35, the formula for converting voltage to centigrade temperature is [21]:

$$V_{out}\ (Voltage\ Read\ by\ ADC) = 10\ mv/℃\ (\ Linear\ scale\ factor) * T\ (Temperature\ in\ ℃)$$
$$\Rightarrow V_{out} = f\left(T\ (℃)\right)$$

And from the previous equation we conclude that: $T(℃) = \frac{V_{out}\ (V)}{10\ (mv/℃)}$

2.5.1.2 The Calibration Test of LM35:

The Calibrating test is a method used to check our LM35 temperature sensor's accuracy and to ensure that it operates at the best possible rate, giving the best performance, by comparing it to a digital thermometer.

For testing, we tried to read the core body temperature from the LM35 and the digital thermometer at the same time by taking several values numerous times in different states (resting and action state). As a result, we got these curves that are shown in the following image:

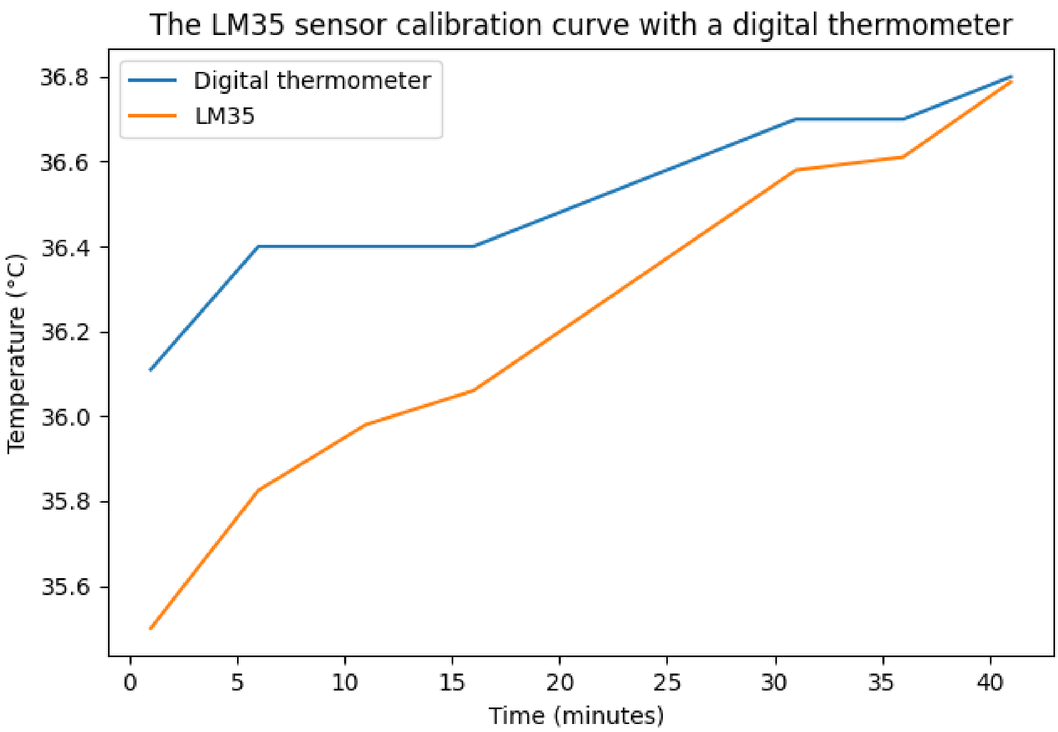

Figure 2.8: The LM35 sensor calibration curve with a digital thermometer

Based on the curves, we can clearly see that there is not much difference between the measurements of the LM35 and the digital thermometer, which proves the LM35's reliability and capability to work as a core body temperature sensor.

After analyzing the result and calculating the average differences, we obtained the calibration value (0.3 °C), which corrects the LM35 values and approximates them to the measurements of the digital thermometer in the best possible way.

The calibration equation is:

$$The\ correct\ temperature = LM35\ temperature + 0.3\ °C$$

When it comes to Non-Invasive Heart Rate Measurement, there are two types of sensors, each with their own method of measuring heart rate: ECG sensors and PPG sensors.

2.5.2. ECG sensors:

ECG (electrocardiography) sensors measure the bio-potential generated by electrical signals that control the expansion and contraction of heart chambers.

2.5.2.1 Ad8232 ECG Heart Rate Sensor:

The AD8232 is a low-cost, integrated front-end card and signal conditioning block for heart rate monitoring of cardiac bioelectrical signals. It is a low power analog monitor with a single heart rate speed for all types of vital signs monitoring applications. The electrical activity of the heart that is measured by the sensor can be plotted as an ECG or electrocardiogram and output as an analog reading.

Typically, ECGs can be extremely noisy, so the AD8232 Single Lead Heart Rate Monitor acts as an operational amplifier to eliminate extra noise and help get a clear signal of PR and QT intervals easily.

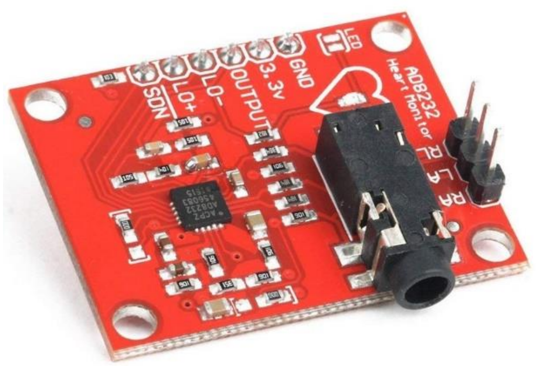

Figure 2.9: The Ad8232 ECG heart rate sensor

The AD8232 heart rate monitor breaks out nine integrated circuit (IC) connections to which we can solder pins, wires, or other connectors. SDN, LO+, LO-, OUTPUT, 3.3V, GND provide the essential pins to operate this monitor with an Arduino or Raspberry pi or any other development board.

Additionally, it has a LED indicator that flashes in time with a detected heart rate as well as RA (right arm), LA (left arm), and RL (right leg) pins are also available on this board to attach and use our own sensors personalized.

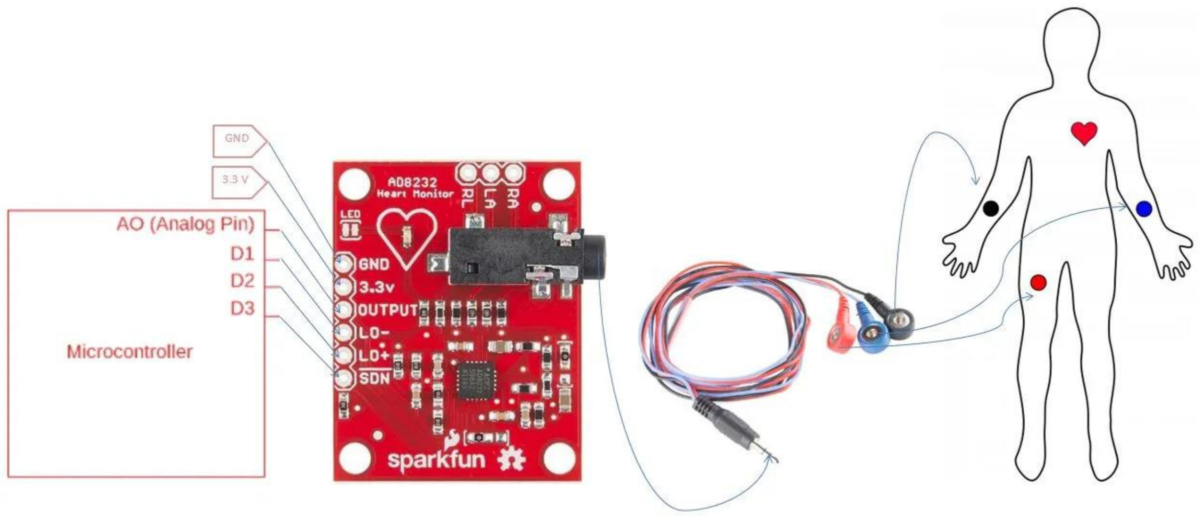

Figure 2.10: The connection principle of the Ad8232 and its Electrodes with MCU [22]

For the other type of cardiovascular sensor:

2.5.3. PPG Sensors:

PPG (photoplethysmography) sensors use a light-based technology to sense the rate of blood flow as controlled by the heart's pumping action.

Some available modules such as:

- Heart rate sensor max30102
- XD-58C heart rate sensor

So, which one of them is better for our system, ECG or PPG sensors?

ECG biosensors can provide the most extensive range of heart health measurements because they can capture more comprehensive signals of overall heart performance, such as Heart Rate (HR) and Heart Rate Variability (HRV). PPG sensors, on the other hand, are only capable of measuring HR, and less reliably than ECG biosensors [23].

As a result, the main issues with PPG technology include cancelling the effects of ambient light, fitting diverse skin conditions and colors, and dealing with physical motion artifacts. Furthermore, PPG can only be used on areas of the body with a high concentration of blood vessels while the ECG does not require it. These are the main reasons why we picked the ECG sensor (Ad8232) over the PPG sensor for our project.

2.6. Time Sheet Project Development:

Period	Activities
01/03/2022 to 20/03/2022	• Study on various projects (state of the art). • A comprehensive study on various chronic diseases. • Conducting Deep research for hypertension, diabetes, and cardiovascular sensors.
20/03/2022 to 01/04/2022	• Searching for the devices we need which are available in the electronic markets. • Choosing the most suitable ones for our project. • Designing our Electronic circuit Shema and the synaptic of the overall system.
02/04/2022 to 10/05/2022	• Learning the python language and how to program and use Raspberry Pi and all of its accessories and functions. • Amassing a significant level of knowledge about the IoT platform and the IoT area in general and how to use the platform's built-in functions and features. • Making hardware and software solutions for our Project problems.
11/05/2022 to 7/06/2022	• Conducting the experimentation tests to show the quality and reliability of our work with the final results of our system in the IoT platform. • The preparation of the main thesis document (word/pdf).
8/06/2022 to 22/06/2022	• Starting the preparation for the PowerPoint presentation (PPT).

Table 2.1: The Project Time Sheet Development

2.7. Software Description:

2.7.1. Introduction:

This part focuses on application, where we will demonstrate in detail the plans and techniques that we used to develop an embedded system to transfer data to the cloud and send a warning message to the e-mail as a precaution in case of danger using the Raspberry Pi 4 B+, Python, and other libraries by following specific procedures to achieve the desired result.

2.7.2. Software definition:

2.7.2.1 Raspbian (OS):

Raspbian is a free Debian-based computer operating system optimized for the Raspberry Pi hardware. An operating system is a collection of fundamental programs and tools that allow the Raspberry Pi to operate properly.

Raspbian is more than just an operating system, it includes over 35,000 packages, which are pre-compiled software packaged in a convenient style for simple installation on the Raspberry Pi. It is still actively being developed, with the objective of improving the performance and durability of as many Debian packages as feasible.

Raspbian installation (OS):

- **Step 1: Formatting the microSD card:**
  The first step was to reformat the microSD card, since many new microSD cards come with unwanted or unnecessary files on them. As a result, reformatting erases and assists in the removal of all files on the microSD card.
- **Step 2: Download and installing Raspbian:**
  Using a Raspberry Pi Imager, Raspbian was then downloaded and installed onto the microSD. After this, the microSD card was then inserted into the Raspberry Pi. The operating system (Raspbian) started automatically booting after the installation has been finished. Afterwards, the operating system was set up in our RPI successfully.

2.7.2.2 Python:

Python is a programming language used to construct websites and applications, automate operations, and analyze data. Python is a general-purpose programming language, which means it can be used to develop a wide range of applications without being customized for any particular problem.

2.7.2.3 The Integrated Development Environment (IDE):

The sensors in the system are controlled using Python 3 code in an IDE (Integrated Development Environment). Thonny Python IDE has been utilized as the IDE application. This IDE aided us in the creation of the code required to control and read the sensor data. It helped us in building the code by including a powerful troubleshooting tool that discovers and corrects errors in the code, and also works with the Graphical Python Library (MATPLOTLIB), which has been used to display the data to the user.

2.7.2.4 Installation and Descriptions of Python Libraries:

We installed and added new libraries in python by using the following command in the terminal:

sudo pip install (The library name)

In our project we needed the following python libraries:

- **OS:** In Python, the OS module contains functions for interfacing with the operating system.
- **Time:** The Python time module provides a variety of ways to represent time in programs.
- **CSV (Comma Separated Values):** is a simple file format for storing tabular data, such as a spreadsheet or database.
- **Sys:** is a Python library that offers several functions and variables for manipulating various areas of the Python runtime environment.
- **Statistics:** is a built-in Python library for descriptive statistics.
- **Matplotlib:** Matplotlib is a cross-platform data visualization and graphical plotting package for Python and its numerical extension NumPy.
- **base64:** is a python library used to encode decode data such as images.
- **Pandas:** is a software python library for data manipulation and analysis. It provides data structures and functions for manipulating numerical tables and time series in particular.
- **Paho-mqtt client:** This library provides a client class that allows applications to connect to a MQTT broker in order to publish messages, subscribe to topics, and receive published messages. It also includes several assistance functions to make publishing one-time messages to a MQTT server very straightforward.
- **PySerial:** PySerial is a library which supports serial connections across a wide range of devices. It is a Python API module for reading and writing serial data from an Arduino or

other microcontrollers. It helped us in our project by allowing us to access the RPI 4's serial port and receive the raw ECG data from the Arduino through Serial USB Communication.

- **Heartpy:**
  Heartpy is a sensor-independent heart rate analysis tool designed for embedded devices with limited CPU resources, which provides a rapid way of extracting heartbeats that is resistant to noise that is common when recording ECG or PPG with low-cost sensors in fieldwork. Heartpy is using an algorithm that is designed for short heart rate recordings but can also handle longer segments [24].
- **Scipy:** is an open-source scientific and technical computation python library that uses NumPy underneath. It provides Additional utility functions for optimization, stats and signal processing such as filtering.
- **Gpiozero:** is a Python library that allows programmers to control GPIO pins by importing them directly at the beginning of a code, functioning as a simple interface to GPIO devices with Raspberry Pi. It has numerous APIs that facilitated for us the interaction with the MCP3008 ADC converter to get the temperature value through SPI communication.
- **Numpy:** is a Python library that allows us to interact and manipulate arrays. It also includes matrices, Fourier transforms, and linear algebra functions.
- **Spidv:** is a python library that enables us to communicate with the RPi's SPI bus.
- **Crypto:** is a python library which gives the ability to employ The AES cipher algorithm to encrypt the data.
- **PyCryptodome:** is a Python package that contains low-level cryptographic primitives. It is a derivative of PyCrypto which has been improved to include more implementations and changes to the original PyCrypto library.

2.7.3. The System Flowchart:

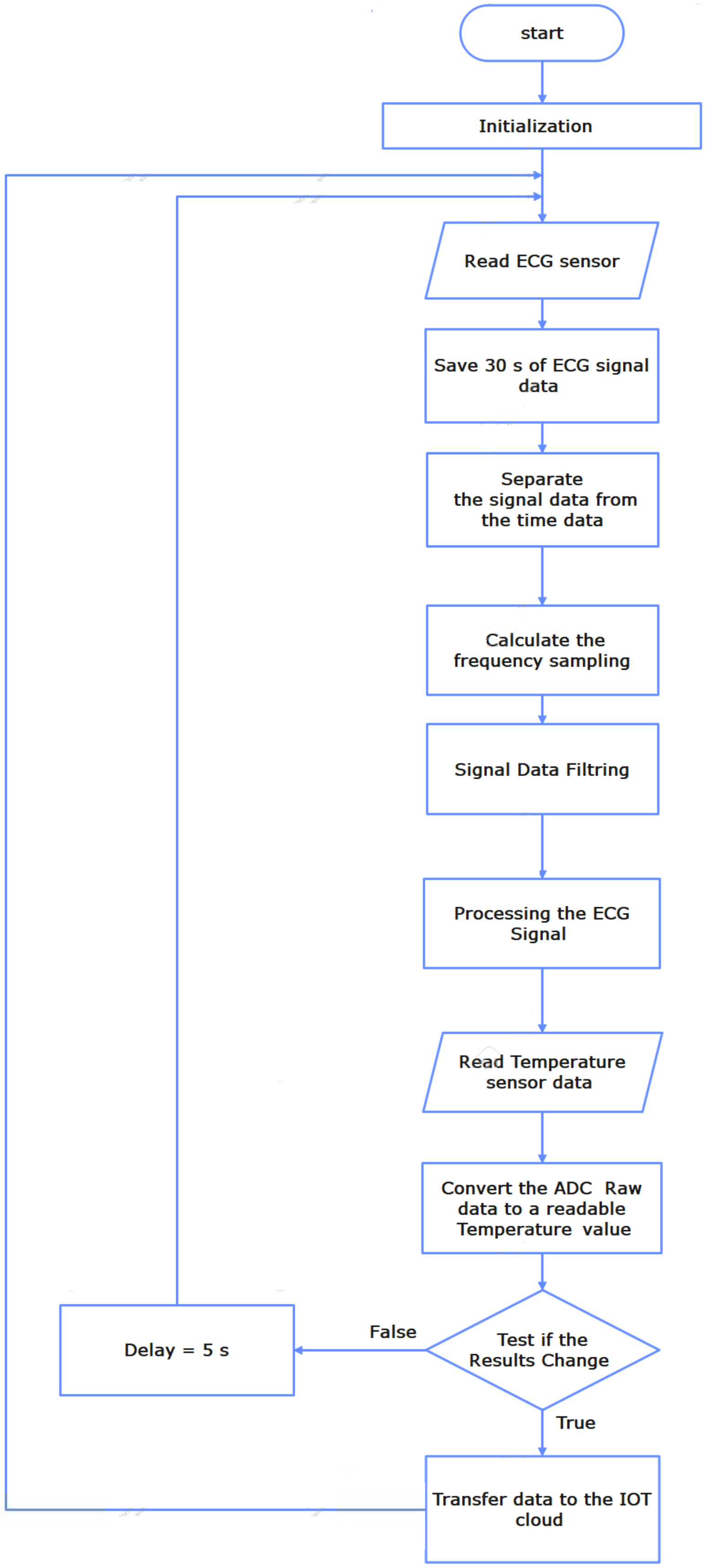

Figure 2.11: The Flowchart of the overall System

2.8. Project hardware realization: (Real pictures of our system):

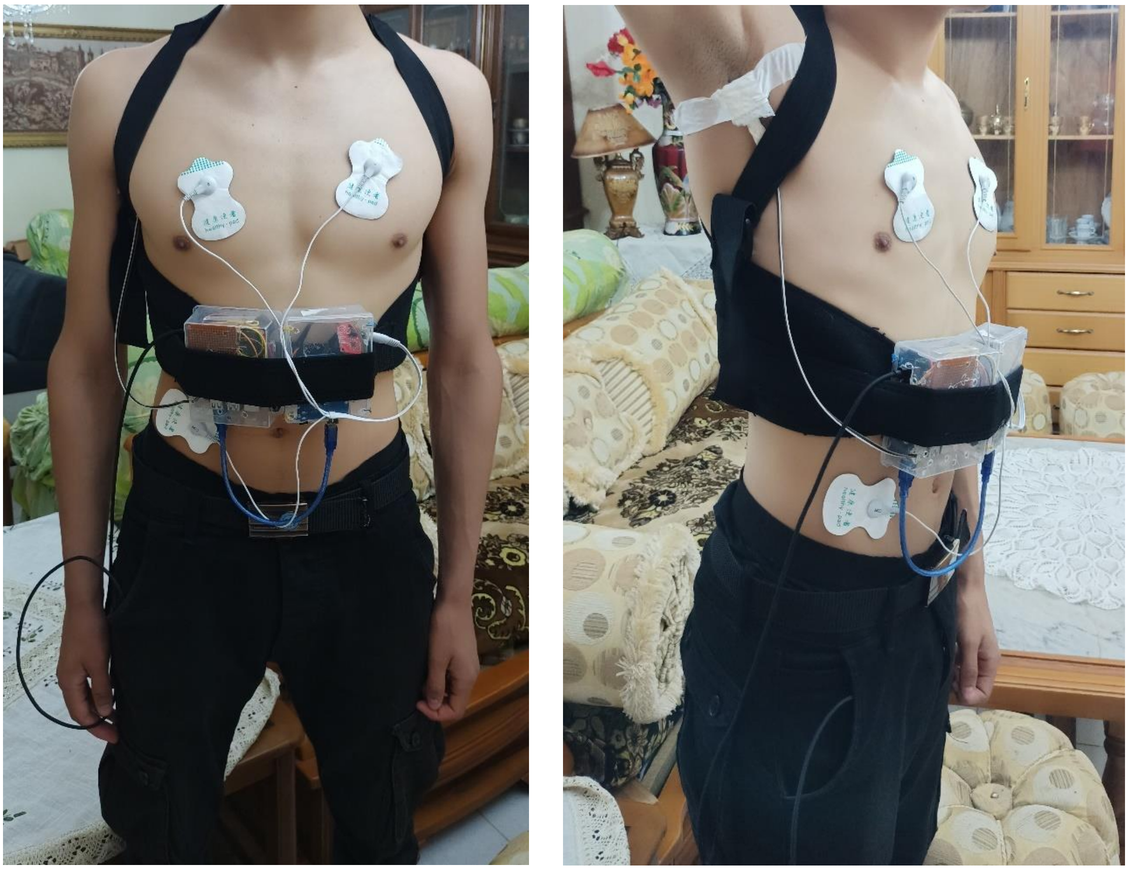

Figure 2.12: Project realization of the wearable monitoring system

2.9. Project Design Price:

Components	Price (DA)
Raspberry Pi 4 Model B	30 000 DA
Arduino UNO ATmega328	2400 DA
MCP3008	700 DA
Ad8232 ECG sensor	4500 DA
LM35 temperature sensor	400 DA
Power Bank (5V/3A)	5000 DA
“14” male/female jumper wires	210 DA
Total:	**43 210 DA**

Table 2.2: The Project Cost Breakdown

Discussion:

The Raspberry Pi 4 is the most expensive device due to its high processing power, large storage memory, open-source OS and its advanced powerful features, which will be more beneficial even for future developments compared to using an ESP32 with low storage memory.

2.10. Conclusion:

In this chapter we have focused on hardware and software side in which we have defined the available MCUs and sensors which we can use them with specific software libraries and algorithms to solve the problematic presented in the previous chapter.

Chapter 3 : The Experimentations and Implementation of the System

3.1. Introduction:

This part focuses on the practical side, where we detailed the results of our experimental project with the aim of testing our ECG sensor Ad8232 by applying our system to two age categories: young people (in their 20's) and old people (in their 60's and 70's), and this to prove its reliability as a medical device and to determine the accuracy and efficiency of the sensor measurement based on specific parameters and in-depth analysis of the ECG signal.

3.2. The Experimentations:

In these experiments we measured the heart rate in three cases of four different people to obtain these results:

- **The first case:** the measurement at rest.
- **The second case:** the measurement after two minutes of walking.
- **The third case:** the Measurement after two minutes of running.

3.2.1. The 1st Experiment: Person "1" (Age = 70+, High-pressure patient):

Resting state:

bpm	65.533981 beat/min
ibi	915.55 ms
Rmssd	18.306964 ms

Table 3.1: 70+ old man resting state parameters

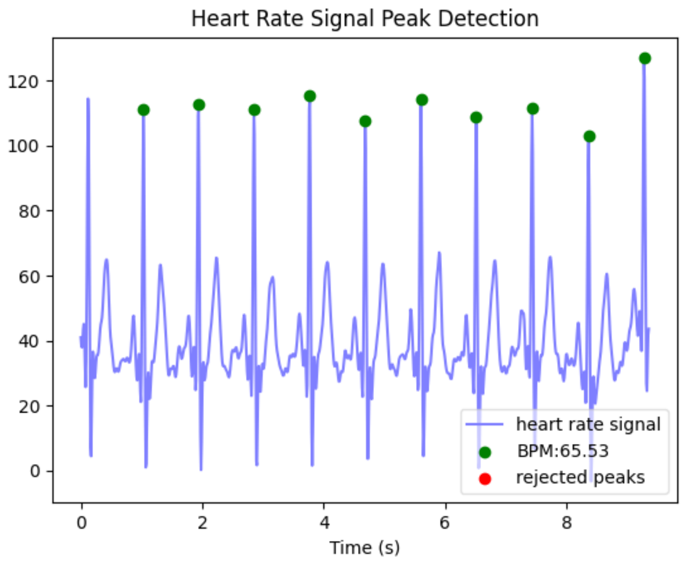

Figure 3.1: ECG of 70+ old man in resting state

Note:

- **BPM:** The number of heartbeats in one minute.
- **IBI:** The interval between individual heartbeats, also known as the interval beat interval (IBI) or the RR-interval, is an important health indicator that represents the time required for one full cardiac cycle.

- **RMSSD:** The root mean square of successive differences (RMSSD) between normal heartbeats and it is obtained by first calculating each successive time difference between heartbeats in milliseconds. Then, each of the values is squared and the result is averaged before the square root of the total is obtained [25], all with the help of this formula :

$$RMSSD = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(|IBI_{i-1} - IBI_i|^2)}$$

Walking state:

bpm	79.778393 beat/min
ibi	752.0833 ms
Rmssd	15.180340 ms

Table 3.2: 70+ old man walking state parameters

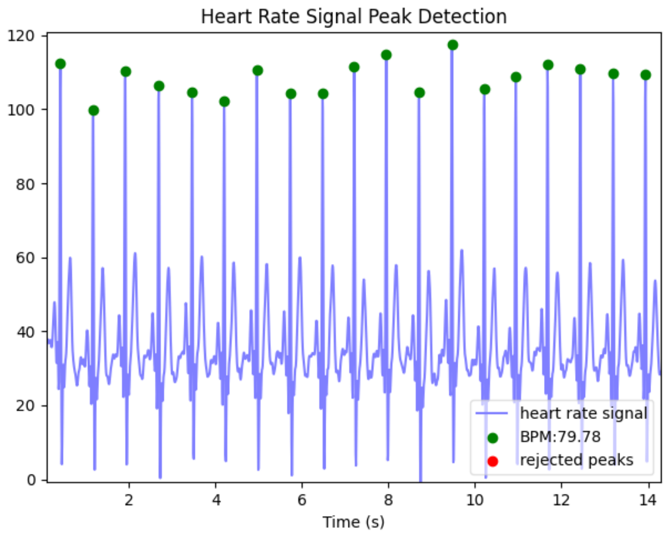

Figure 3.2: ECG of 70+ old man in walking state

Running state:

bpm	93.074792 beat/min
ibi	644.642857 ms
Rmssd	12.691683 ms

Table 3.3: 70+ old man running state parameters

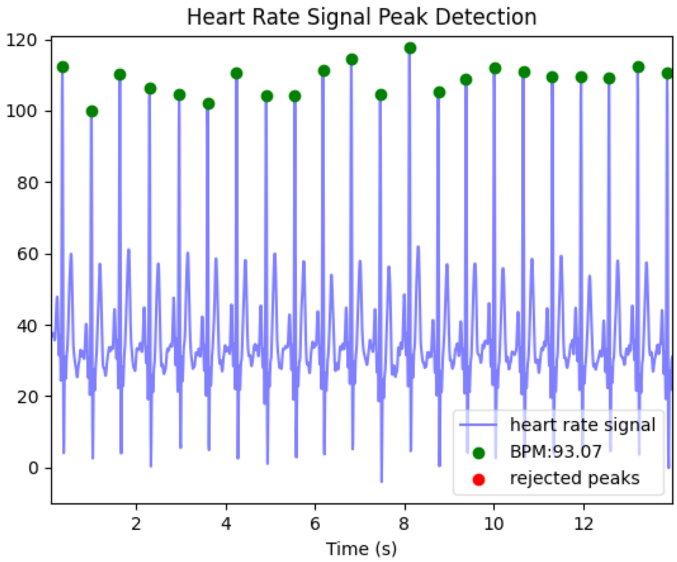

Figure 3.3: ECG of 70+ old man in Running state

3.2.2. The 2nd Experiment: Person “2” (Age = 60+, diabetic patient):

Resting state:

bpm	64.695652 beat/min
ibi	927.4 ms
Rmssd	59.609066 ms

Table 3.4: 60+ old woman resting state parameters

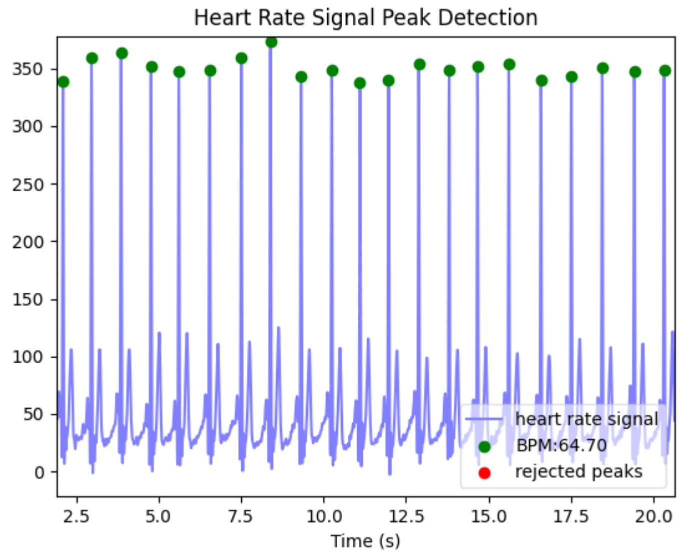

Figure 3.4: ECG of 60+ old woman in resting state

Walking state:

bpm	85.0822334 beat/min
ibi	705.252525 ms
Rmssd	28.333333 ms

Table 3.5: 60+ old woman walking state parameters

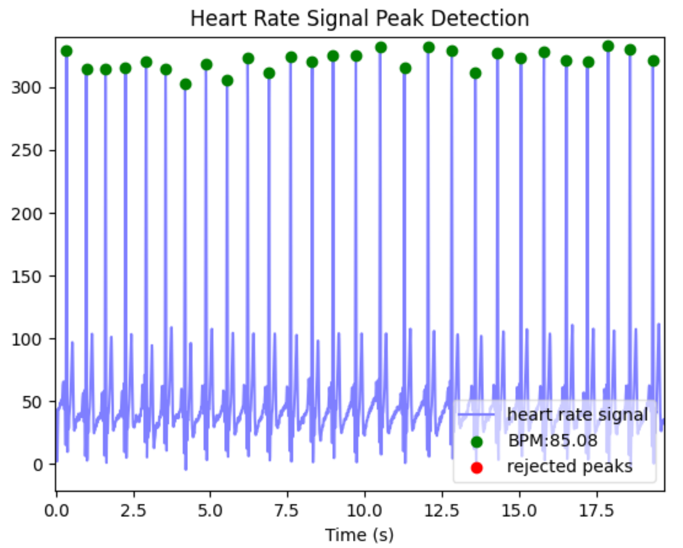

Figure 3.5: ECG of 60+ old woman in walking state

Running state:

bpm	99.567848 beat/min
ibi	602.604167 ms
Rmssd	19.5300 ms

Table 3.6: 60+ old woman running state parameters

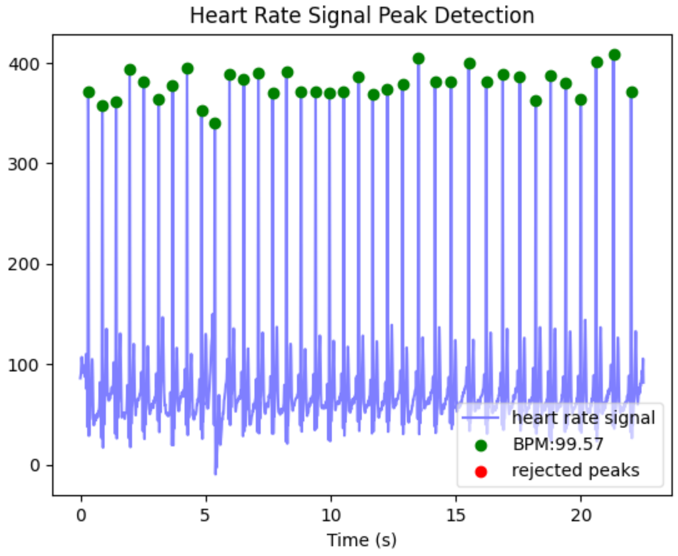

Figure 3.6: ECG of 60+ old woman in running state

3.2.3. The 3rd Experiment: Person "3" (Age = 20+, no heath problem):

Resting state:

bpm	85.263158 beat/min
ibi	703.200 ms
Rmssd	28.3333 ms

Table 3.7: 20+ young woman resting state parameters

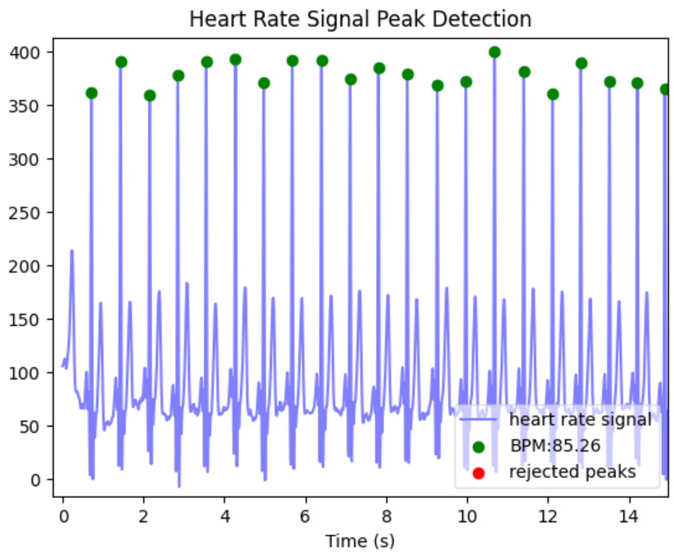

Figure 3.7: ECG of 20+ young woman in resting state

Walking state:

bpm	104.822334 beat/min
ibi	668.70 ms
Rmssd	18.490007 ms

Table 3.8: 20+ young woman walking state parameters

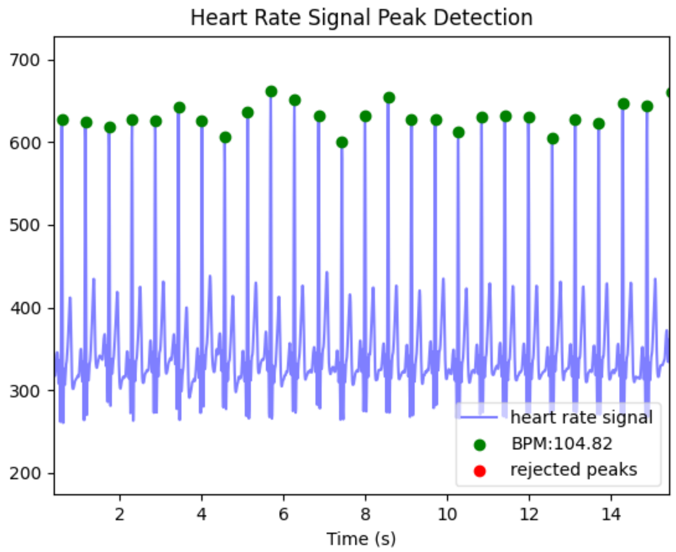

Figure 3.8: ECG of 20+ young woman in walking state

Running state:

bpm	155.293158 beat/min
ibi	609.9960 ms
Rmssd	10.5300 ms

Table 3.9: 20+ young woman running state parameters

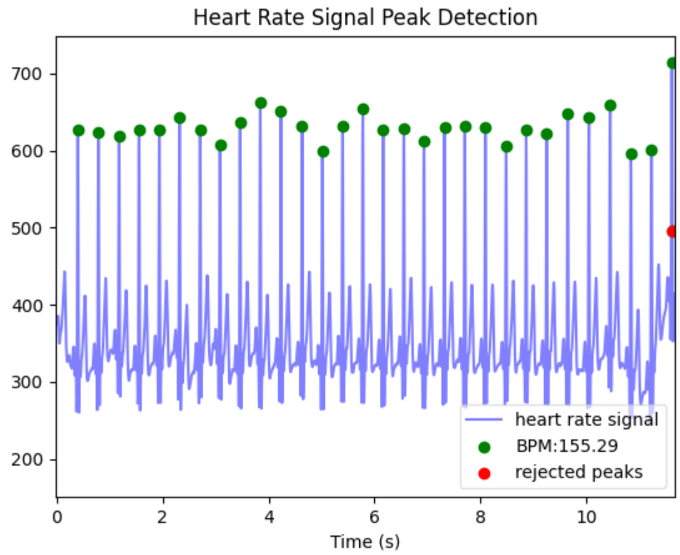

Figure 3.9: ECG of 20+ young woman in running state

3.2.4. The 4th Experiment: Person "4" (Age = 20+, no heath problem):

Resting state:

bpm	74.873808 beat/min
ibi	801.3485 ms
Rmssd	23.898986 ms

Table 3.10: 20+ young man resting state parameters

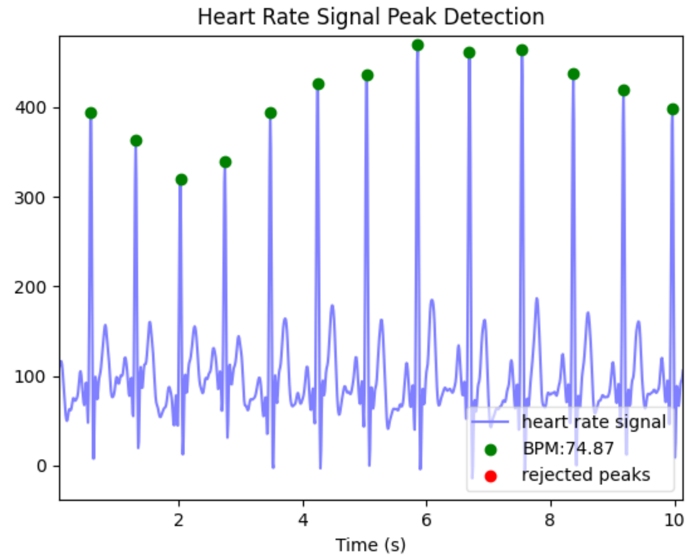

Figure 3.10: ECG of 20+ young man in resting state

Walking state:

bpm	104.823331 beat/min
ibi	752.0833 ms
Rmssd	19.927847 ms

Table 3.11: 20+ young man walking state parameters

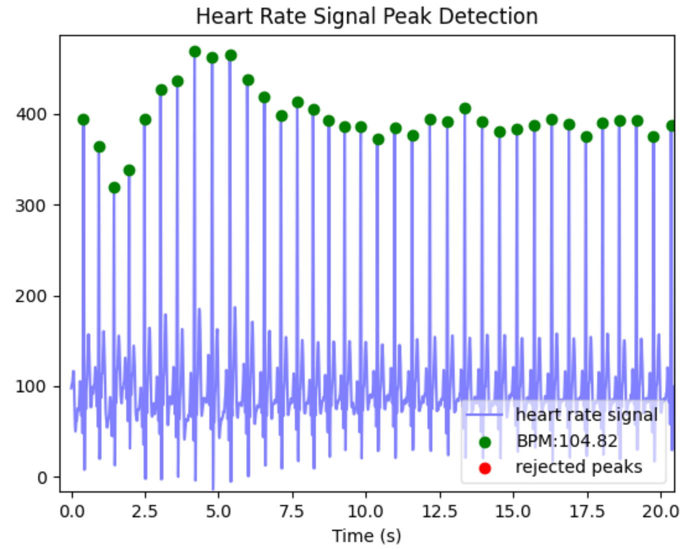

Figure 3.11: ECG of 20+ young man in walking state

Running state:

bpm	127.285474 beat/min
ibi	671.381362 ms
Rmssd	12.175874 ms

Table 3.12: 20+ young man running state parameters

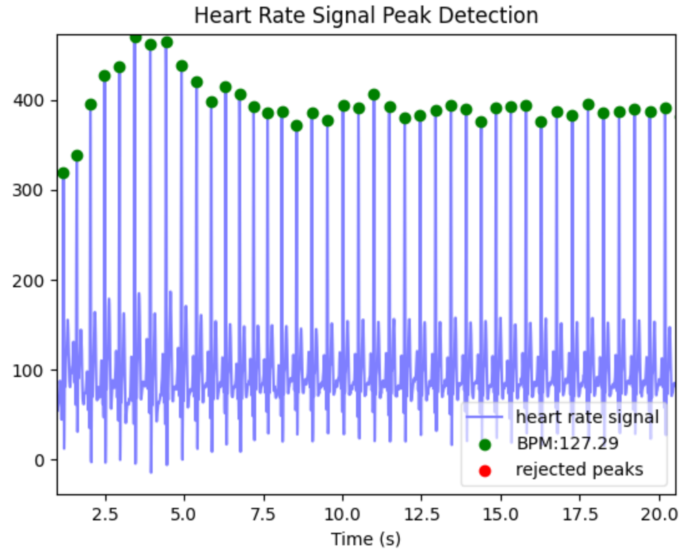

Figure 3.12: ECG of 20+ young man in running state

3.2.5. The observation:

Let's start with the results from the resting case. The heart rates of the four people were within the normal range, which is 60 to 100 beats per minute and decreases with age.

Secondly, the results during walking and running state were reasonable to some extent, and they did not exceed or deviate from the expected ranges.

The expected ranges according to what our references state:

- For all ages, in resting-state bpm should be in the range of [60 – 100] beat/min [26], whereas IBI (R-R interval) should be in the range of [0.6 sec to 1.2 sec] or it'll indicate danger [27], and for the Rmssd parameter should always be greater than 13ms [28].

In case of walking and running state, a good bpm value differs for each age category [29]:

- For ages 20+ between [100-170] and the bpm maximum value reach 200 beat/min.
- For ages 60+ between [78-136] and the maximum value of bpm is 160 beat/min.
- For ages 70+ between [75-128] and the maximum value of bpm is 136 beat/min.

3.3. Conclusion:

Even though after seeing all our previous experiments and that all results were great and satisfying, we still concluded that our sensor is not working perfectly as a real advanced ECG machine Like in hospitals but nevertheless, it gives us reasonable and acceptable results and measurements making it trustworthy for its user.

Chapter 4 : The development of The IoT platform

4.1. Introduction:

In this chapter, we discussed the aspects and features of the IoT platform that must be available in our project. Starting from that, we made a detailed comparison between three specific platforms, picked the most suitable one among them along with a full demonstration of why we chose it and why it fits perfectly with our requirements, and then we finished with the presentation of the final results of our IoT interface, together with a simple explanation of the warning email system which we have been developed.

4.2. IoT Platform Selection:

We should first make a list of features that our platform must provide to meet our needs. After we have examined our system, we came up with this list:

- Data security.
- Ability to accept data from various devices.
- Simple to use.
- Ability to trigger alarms and send emails and SMSs.
- Process and visualize data from different variables at the same time.

4.2.1. Comparison Between Different IoT Platforms:

	ThingsBoard [30]	AWS IoT Core [31]	Google Cloud IoT Core [32]
communication Protocols	**MQTT, LwM2M, CoAP and HTTP**	**HTTP, MQTT, Websockets**	**HTTP, MQTT**
The key offering and its main functions	✓ **Open-source server-side platform** ✓ **Connectivity** ✓ **Authentication** ✓ **Data Security** ✓ **Hybrid Database support** ✓ **Device management.** ✓ **Rule engine** ✓ **Alarm management**	✓ **Connectivity.** ✓ **Authentication.** ✓ **Rules engine.** ✓ **Development environment.** ✓ **Data Security** ✓ **Alarm management**	✓ **Connectivity.** ✓ **Device management.** ✓ **Development environment.** ✓ **Data Security** ✓ **Alarm management**

Top Use Cases	✓ Smart Farming ✓ Smart Metering ✓ Smart Energy ✓ Fleet management	✓ Smart City. ✓ Smart Home. ✓ Farming.	✓ Energy. ✓ Smart parking. ✓ Transport and logistics.
Price of service	10 $ per month	29 $ per month	20 $ per month
Device management	✓ Devices are basic IoT entities that can produce telemetry data and handle RPC commands. ✓ Sensors, actuators, and switches, for example, also support device management features such as: Device attributes, Device telemetry, Device alarms, Device events, Device relations, and Device audit logs.	✓ Individual and bulk device registrations ✓ individual permission management ✓ Monitoring and troubleshooting, which are unaffected by device type or OS.	✓ For registered devices, Google allows coarse configuration and control of devices.

Data analysis	✓ **Things Board provides an Analytics Platform called Trendz which converts IoT datasets into insights and facilitates decision-making process.** ✓ **It offers the ability to monitor, filter, share, review, Analyze and Predict system behavior.**	✓ **AWS only collects data and provides basic data management (e.g., filtering and transforming it before routing it elsewhere).** ✓ **For the processing side requires the use of the AWS IoT Analytics Service.**	✓ **Offers out-of-the-box tools, including integration with Google Big Data for data analysis and a variety of machine learning services (e.g., Cloud Dataflow, BigQuery, etc.).**
Some of the functionalities	✓ **Dashboard and Data Visualization** ✓ **Rest API and RPC Support** ✓ **Widget developments**	✓ **Integrate bulk connected devices easily.** ✓ **Organize the connected devices in groups.** ✓ **Fleet indexing and search.**	✓ **End-to-end security.** ✓ **Unique global system.** ✓ **Ready-to-use data information.**

Table 4.1: Comparative Table between different IoT platforms

4.2.2. Choosing The Best IoT Platform:

When it comes to IoT platforms There are several solutions available on the internet, however we noticed that the more features we need, the more expensive it becomes. Even though we can use the most well-known platforms for free, such as Google Cloud and AWS cloud but we are limited to a certain level, which forces us to spend more money to get more advanced features to meet our needs, but since this goes against our spending capacity, so what we did was searching for a platform that provides the best options at low cost and even for free, and the best platform that meets these requirements is ThingsBoard.

These are the details of what ThingsBoard platform gives:

- ✓ **Data Security:**

  The ThingsBoard platform offers transport encryption for both MQTT and HTTP(s) protocols, as well as device authentication and credential management, and it allows applying Custom security rules for each communication protocol as well.

- ✓ **Collection and Visualization of Data:**

  Collect and store large amounts of 300 million telemetry data per month [33] in a scalable and error-tolerant way, and the ability to visualize several data from multiple devices and assets at the same time (30 max for both [33]) with built-in support for over 100 custom widgets, as well as numerous configurable and flexible dashboards that can be shared with multiple customers.

- ✓ **IoT Rule Engine:**

  ThingsBoard allows us to create complicated Rule Chains to process data from devices, as well as the ability to trigger different alerts or alarms based on the device's telemetry and the configured rules with complex event processing to transmit these alerts via email or SMS (100 max per month for both [33]).

- ✓ **Quick upload Capacity:**

  ThingsBoard platform provides us with the ability to send data every 0.1 second (10HZ minimum [33]) which is sufficient for our system.

4.3. The Final Results:

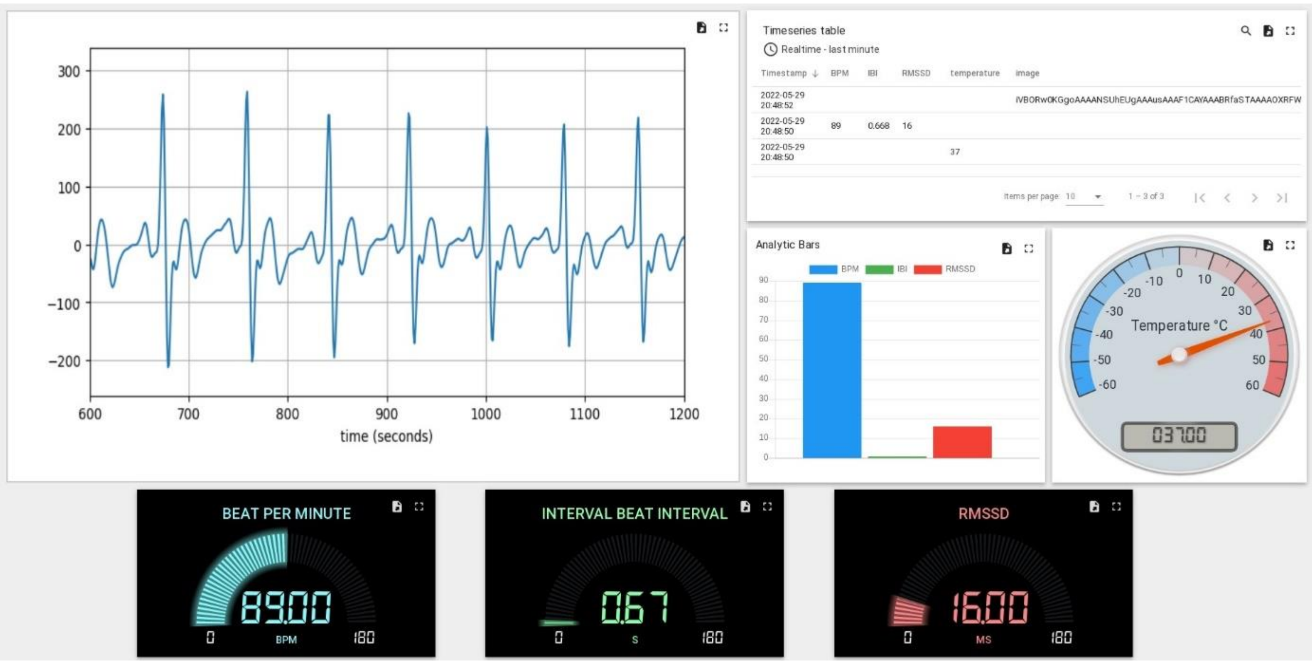

Figure 4.1: The patient's dashboard on the ThingsBoard IoT platform

The picture of the final result of our project shows the Analytic dashboard on the IoT platform that contains all of the necessary data about the specific heart patient. For testing, we placed the electrodes in the designated spots on our bodies, captured the ECG signal along with the core temperature of our bodies, filtered it, and processed it, which resulted in the extraction of valuable parameters with an actual image of the ECG signal itself that in turn was sent to the ThingsBoard platform, to show all the beneficial information that would help the doctor in performing an overall diagnosis on the selected patient and to figure out if there is a problem.

4.4. The Warning Emails:

We added this feature because it is beneficial in emergency situations when patients are in a critical condition, alerting and warning the doctor to take certain precautionary measures to save them by providing first aid in the fastest way possible.

As a result, we have developed a special customizable and configurable system using a framework called Rule engine to send the urgently needed alerts to the specified emails and SMSs, as shown in the following images:

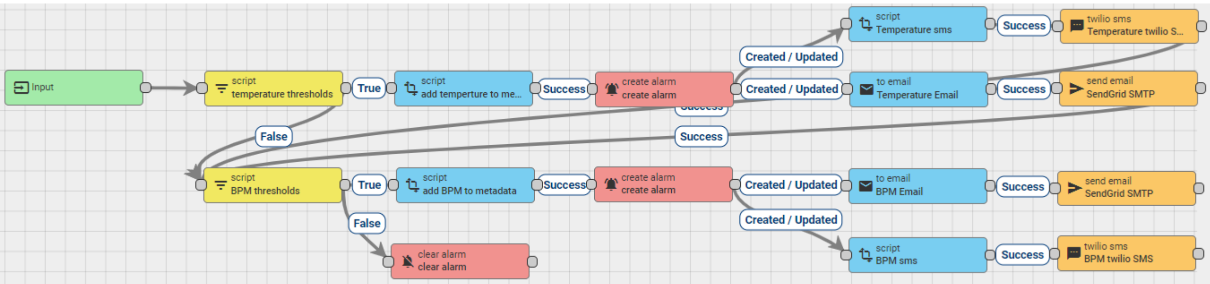

Figure 4.2: The Rule chain alarms for both temperature and BPM parameters

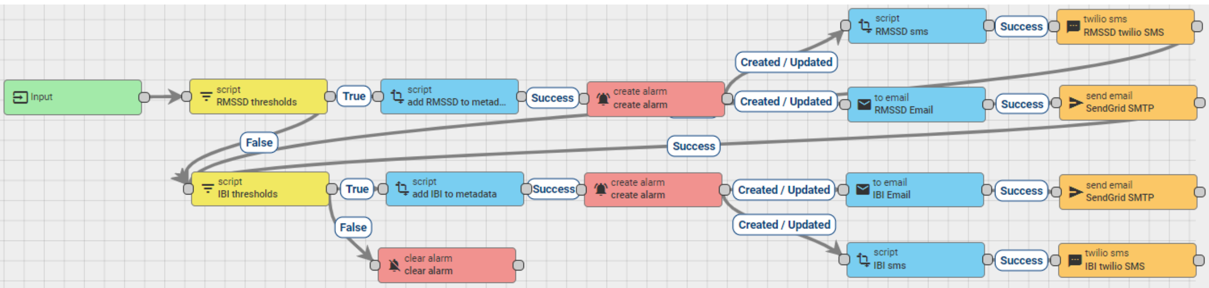

Figure 4.3: The Rule chain alarms for both RMSSD and IBI parameters

For testing, since the parameters of the ECG signal and the core body temperature value do not change easily, we tried to send random values that exceeded and deviated from their expected normal ranges, triggering alarms and successfully sending the warning emails, as shown in the following images:

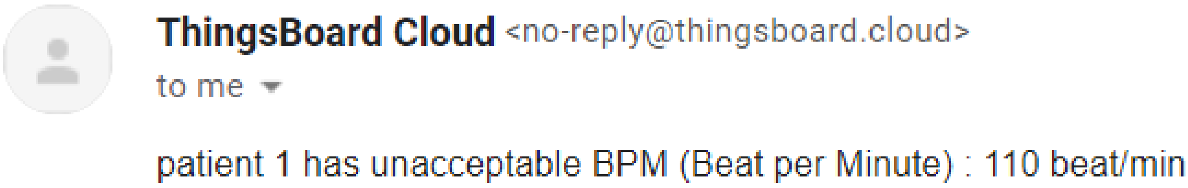

Figure 4.4: A Warning email indicating an abnormal BPM from patient

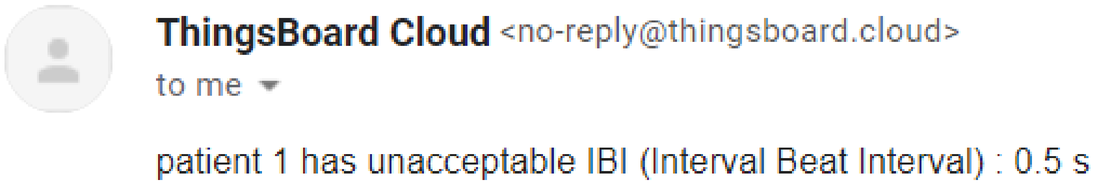

Figure 4.5: A Warning email indicating an abnormal IBI from patient

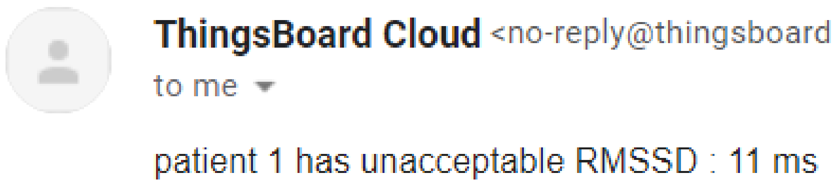

Figure 4.6: A Warning email indicating an abnormal RMSSD from patient

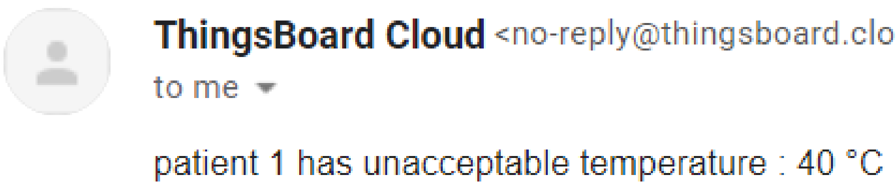

Figure 4.7: A Warning email indicating an abnormal temperature from patient

4.5. The Warning SMSs:

This feature is more effective than the previous one where it assures the doctor will see the messages through his mobile even if he wasn't in his office while being busy treating patients in hospital or walking outside and this is more advantageous over emails since we all know phones are very light and constantly being carried with us wherever we go nowadays. For testing, it was quite similar to emails where we sent random values to trigger alarms and successfully delivered the warning SMSs, as shown in the following image:

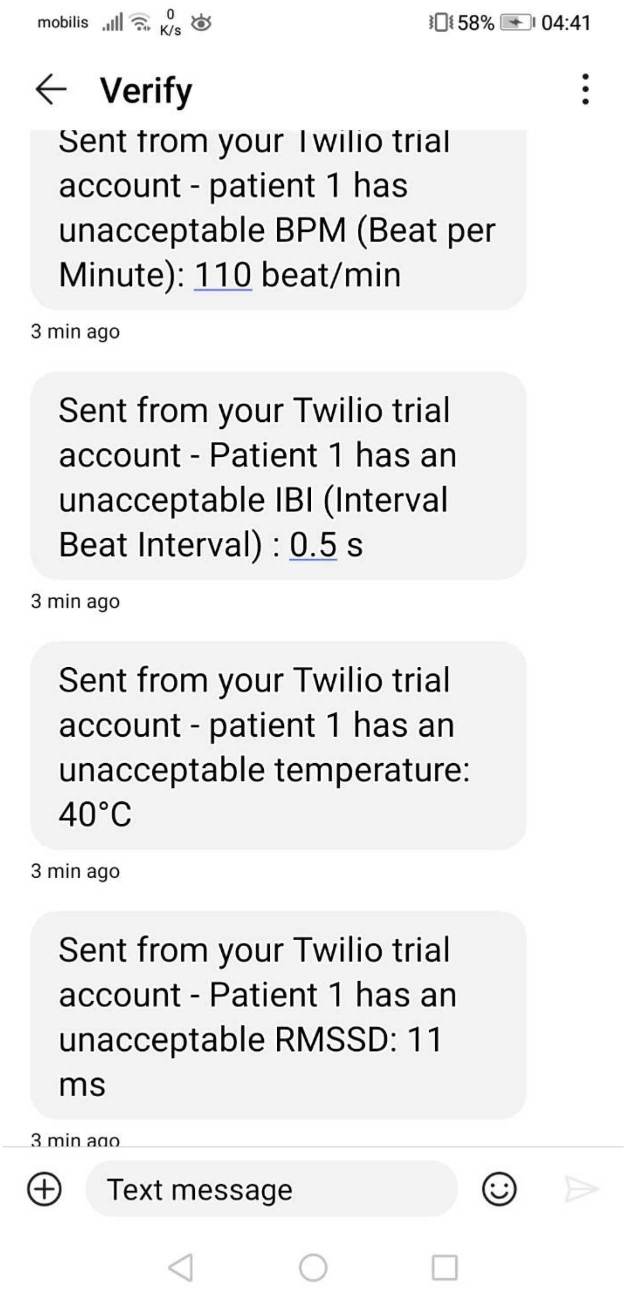

Figure 4.8: A Warning SMSs indicating abnormal parameters from the patient

4.6. Data Transmission Security:

While transferring patients’ data, we discovered that the communication protocol is not secure enough, which gave the ability to intervene between us and the IoT platform, making it possible for hackers, thieves, or even spies to easily corrupt and steal our information. So, we added this Security feature since it is crucial in terms of providing privacy and security to patients’ data, ensuring the doctor receives trustworthy data and preventing hackers or any other malicious attempts from manipulating information or intervening in the midst of the process.

For data Encryption, we used a robust algorithm called AES algorithm (Advanced Encryption Standard), which is a symmetric block cypher algorithm and one of the most secure encryption methods used in most modern encryption algorithms that are considered unbreakable against any "brute force" attacks and even by using a supercomputer, a "brute force" attack would take one billion years to crack the AES 128-bit encryption [34]. In order to decrypt the received encrypted data, we have developed our own interface on ThingsBoard. Even though time was not on our side to integrate it into our final product, we still managed to create a practical and workable solution which can get more great developments in the future.

Figure 4.9: The Reception of the Encrypted data with Time in ThingsBoard dashboard

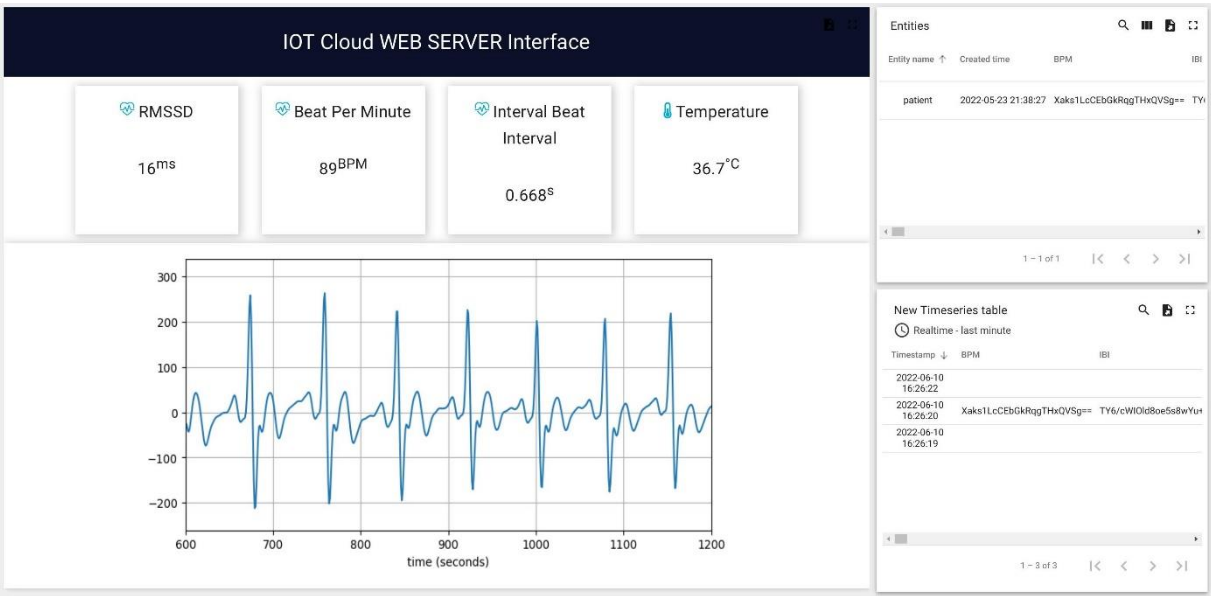

Figure 4.10: Secured data visualization on IOT cloud web server interface in ThingsBoard

4.7. Conclusion:

Finally, we did our hardest in this chapter to construct an appropriate IoT interface for our monitoring system, starting with the IoT platform selection and finishing with the alarm system and data transmission Security, and the end result of our efforts was a reasonable and practical outcome that met our requirements.

General Conclusion:

In this project, we wanted to develop an embedded monitor system for chronic disease patients with an IoT interface that allows the doctors to access it and monitor their health state from any place in the world, this system constantly saves patients' data using medical sensors and processes it to extract vital details about the patient's health and, finally, sends the result to the IoT cloud where it will be organized into an interface making it easier to use and understand, knowing chronic disease patients are in permanent danger, we have integrated software into the IoT platform that warns the doctor when the patient enters an abnormal state.

When it comes to the financial side, the budget of the project is acceptable and compared to what the patients pay for their Regular medical check-ups, it is very reasonable and will save them a lot of money.

While working on our project, we used a lot of knowledge that we learned from our years of study in this domain, and also, acquired a new wealth of information in the health field, which helped us a lot in building a foundation for our project. What we learned was not confined to paper only, we gained a lot of practical experience by attempting to turn our project from a theoretical idea on paper into something workable.

This project gave us the opportunity to learn the following skills:

- How we program and use Raspberry Pi and all of its accessories and functions.
- How to program in Python, and also how to add and use multiple libraries.
- How we transmit data from one device to another and from a device to an IoT platform securely using protocols such as SPI, MQTT, USB.
- How to use Python to manipulate and filter digitized signal data.
- We were able to gain a better understanding of chronic diseases and the patients who suffer from them in our society.
- We learned about electrocardiograms (ECGs), their overall structure, their numerous properties and features, and the critical characteristics that doctors must possess in order to provide an accurate diagnosis.

- We have amassed a significant level of knowledge about the IoT platform and the IoT area in general, as well as how we use the platform’s functions and features, and finally, how we integrate our personal modifications into it.
- How to deal with practical problems, not only theoretical ones, and know how to handle them, as well as develop effective solutions to these issues.

Even with our best efforts, there were limits and obstacles beyond our control, such as a lack of information about IoT software and, most importantly, a shortage of electronic components, which was limited due to a lack of demand for these sorts of components.

Finally, we hope that our efforts will help us achieve our aim of making chronic disease patients’ lives more comfortable, and we hope that our colleagues in our field will focus on this group of individuals in society and assist in the development of new projects to solve their problems in the future.

Future developments:

This project is not limited to certain functions; we intended to add more, but time and other constraints prevented us from doing so. As a result, we left it for future projects, and here is a list of some ideas:

- Add new sensors, such as oximeters, glucometers, and other sensors, to expand the patient data base.
- Developing a smartphone apps to connect to the system.
- Developing a complete independent IoT interface with its own APIs.
- Developing a charting system for data analysis.
- Integrate artificial intelligence and machine learning technologies into the system to detect and classify the disease of patients.

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ANNEX A. Additional Details of MCP3008:

Characteristics:

- 8-channel ADC IC with 10-bit resolution and serial SPI interface communication protocol.
- It has a sampling rate of 200ksps for 5V and 75ksps for 2.7V respectively.
- Operate over a range of 2.7V to 5V.
- It has a standby current of 5 nA (2 µA) and typical active currents of 320 µA.
- It has Analog inputs programmable as single-ended or pseudo-differential pairs.
- It is based on low power CMOS technology.
- The industrial temperature range for this chip is -40°C to +85°C.

Pinout Configuration:

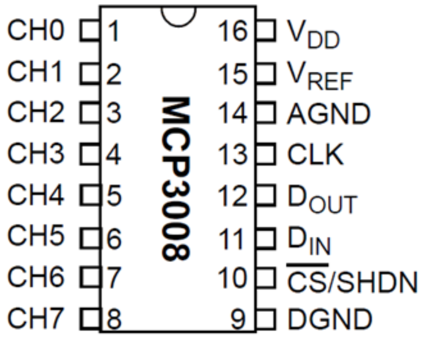

Figure: The MCP3008 A/D converter [18]

- **CH0 to CH7:** These are the analog inputs for channel 0 to channel 7 which can be configured as four single-ended inputs or two pseudo-differential pairs.
- **DGND:** The digital ground pin which is linked internally to the digital circuitry of chip.
- **CS`/SHDN:** It is a Chip Select pin used to initiate communication with the device.
- **Din:** This is the input pin for serial data.
- **Dout:** It is the serial data output used for SPI communication.
- **CLK:** It is a serial clock signal used to initiate a conversion and sends each bit out as conversion takes place
- **AGND:** It is the analog ground pin which is connected internally with analog circuitry. It is connected to the reference voltage.
- **VREF:** It is connected to the reference voltage which is used to determine the range of analog voltage.
- **VDD:** It is the connection for applying a positive voltage to the circuit.

ANNEX B. Additional Details of LM35:

Characteristics:

- Calibrated Directly in Celsius (Centigrade)
- Low cost Due to Wafer-Level Trimming and small size
- It is simple to integrate
- Linear + 10.0 mV/°C Scale Factor (Sensitivity)
- 0.5°C Ensured Accuracy (at 25°C)
- Temperature full ranges from −55 to 125°Celsius
- Voltage Range: 4 V to 30 V (recommended voltage up to 20V)
- Supply Current: Less than 60 µA Current Drain
- Max output voltage: 1.5 volt
- Suitable for Remote Applications
- Low Self-Heating, 0.08°C in Still Air

Pinout Configuration:

- **VCC:** It can be used to power the sensor, which is usually done with 5V.
- **Analog Output:** There will be an increase of 10mV for raise of every 1°C. Can range from -1V(-55°C) to 6V(150°C).
- **GND:** it serves as the Ground of the circuit.

ANNEX C. Additional Details of Ad8232:

Characteristics:

- Fully integrated single-lead ECG front end Low supply current: 170 µA (typical).
- Operating voltage: 2.5 to 3.3V (DC).
- Common-mode rejection ratio: 80 dB at 60 Hz.
- 8 kV electrostatic discharge for the human body model.
- Two or three-electrode configurations.
- It has an analog output signal which is easy to read with microcontrollers.
- Conventional ECGs are quite noisy, this module functions as an operational amplifier, extracting a clear signal during the PR and QT intervals of the heartbeat.
- Detect which lead is connected or disconnected.
- It features a shutdown pin that may be used to switch to energy-saving mode.
- Internal RFI filter and 3-pole adjustable low-pass filter with adjustable gain Leads off detection: ac or dc options.

Pinout Configuration:

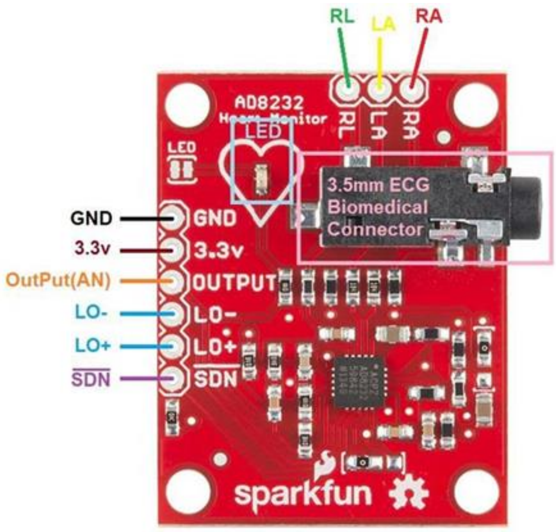

Figure: AD8232 ECG module Pinout Diagram

- **GND:** it serves as a Power Supply Ground.
- **3.3v:** used as a Power Supply for the sensor (3.3v).
- **Output (ADC):** Operational Amplifier Output. The fully conditioned heart rate signal is present at this output. OUT can be connected to the input of an ADC.
- **LO-:** Leads Off Comparator Output (high only if −IN electrode is disconnected).
- **LO+:** Leads Off Comparator Output (high only if +IN electrode is disconnected).

- **SDN Pin:** Shutdown Control Input, drive it low to enter the low power shutdown mode.
- **RA (Right Arm):** RED Biomedical electrode pad RA (the negative input (-IN)).
- **LA (Left Arm):** YELLOW Biomedical electrode pad LA (the positive input (+IN)).
- **RL (Right Leg):** GREEN Biomedical electrode pad RL (input).