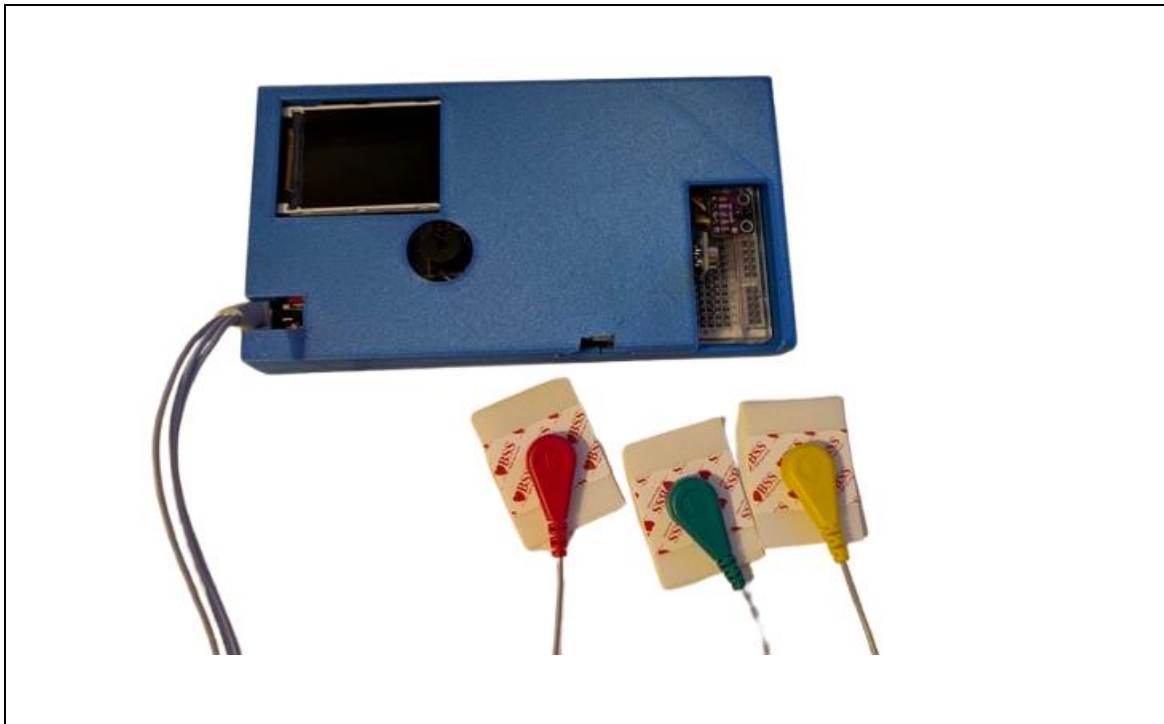


SCHOOL OF ENGINEERING
DEPARTMENT OF COMPUTER ENGINEERING
AND ELECTRONIC SYSTEMS

THESIS

"Biometric Health Data Measurement with Live Broadcast"



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"Always creating"

Prologue

Human health will always be an issue that can be continuously improved over time with the help of technology and new discoveries. So with this thesis I would like to create a 'Home Health Monitoring Platform' with which the most basic health measurements will be recorded, as well as their live transmission.

Summary

This thesis examines the development of a "Home Health Monitoring Database", which aims to continuously and easily record basic biometric data at home. Initially, a brief historical review is made of the way in which people recorded their health in the past and the methods used. Subsequently, the individual technological systems and sensors used in this database are analyzed, as well as the design and implementation process. The programming of the system, its mode of operation and the possibilities for live data transmission are also presented. Finally, the conclusions of the research are presented, as well as suggestions for improvements and future extensions of the system.

« Biometric Health Data Measurement with Live Streaming»

"Aslanidis Konstantinos"

Abstract

This thesis examines the development of a "Home Health Monitoring Base," aimed at continuous and convenient recording of essential biometric data at home. Initially, it provides a brief historical overview of how people used to record their health in the past and the methods available at the time. Following this, the individual technological systems and sensors used in the base are analyzed, along with the design and implementation process. Additionally, with programming of the system, its mode of operation and the possibilities for live data transmission are also presented. Finally, the conclusions of the research are presented, as well as suggestions for improvements and future extensions of the system.

Thanks

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Abbreviations

P.E.	Diploma Thesis
DIPAE	International Hellenic University
ECG	Electrocardiogram
SpO ₂	Blood Oxygen Content (Saturation of Peripheral Oxygen)
HR	Heart Rate
COPD	Chronic Obstructive Pulmonary Disease
REM	rapid eye movement or otherwise: rapid eye movement sleep
GUI	Graphical User Interface
IoT	Internet of Things
TLS	Transport Layer Security
GSM	Global System for Mobile Communications (Global System for Mobile Communications)
IFTTT	If This Then That
Cloud Computing	
PWM	Pulse Width Modulation
GPIO	General Purpose Input/Output
ADC	Analog-to-Digital Converter
DAC	Digital-to-Analog Converter
SPI	Serial Peripheral Interface
I2C	Inter-Integrated Circuit Interface
I2S	Integrated Audio Interface (Inter-IC Sound)
UART	Universal Asynchronous Receiver/Transmitter Receiver/Transmitter)
IR	Infrared Radiation

Chapter 1: Historical Review and Evolution of Health Recording Methods

1.0 Import

The first chapter of the thesis will present the historical review and evolution of methods for recording vital signs, such as heart rate, temperature and blood oxygen level. Subsequently, the importance of these parameters in the diagnosis and assessment of the clinical condition of patients will be analyzed. Also, an overview of modern monitoring systems such as smart-watches and wearable sensors will be provided, as well as the role of artificial intelligence, focusing on technological developments and their applications in medicine. Finally, the main conclusions regarding the contribution of new technologies to improving healthcare will be presented.

1.0.1 Health Record History

The recording of vital signs, such as heart rate, temperature, and blood oxygen, has evolved from simple observations to modern precision technologies. In ancient times, Hippocrates relied on the observation of the pulse, while in China they used pulsology techniques. The discovery of blood circulation by William Harvey (17th century) and the development of the thermometer and pulsograph in the 19th century laid the foundation for the scientific monitoring of vital signs. The electrocardiogram (ECG), introduced by Willem Einthoven in 1903, revolutionized the diagnosis of heart disease. In the 1970s, the development of the pulse oximeter offered a new possibility of monitoring oxygen saturation in the blood. Today, wearable devices and "smart" sensors allow for the continuous recording of vital data, improving prevention and treatment.[1][6]

1.0.2 Importance of Vital Signs

Vital signs are critical indicators of the body's normal functioning. Heart rate reveals abnormalities such as tachycardia or bradycardia. Blood oxygen is related to respiratory function, while temperature is a key indicator of infection or inflammation. Early detection of abnormalities in vital signs can prevent serious complications, making their measurements essential for the diagnosis and monitoring of patients, especially in critical situations.[2]

1.0.3 Modern Health Monitoring

The rapid development of technology in recent decades has led to a real revolution in the field of health monitoring. Today, so-called "smart" devices have become indispensable tools for both doctors and patients, offering the possibility of continuous recording and analysis of vital signs. Wearable devices, such as smartwatches and sports activity bands, have become familiar tools in the everyday lives of many people. These devices are no longer limited to simply recording steps or calories, but have evolved into powerful health monitoring tools. For example, modern smart-watches can accurately measure heart rate, blood oxygen level (SpO₂) and even produce electrocardiograms (ECG). These functions, which previously required specialized medical equipment, are now accessible to everyone through a device we wear on our wrist.



Figure 1.1 Apple Watch ECG

Furthermore, the advent of the Internet of Medical Things (IoMT) has further enhanced the capabilities of modern medicine. Through IoMT, devices can communicate with each other and transmit data in real time to doctors or health platforms. For example, a patient with diabetes can use a continuous glucose monitor (CGM) that automatically sends their readings to an app on their smartphone, while also alerting the doctor in case of dangerous fluctuations. Another important advance is the application of artificial intelligence (AI) algorithms to medical data analysis. These algorithms can identify patterns or anomalies that may escape human perception, helping in the early diagnosis of serious conditions such as cardiac arrhythmias or respiratory dysfunctions. For example, some devices use AI to predict potential episodes of hyperglycemia or hypoglycemia in patients with diabetes, based on historical data and current measurements. Undoubted advances in this field, however, are accompanied by practical and technical difficulties, issues such as measurement accuracy, data protection and the ethical use of artificial intelligence remain critical points that require continuous attention and improvement. For example, while many devices offer high accuracy, there are cases where the results can be affected by external factors, such as the user's movement or skin color. Overall, modern technology has opened up new horizons in the prevention, diagnosis and management of diseases. However, its proper use depends on the collaboration between technologists, doctors and patients to ensure that these innovations benefit the entire population. Below is an analysis of smartwatches and wearable devices and the role that artificial intelligence plays.[3]

Smartwatches and Wearables

Modern smartwatches (e.g. Apple Watch, Samsung Galaxy Watch, Fitbit Sense) have transformed the way we monitor health, offering:

- Continuous heart rate monitoring with optical sensors (PPG), capable of detecting tachycardia, bradycardia or atrial fibrillation (AFib).
- Real-time electrocardiogram (ECG) (Apple Watch Series 4+, Fitbit Sense 2, Samsung Galaxy Watch), with storage and clinical analysis capabilities.
- SpO₂ (oxygen saturation) measurement, particularly important for patients with COPD or COVID-19.
- Sleep monitoring (REM, deep sleep) with motion and heart rate sensors.

Clinical Application Example: A Stanford Medicine study (2021) showed that the Apple Watch can detect AFib with ~84% accuracy, while its use in combination with AI improved early diagnosis of heart attacks.[4]

Role of Artificial Intelligence (AI)

AI algorithms enhance the functionality of wearables by:

- Predictive analysis: E.g., prediction of hyperglycemia in diabetics (combining data from CGM and smartwatch).
- Anomaly detection: AIs like AliveCor KardiaAI analyze ECGs for signs of heart attacks.
- Personalized recommendations: Apps (e.g. Fitbit Premium) use machine learning to recommend exercise or nutrition programs.[5]

1.1 Epilogue

Vital signs recording has evolved from simple observations to advanced, highly accurate systems, enhancing diagnosis and health monitoring. Modern technologies, through smart devices and artificial intelligence algorithms, allow for early detection of problems and improved patient management. As technology continues to develop, the possibilities for prevention and treatment are expected to expand more and more, contributing substantially to the overall improvement of medical care and quality of life.

Chapter 2: Vital Signs: Cardiac Function, Oxygenation and Thermoregulation

2.1 Import

Monitoring of basic vital signs, such as electrocardiogram (ECG), pulse oximetry, and body temperature, is a fundamental element of clinical practice. These tools provide critical information for the diagnosis, monitoring, and management of various pathological conditions. In this section, we will focus on electrocardiography (ECG), one of the most important techniques for assessing cardiac function. ECG is not only a diagnostic tool, but also a method for monitoring the effectiveness of treatments and predicting potential cardiac events [6]. Finally, pulse oximetry and body temperature will be developed.

2.2 Electrocardiography (ECG)

Electrocardiography is a non-invasive method that records the electrical activity of the heart. The electrocardiogram (ECG) graphically depicts the electrical changes that occur during depolarization (depolarization) and repolarization of the heart muscle. These changes are recorded through electrodes placed at specific points on the body (limbs and chest) and reflect the function of the heart. The ECG allows the detection of heart rhythm disorders (arrhythmias), ischemic lesions (e.g. myocardial infarction) and other heart diseases [7].

2.2.1 Cardiac Anatomy, Electrical Activity and Cardiac Cycle

The heart is a muscular organ that functions as a pump, ensuring the circulation of blood throughout the body. It consists of four chambers: two atria (left and right) and two ventricles (left and right). The atria receive blood from the veins, while the ventricles pump it to the arteries. Each cardiac cycle consists of the contraction (contraction) and dilation (relaxation) of the myocardium, ensuring the uninterrupted supply of tissues with oxygen and nutrients [8].

Η Φυσιολογική καρδιά

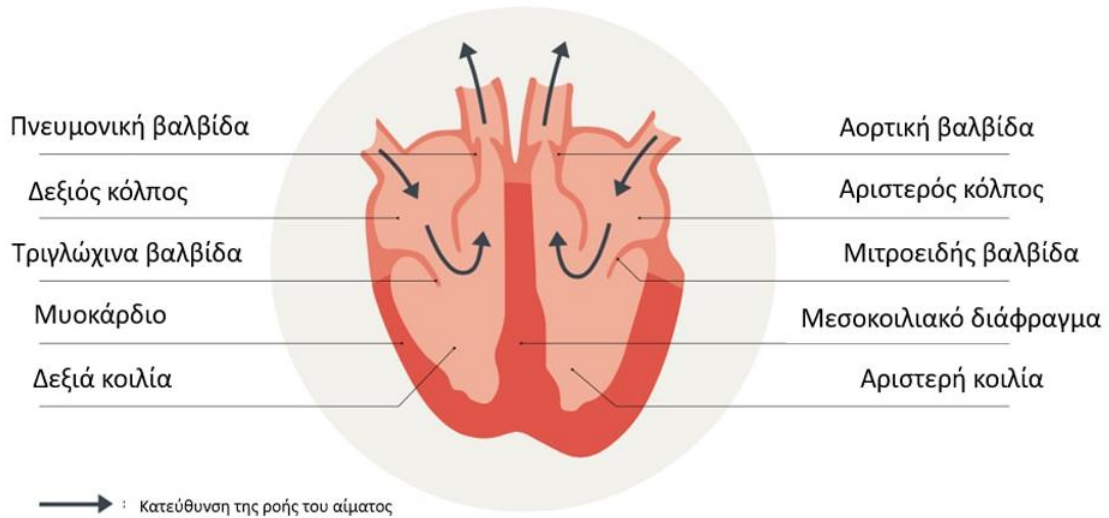


Figure 2.1 Cardiac Anatomy

The Circulations of the Blood:

The heart serves two main circulations:

- Pulmonary circulation: Deoxygenated blood returns from the body to the right atrium and is directed through the tricuspid valve into the right ventricle. From there, it is transported to the lungs via the pulmonary artery, where it is enriched with oxygen. Oxygenated blood returns to the left atrium via the pulmonary veins [9].
- Systemic circulation: Oxygenated blood from the left atrium passes through the mitral valve into the left ventricle. From there, it is pumped into the aorta and distributed to all tissues of the body. Deoxygenated blood returns to the right side of the heart through the veins [9].

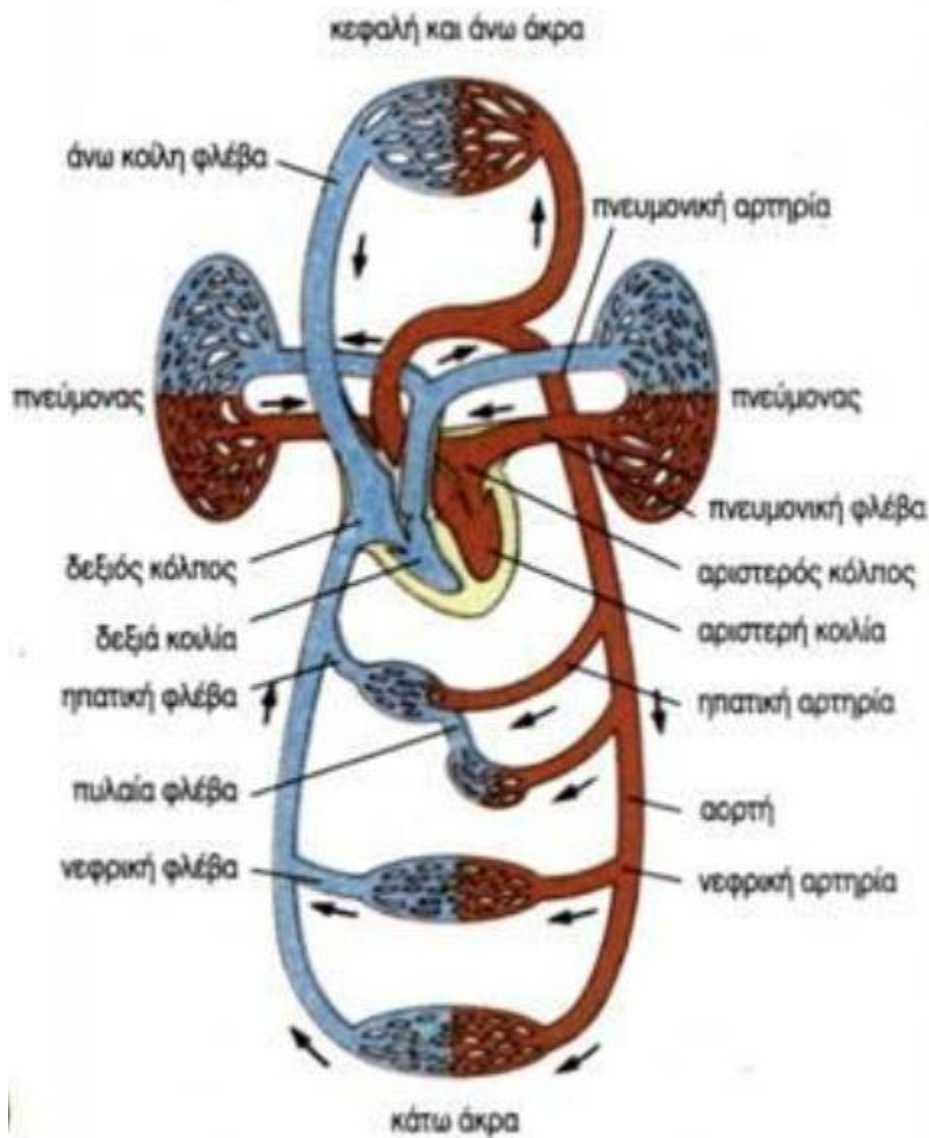


Figure 2.2 Cardiovascular System

The Electrical System of the Heart:

The heart has a specialized electrical system, known as the conduction system, which ensures the rhythmic and synchronized contraction of the heart muscles. The electrical impulse originates from the sinoatrial node (SA node), which is located in the right atrium and acts as the heart's natural pacemaker. The sinus node automatically generates electrical impulses at a rate of 60-100 beats per minute at rest [10].

The electrical signal travels through the atria, causing them to contract and pump blood into the ventricles. The signal then reaches the atrioventricular node (AV node), where it slows down for about 0.12–0.20 seconds. This delay allows the ventricles to fill with blood before they contract. The signal continues through the bundle of His and branches into the right and left bundle branches, reaching the Purkinje fibers, which cause the ventricles to contract and eject blood into the arteries [10].

The Electrocardiogram (ECG) and its Discovery

The first step in understanding cardiac arrhythmias was taken with the discovery of the electrocardiogram (ECG). The Dutch physician and physiologist Willem Einthoven (1860-1927) recognized that the electrical activity of the heart propagates to the surface of the skin. Using a special galvanometer in 1901, he recorded this activity, creating the first ECG. For his discovery, he was awarded the Nobel Prize in Medicine in 1924[6]. Today, the electrocardiogram is one of the most important tools for diagnosing heart disease[11]. The electrocardiograph has electrodes that are placed at specific points on the body (limbs and chest) and record the electrical activity of the heart through 12 leads. Each ECG deviation reflects a specific phase of the cardiac cycle, allowing the detection of even minor abnormalities in the structure or function of the heart. The electrical activity of the heart begins in the sinus node, located in the right atrium. The electrical discharges of this pacemaker cause depolarization, which spreads in the myocardium from the right to the left atrium. The transmission of electrical activity from the atria to the ventricles occurs exclusively through the atrioventricular node. From there, the electrical impulse passes to the bundle of His, which branches into left and right branches, with the left being subdivided into anterior and posterior bundles. Transmission continues to the Purkinje fibers, causing the ventricles to contract.[10]

The ECG Abductions

The electrocardiogram records cardiac activity through 12 leads:

- **Bipolar leads:**I, II, III (coronal level).
- **Unipolar limb leads:**aVR, aVL, aVF (enhanced, coronary level).
- **Unipolar precordial leads:**V1-V6 (horizontal plane).

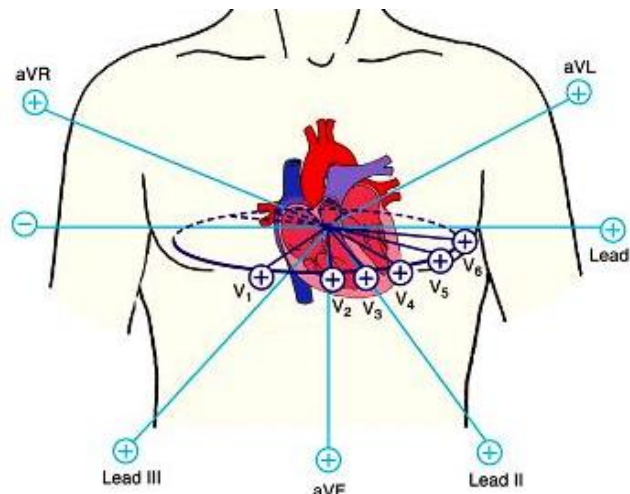


Figure 2.3 ECG leads

Basic Elements of a Normal ECG

1. **P-wave:** Represents the depolarization (depolarization) of the atria. Its duration is usually 0.08-0.12 seconds [7].
2. **PR interval:** It represents the time it takes for the electrical impulse to propagate from the atria to the ventricles. Its normal duration is 0.12-0.20 seconds [7].
3. **QRS complex:** Represents the depolarization of the ventricles. Its duration is usually less than 0.12 seconds [7].
4. **ST Department:** Represents the beginning of ventricular repolarization. Abnormalities in the ST segment (e.g., elevation or depression) may indicate ischemia or infarction [7].
5. **T wave:** Represents ventricular repolarization. Abnormal T waves may be associated with electrolyte disturbances or ischemia [7].
6. **U-wave:** A small deviation that occurs after the T wave, which has not been fully explained but may be related to repolarization of the deeper layers of the myocardium [7].

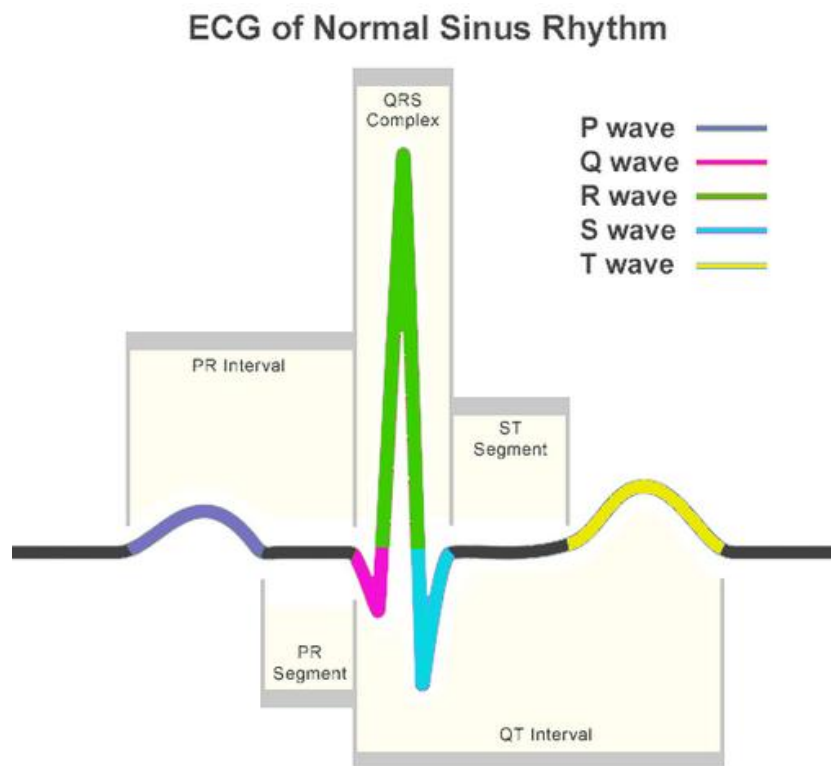


Figure 2.4 ECG Explanation

ECG analysis

To diagnose cardiac abnormalities via ECG, a methodical approach is required:

1. **Heart rate calculation:**The rate is calculated by counting the large squares between two consecutive R peaks (RR interval). For example, if the RR interval is 4 squares, the heart rate is 75 beats per minute [7].
 - 1 square = 300 beats per minute
 - 2 squares = 150 beats per minute
 - 3 squares = 100 beats per minute
 - 4 squares = 75 beats per minute
 - 5 squares = 60 beats per minute
 - 6 squares = 50 beats per minute
2. **Rhythm determination:**The normal rhythm is sinus rhythm, with regular and regular P waves. Abnormal rhythms (e.g. atrial fibrillation) are characterized by irregular P waves and RR intervals [7].
3. **Assessment of electrical activity:**The axis of the heart is calculated from leads I, II, and III. An abnormal axis may indicate ventricular hypertrophy or other pathological conditions [7].
4. **Diagnosis of arrhythmias and ischemic lesions:**ECG analysis includes observation of the P, QRS, and ST waves for abnormalities that may indicate arrhythmias, ischemia, or infarction [7].

2.2.2 Heart Rhythm Regulation and Disorders

Heart rate is one of the most important physiological phenomena of the human body, as it determines the ability of the heart to pump blood and ensure the supply of oxygen and nutrients to all cells of the body. The regulation of heart rate is a complex process involving electrical and chemical mechanisms, while its disorders can lead to serious clinical conditions. In this section, we will examine the various

forms of its disorders (arrhythmias), their causes, symptoms, diagnostic methods and therapeutic approaches.

Heart Rhythm Disorders (Arrhythmias)

Arrhythmias are abnormalities in the heart rhythm that can manifest as tachycardia (acceleration of the heart rate), bradycardia (slowing of the heart rate), or irregular rhythms. These disorders can result from abnormalities in the generation or propagation of electrical impulses in the heart and can have serious clinical consequences.

- **Tachycardia**

Tachycardias are characterized by a heart rate of more than 100 beats per minute at rest. They can result from overactivity of the SA node or from abnormal electrical pathways in the heart. Examples of tachycardias include:

- **Atrial Fibrillation** Atrial fibrillation: A common form of arrhythmia in which the atria contract rapidly and reflexively, leading to an irregular and rapid heart rate. Atrial fibrillation increases the risk of stroke due to the formation of blood clots in the atria [12].
- **Atrial Flutter**: Similar to atrial fibrillation, but with a more organized electrical pattern. The atria contract at a rate of 250-350 beats per minute [12].

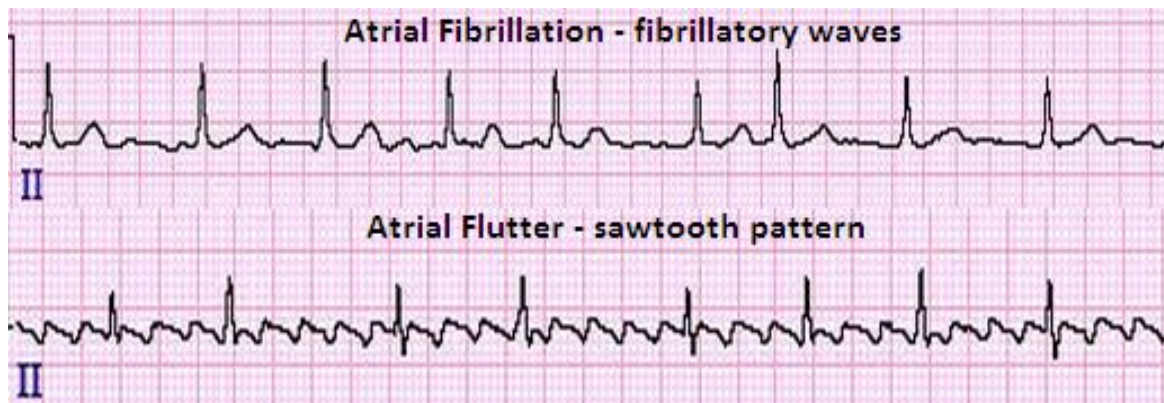


Figure 2.5 Atrial Fibrillation & Atrial Fibrillation ECG

- **Ventricular Tachycardia**: A dangerous condition in which the ventricles contract too rapidly, reducing the effectiveness of the heart's pumping function. It can lead to loss of consciousness or even sudden cardiac death [12].

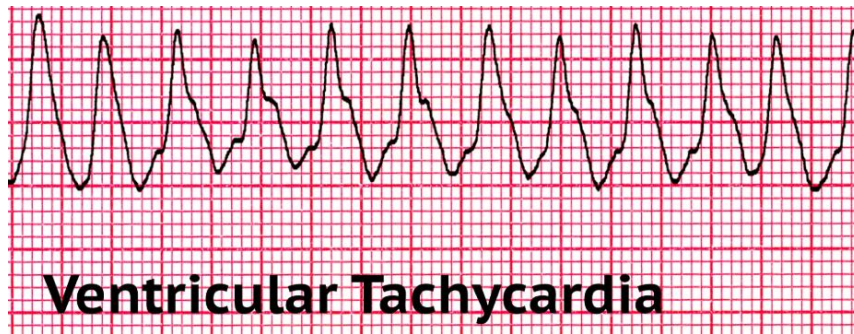


Figure 2.6 Ventricular Tachycardia ECG

- **Bradycardia**

Bradycardias are characterized by a heart rate below 60 beats per minute. They can be due to SA node dysfunction or problems with the propagation of electrical impulses. Examples of bradycardias include:

- **Heart Block:** A condition where electrical impulses do not propagate properly from the atria to the ventricles, leading to a slowing of the heart rate [13].
- **SA Node Disease (Sick Sinus Syndrome):** A disorder where the SA node does not produce electrical impulses at the correct rate, leading to alternating tachycardia and bradycardia [13].

- **Abnormal Rhythms**

Abnormal rhythms can result from abnormalities in the generation or propagation of electrical impulses. Examples include:

- **Ventricular Fibrillation:** A dangerous condition in which the ventricles contract reflexively and uncoordinated, leading to loss of the heart's pumping function. Without immediate intervention (e.g., use of a defibrillator), this condition is fatal [14].

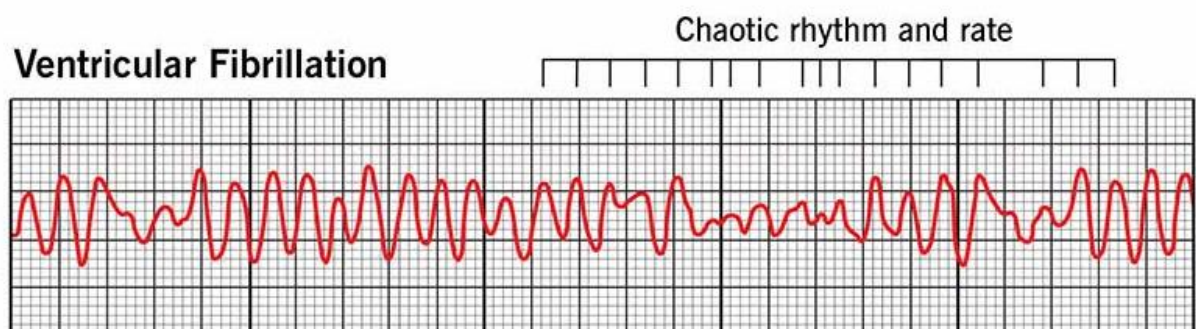


Figure 2.7 Ventricular Fibrillation ECG

- **Premature Ventricular Contractions (PVCs):** Extra contractions of the ventricles that can cause a feeling of "skipping" the heartbeat [14].

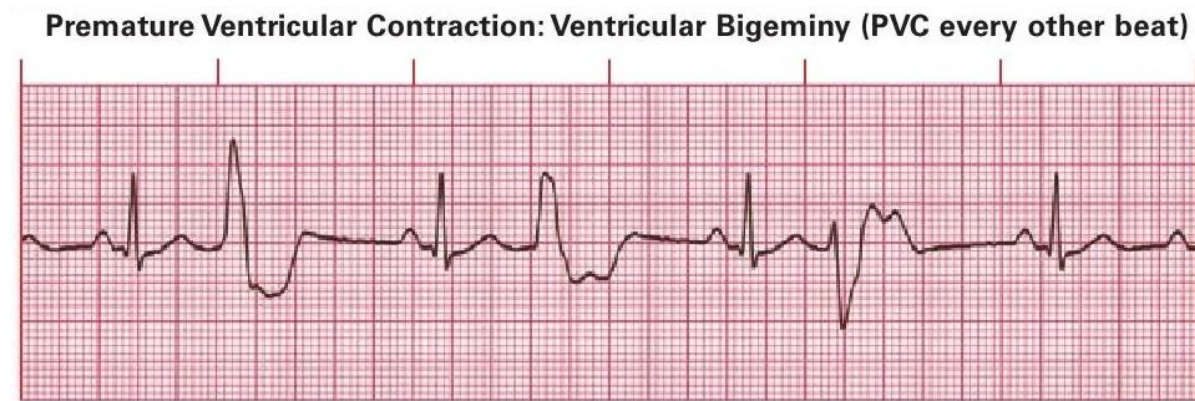


Figure 2.8 Premature Ventricular Contraction ECG

Causes and Risk Factors

Arrhythmias can result from many factors, including:

- **Heart Diseases:** Coronary artery disease, heart failure, cardiomyopathies and valvular diseases [14].
- **Electrolyte Abnormalities:** Disturbances in potassium, sodium or calcium levels [14].
- **Medicines:** Some medications can cause arrhythmias as a side effect [14].
- **Genetic Factors:** Some arrhythmias, such as long-QT syndrome, have a genetic basis [14].
- **Other Reasoning Elements:** Hypertension, thyroid dysfunction, alcohol or caffeine consumption [14].

Diagnostic Methods

The diagnosis of arrhythmias is based on clinical tests, such as:

- **Electrocardiogram (ECG):** The main method for recording heart rate [14].
- **Holter Monitor:** A portable device that records the ECG for 24-48 hours [14].
- **Conductive Study (Electrophysiology Study):** An invasive method for detecting the source of arrhythmias [14].

Therapeutic Approaches

Treatment options include:

- **Pharmaceutical Education:** Antiarrhythmic drugs, such as beta-blockers or antiplatelet agents [14].
- **Catheterization:** Ablation of abnormal electrical activity by catheterization [14].
- **Defibrillators:** Devices that are implanted to treat dangerous arrhythmias [14].
- **Surgical Intervention:** In severe cases, such as Maze surgery [14].

2.3 Oxygen Oximeter

An oxygen oximeter, also known as a pulse oximeter, is a device used to measure blood oxygen saturation (SpO_2) and heart rate. This device is non-invasive, easy to use, and is one of the most essential monitoring tools in clinical settings, such as hospitals, intensive care units, and even for home use.

Principle of Operation of the Oximeter

The oximeter is based on optical plethysmography, a technique that exploits the properties of hemoglobin to absorb light differently depending on its oxygenation state. Hemoglobin exists in two forms:

1. **Oxyhemoglobin (HbO_2):** Absorbs more infrared light (940 nm).
2. **Deoxyhemoglobin (Hb):** Absorbs more red light (660 nm).

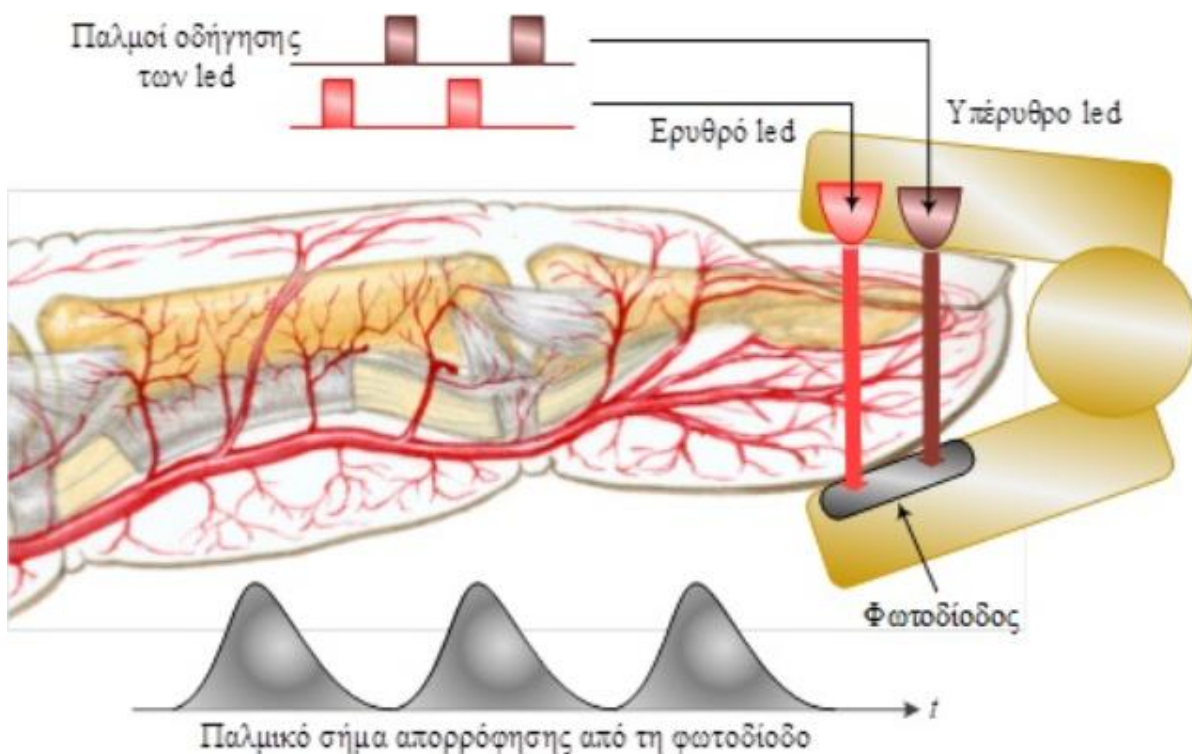


Figure 2.9 Principle of Operation of the Pulse Oximeter

The oximeter uses two light-emitting diodes (LEDs) that emit light at these wavelengths. The light passes through the finger (or fingertip) and hits a photodiode, which measures the amount of light absorbed by your blood. Based on the absorption of the light, the oximeter calculates your SpO_2 and heart rate. [15]

Oxygen Saturation (SpO_2)

Oxygen saturation (SpO_2) is the ratio of oxyhemoglobin to total hemoglobin in the blood and is expressed as a percentage. The normal value of SpO_2 in healthy adults ranges between 95% and 100%. Values below 90% may indicate hypoxia (lack of oxygen) and require medical intervention. [16]

Heart Rate

The oximeter can also measure heart rate by analyzing pulsatile changes in light absorption. Each heartbeat causes a small increase in blood volume in the blood vessels, which leads to changes in light absorption. By measuring the frequency of these changes, the oximeter calculates the heart rate in beats per minute (bpm). [17]

2.4 Body Temperature:

Body temperature is another key vital parameter that reflects the normal functioning of the body. The normal temperature of a healthy adult ranges between 36.5°C and 37.5°C. Temperature regulation is carried out by the hypothalamus of the brain, which maintains temperature within a narrow range to ensure the smooth functioning of metabolic processes. [18]

Temperature Monitoring

Temperature monitoring is important for detecting conditions such as fever (high temperature) or hypothermia (low temperature). Fever may indicate infection, while hypothermia may be associated with hypothermic conditions or metabolic disorders.[19]

2.5 Epilogue

In this chapter, the basic principles and functions of vital signs were examined, with an emphasis on cardiac function, blood oxygenation, and body thermoregulation. Understanding these parameters is critical for monitoring health and detecting pathological conditions. Monitoring vital signs, such as heart rate, oxygen saturation, and body temperature, is a fundamental element of modern medicine. These parameters provide valuable information about the functioning of the body and help in the rapid detection and treatment of pathological conditions. Understanding the basic principles underlying these functions is essential for effective health monitoring and management.

Chapter 3: The Internet of Medical Things (IoMT)

3.1 Introduction

The Internet of Medical Things (IoMT) is a rapidly growing branch of digital healthcare, leveraging the capabilities of the Internet of Things (IoT) to collect, transmit, and analyze medical data in real time[20]. Through interconnected medical devices and sensors, IoMT enables personalized health monitoring, facilitating prevention and early intervention. The COVID-19 pandemic has catalyzed the need for remote monitoring solutions, highlighting IoMT as a critical tool in the global response strategy [22]. In

the context of this thesis, IoMT is the theoretical basis for the implementation of a home health monitoring system, which utilizes biometric data sensors and the Blynk platform, offering an affordable and scalable application example of the technology.

3.2 Architecture and Scope of Applications

The operation of an IoMT system is based on a three-layer architecture: the device, the network and the cloud [20]. Initially, the device collects data from the user. Then, through wireless protocols such as Wi-Fi, Bluetooth or 5G, the data is transferred to remote servers, where it is either analyzed using artificial intelligence algorithms or displayed directly to the doctor or patient [21]. This architecture is implemented in this work with the ESP32 microcontroller, which acts as an intermediate link between the sensors and the Blynk Cloud, allowing the interactive visualization of vital measurements.

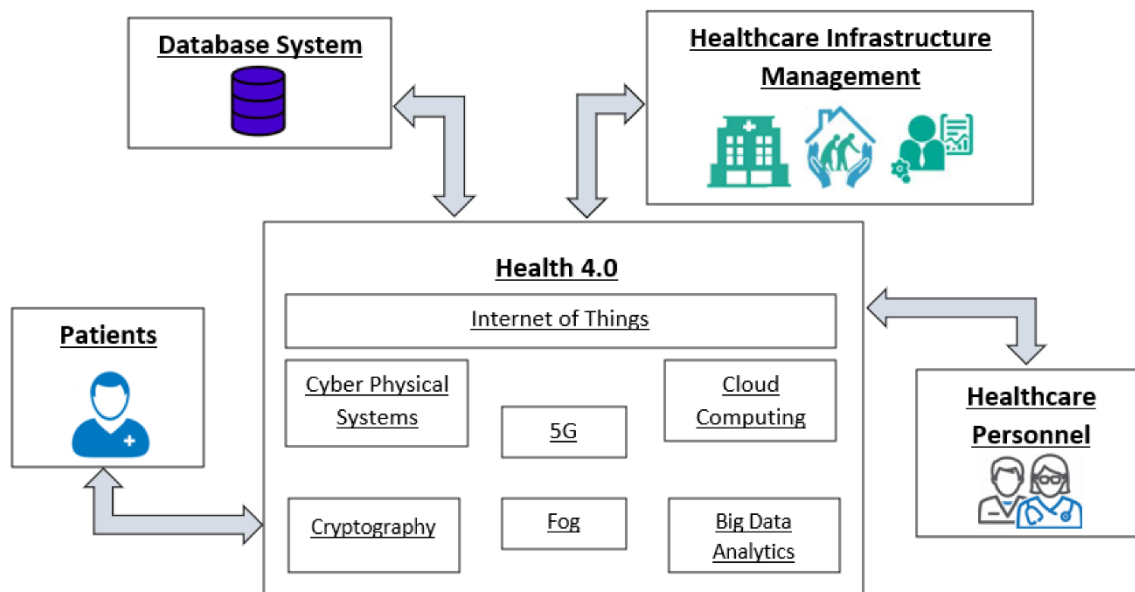


Figure 3.1 Healthcare IoT Architecture

The applications of IoMT are multidimensional. At the individual level, remote monitoring allows patients to stay in touch with their clinical picture from home. At the same time, telemedicine leverages technology for the remote provision of care, reducing the need for physical presence in medical facilities [30]. Furthermore, at the infrastructure level, “smart” hospitals rely on interoperability between diagnostic machines and electronic medical records, creating a coherent digital ecosystem. This work focuses on the category of home monitoring, aiming to develop an affordable and adaptable solution, suitable for elderly or vulnerable individuals without technical training.

3.3 Challenges and Technological Solutions

The implementation of IoMT, despite its advantages, is accompanied by technological challenges that require careful consideration [21]. A key challenge concerns the reliability of measurements. Factors such as user movement or external environmental noise may affect the accuracy of sensors. To address this issue, the system of this work applies filtering and signal quality assessment techniques, ensuring the validity of the data.

An equally critical issue is ensuring the privacy and security of sensitive medical information. The use of encryption protocols (such as TLS in Blynk Cloud), combined with the ability to host the system on

a local server, offers flexibility and protection, especially in environments with strict regulatory compliance requirements [23].

Finally, energy efficiency is a critical factor, especially for portable or standalone devices. The ESP32 microcontroller supports power-saving features such as Deep Sleep and Ultra Low Power mode, while the optimal sampling frequency ensures a balance between accuracy and battery life [26].

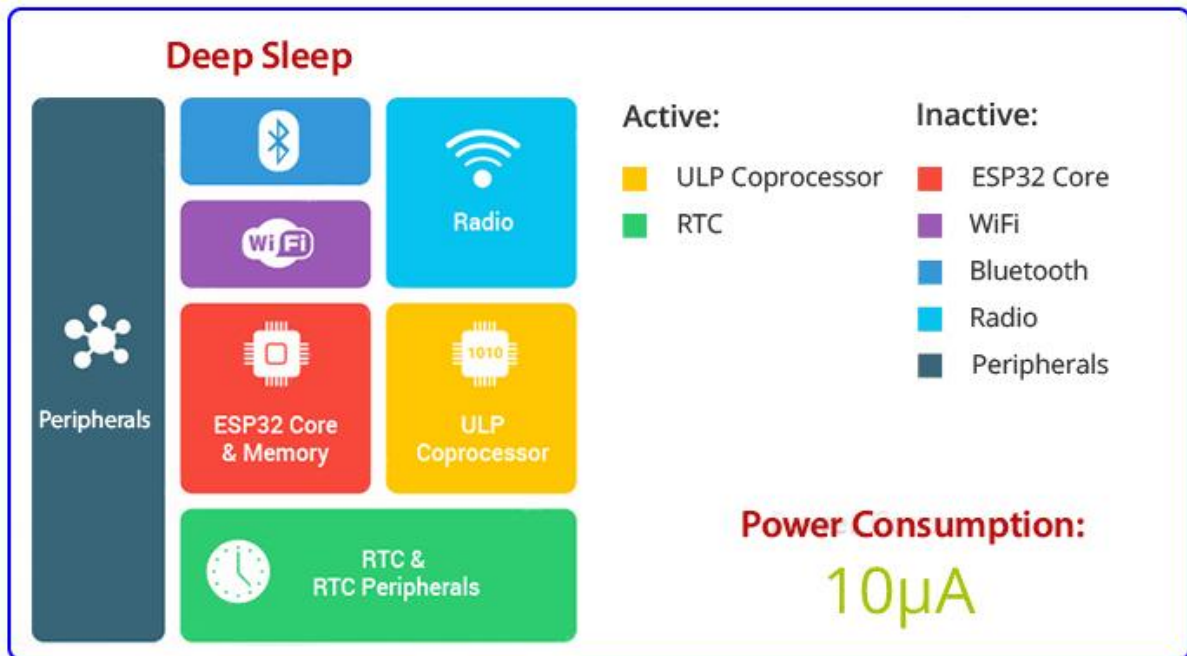


Figure 3.2 ESP32 Power Mode

3.4 Connection to the Work System

The prototype system implemented in this work incorporates the basic principles of IoMT, applying them to a functional and scalable framework. The collection of biosignals is carried out through approved methods and interconnected components, while the data transmission is implemented through virtual terminals on the Blynk platform[24]. At the same time, the system incorporates basic analysis features, such as the recognition of values outside the normal range and the activation of alerts in real time. The differentiation of the system lies in the use of open software and hardware, offering significant advantages in terms of customization and cost, without sacrificing functionality.

3.5 Epilogue

IoMT represents one of the most dynamic areas of digital medicine, offering capabilities that transcend traditional limitations of distance and time. This work demonstrates that even with low-cost components and open technologies, it is possible to implement an effective home monitoring system, with upgrade and interconnection capabilities. Future developments are expected to further enhance the reliability, security and interoperability of such solutions, making IoMT a pillar of a more personalized and preventive healthcare.

Chapter 4: Blynk Platform

4.1 Import

This chapter will discuss the Blynk application, which was used to remotely control the system. Blynk is a popular platform for developing Internet of Things (IoT) applications, which allows users to connect, control, and monitor smart devices via mobile devices or computers. This platform is particularly useful for projects involving microcontrollers, sensors, and other IoT devices, as it offers ease of connection and remote management.

4.2 Definition/Architecture

Blynk is an IoT platform that allows the creation of applications for controlling and monitoring devices over the internet. It is based on an architecture that includes three main components:

1. **Blynk App:** The mobile application (iOS and Android) that allows users to create user interfaces (GUI) to control their devices.
2. **Blynk Server:** The server that manages the communication between the application and the devices. The server can be public (Blynk Cloud) or installed locally (Private Server).
3. **Blynk Libraries:** The libraries that are installed on devices (e.g. Arduino, ESP8266, Raspberry Pi) to allow communication with the Blynk Server.

Blynk supports a variety of communication protocols, including Wi-Fi, Ethernet, Bluetooth, GSM, and more, making it ideal for a wide range of IoT applications.[24]

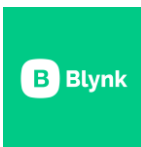


Figure 4.1
Blynk
logo

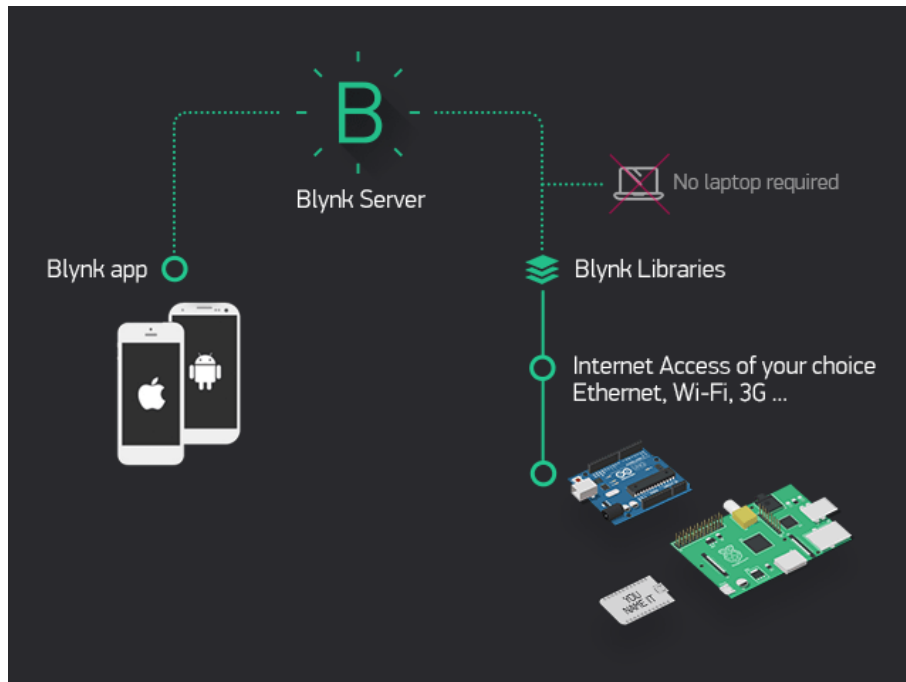


Figure 4.2 Blynk Architecture

4.3 Features

Blynk offers a number of features that make it ideal for IoT projects:

1. **Simple User Interface:** The Blynk app offers an easy-to-use interface that allows users to create graphical user interfaces (GUIs) to control their devices without having to write code. Users can add buttons, graphs, input devices, and other elements with simple drag-and-drop.
2. **Variety of Tools for Data Presentation:** Blynk offers a range of widgets (control elements) such as graphs, meters, LEDs, buttons, sliders and more, which allow for the visualization and control of data in real time.
3. **Remote Access and Control:** With Blynk, users can control and monitor their devices from anywhere in the world, as long as there is an internet connection. This makes the platform ideal for applications such as smart homes, automation, and industrial controls.
4. **Support for a Variety of Devices and Protocols:** Blynk supports a wide range of hardware, such as Arduino, ESP8266, ESP32, Raspberry Pi, and more. It also supports various communication protocols, such as Wi-Fi, Ethernet, Bluetooth, GSM, and more.
5. **Secure Communication:** Blynk uses security protocols to ensure that communications between the app, server, and devices are secure. This includes data encryption and device authentication.
6. **Data Storage with History:** Blynk offers the ability to store data in the cloud, allowing users to access measurement history and analyze their data over time.
7. **Support for Cloud Services:** Blynk integrates seamlessly with cloud services, allowing users to store and analyze data in the cloud. This is especially useful for applications that require long-term data storage and analysis.
8. **Integration with Other Platforms:** Blynk can be integrated with other platforms and services, such as IFTTT, Google Assistant, Amazon Alexa, and others, offering even greater flexibility and automation capabilities.[25]

4.4 Blynk Advantages

- **Ease of Use:** The Blynk platform is designed to be user-friendly, allowing even beginners to create IoT applications without the need for extensive programming knowledge.
- **Flexibility:** Support for a variety of materials and protocols makes Blynk suitable for a wide range of applications.
- **Scalability:** Blynk can be used for both small projects and large IoT systems, thanks to the ability to use private servers and cloud support.
- **Community and Support:** Blynk has an active user community and extensive documentation, making it easy to solve problems and develop new applications.

4.5 Restrictions

- **Internet addiction:** Blynk relies on an internet connection to function, which may be a limitation in areas with limited or no connectivity.[25]
- **Limited Free Version:** The free version of Blynk has limitations on the number of devices and the amount of data that can be stored, which may require an upgrade to a paid plan for larger applications.

4.6 Epilogue

Blynk is a powerful and flexible platform for developing IoT applications, offering ease of connecting, controlling, and monitoring devices. With its numerous features and support for a wide range of hardware and protocols, Blynk is an excellent choice for IoT projects, from simple prototypes to complex systems.

Chapter 5: Analysis of Materials and Manufacturing Sensors

5.1 Import

In this section, an analysis of the sensors used in the implementation of the thesis will be made. The system is based on a series of sensors, which allow the collection and processing of basic biometric data, such as heart rate, blood oxygen level, body temperature and electrocardiographic activity.

5.2 System Design

The system is based on three main sensors: the MAX30100, which measures heart rate and blood oxygen content (SpO2), the MLX90614, which measures body temperature, and the AD8232, which records electrocardiographic activity (ECG). The data from these sensors are displayed in real time on the ST7789 TFT display, which presents both numerical values (HR, SpO2, temperature) and the ECG curve as a graph. In addition, the data is sent to the Blynk platform for remote monitoring, using virtual terminals to send HR, SpO2, temperature and ECG measurements. The system also includes a buzzer, which is activated when biometric data is within the specified limits. The analysis of the sensors and the design of the system are the basis for the development of a comprehensive health monitoring system, which can find applications in both personal and professional use. The ESP32, as the central microcontroller, manages the collection, processing, and sending of data, while ensuring the reliable and accurate operation of the system.

5.3 Sensor Analysis

Below will be a detailed analysis of the sensors used:

5.3.1 ESP32

The ESP32 Development Board - DEVKIT V1 is a development board based on the ESP32 microcontroller, which is a powerful and versatile microcontroller with built-in Wi-Fi and Bluetooth capabilities. Below we will analyze the features and capabilities of the ESP32 DEVKIT V1, as described by the manufacturer:

1. Basic Features

- Microcontroller: ESP32 (32-bit dual-core Tensilica LX6):
 - Clock speed: Up to 240 MHz.
 - Processing core: Dual-core (two cores), allowing parallel execution of tasks.
 - Memory:
 - RAM: 520 KB SRAM.
 - Flash memory: 4 MB (depends on version).
 - Wi-Fi: Support for Wi-Fi 802.11 b/g/n (2.4 GHz).
 - Bluetooth: Support for Bluetooth Classic and Bluetooth Low Energy (BLE).

- GPIO (General Purpose Input/Output): 36 GPIO pins (many of them can be configured for various functions).
- ADC (Analog-to-Digital Converter): 12-bit, with up to 18 channels.
- DAC (Digital-to-Analog Converter): 2 channels 8-bit.
- SPI, I2C, I2S, UART: Support for multiple communication interfaces.
- PWM (Pulse Width Modulation): 16 channels.
- Touch Sensors: 10 touch sensors.
- Hall Effect Sensor: Integrated Hall sensor for detecting magnetic fields.[26]

2. Structure and Pinout

The ESP32 DEVKIT V1 has 30 physical pins, which are distributed as follows:

➤ 4 terminals for power and ground:

- **3.3V**: For powering devices that operate at 3.3V.
 - **5V**: For power supply via USB or external sources.
 - **GND**: For grounding.
 - **EN (Enable)**: Used to restart or turn off the microinjector.
- 25 physical GPIO pins: These pins correspond to 48 GPIO pins thanks to pin multiplexing. This means that the same pin can be assigned to different functions depending on the needs of the application.

3. GPIO Pin Capabilities

The ESP32's GPIO pins can be assigned to various functions, such as:

- **Analog inputs (ADC)**: 15 12-bit channels for reading analog signals (e.g., from sensors).
- **Analog outputs (DAC)**: 2 8-bit channels for analog signal output.
- **Digital inputs/outputs**: For connection to buttons, LEDs, etc.
- **PWM (Pulse Width Modulation)**: 25 outputs for controlling lighting, motors, etc.
- **Serial communication (UART)**: 2 channels for communication with other devices.
- **SPI**: 3 channels for fast communication with displays, sensors, etc.
- **I2C**: 1 interface for communication with devices such as displays, sensors, etc.
- **I2S**: 2 interfaces for audio processing.
- **Touch sensors**: 9 channels for touch applications.
- **Wi-Fi and Bluetooth**: Built-in interfaces allow wireless communication.[26]

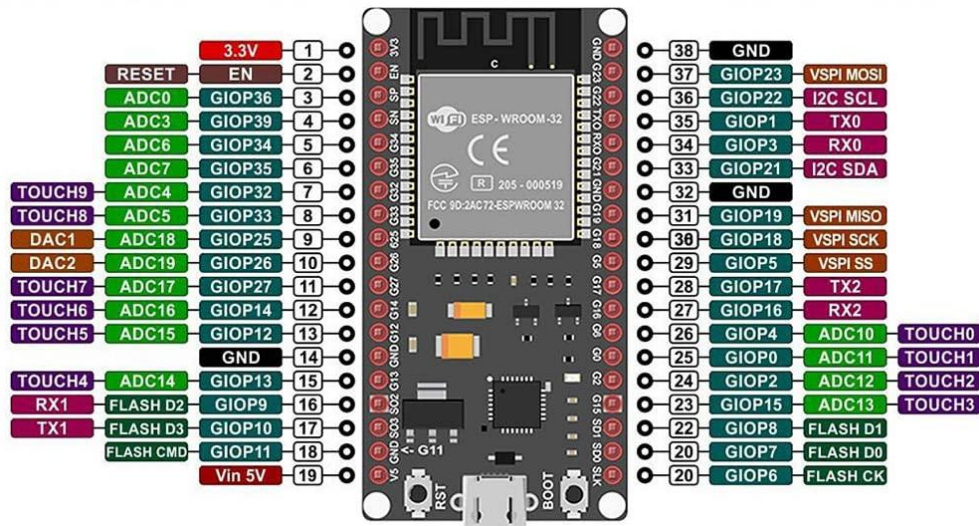


Figure 5.1 GPIO ESP32 DEVKIT V1

4. Importance of Pin Multiplexing

Multiplexing capability allows the same pin to be assigned to different functions depending on the application needs. For example, one pin can be used as an ADC input in one application and as a PWM output in another. This increases the flexibility of the ESP32 and allows for the implementation of complex systems with a limited number of pins.

5.3.2 MAX30100

The MAX30100 is an integrated sensor that combines heart rate (HR) and blood oxygen content (SpO₂) measurement. It is based on optical reflected light technology, using infrared and red LEDs to detect changes in pulse and blood oxygenation. The sensor communicates with the ESP32 via the I2C interface, providing accurate and reliable real-time data.



Figure 5.2 MAX30100 Sensor

1. Key Features:

- **Technology:** Reflected light optics (Photoplethysmography - PPG).
- **LEDs:** Two LEDs (infrared and red) to detect changes in pulse and blood oxygenation.
- **Interface:** I2C (Inter-Integrated Circuit) for communication with the microcontroller (ESP32).
- **Catering:** 1.8V - 3.3V
- **Accuracy:** High accuracy in HR and SpO₂ measurements, ideal for medical applications.
- **Low consumption:** Suitable for portable devices and battery-powered applications.[27]

2. Connecting MAX30100 to ESP32:

- The MAX30100 communicates with the ESP32 via the I2C interface.
- The connection is made as follows:
 - **VIN**: Connects to the 3.3V of the ESP32 for power.
 - **GND**: Connects to the GND of the ESP32.
 - **SCL**: Connects to GPIO 22 of the ESP32 (I2C clock line).
 - **SDA**: Connects to GPIO 21 of the ESP32 (I2C data line).[27]

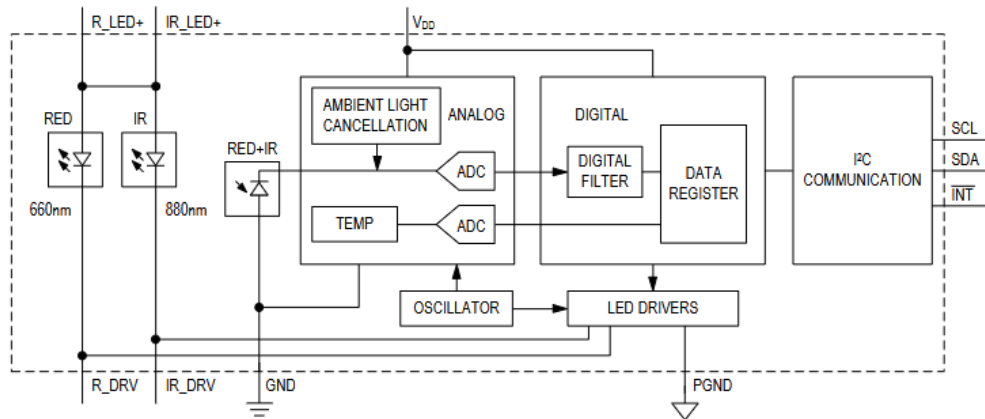


Figure 5.3 MAX30100 Operation Diagram

5.3.3 MLX90614

The MLX90614 is a non-contact infrared (IR) temperature sensor. It uses IR thermopile technology to measure temperature from a distance, without requiring physical contact.



Figure 5.4 MLX90614/GY-906 Sensor

1. Key Features:

- **Technology:** Infrared radiation (Infrared Thermopile).
- **Temperature measurement range:**
 - **Objective:** -70°C to +380°C.
 - **Environment:** -40°C to +125°C.
- **Accuracy:** $\pm 0.5^{\circ}\text{C}$ in the range 0°C to $+50^{\circ}\text{C}$.
- **Interface:** I2C (Inter-Integrated Circuit) for communication with the microcontroller (ESP32).
- **Catering:** 3V - 5V (compatible with ESP32 operating at 3.3V).
- **Low consumption:** Suitable for portable devices and battery-powered applications.[28]

2. Connecting MLX90614 to ESP32

The MLX90614 communicates with the ESP32 via the I2C interface. The connection is as follows:

- **VDD:** Connects to the 5V of the ESP32 for power.
- **GND:** Connects to the GND of the ESP32.
- **SCL:** Connects to GPIO 22 of the ESP32 (I2C clock line).
- **SDA:** Connects to GPIO 21 of the ESP32 (I2C data line).[28]

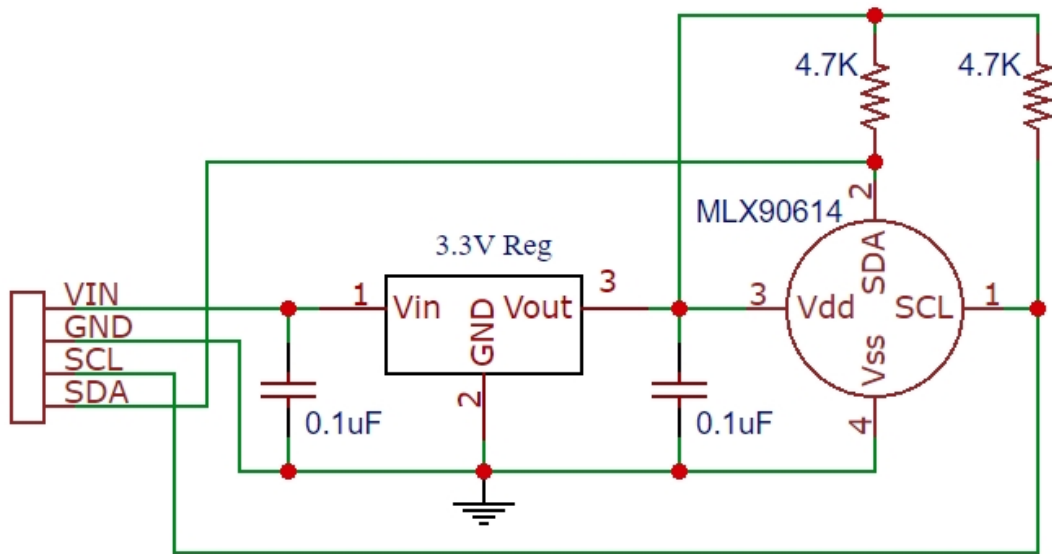


Figure 5.5 MLX90614/GY-906 Schematic Diagram

5.3.4 AD8232

The AD8232 is an integrated signal processing block for electrocardiography (ECG) and other biometric measurement applications. It is designed to extract, amplify, and filter small signals in noisy conditions, such as motion or remote electrode placement. It includes high-pass and low-pass filters to eliminate noise and distortion, as well as a right-leg drive (RLD) amplifier to improve signal quality. The fast recovery feature allows for immediate recovery from abrupt signal changes.

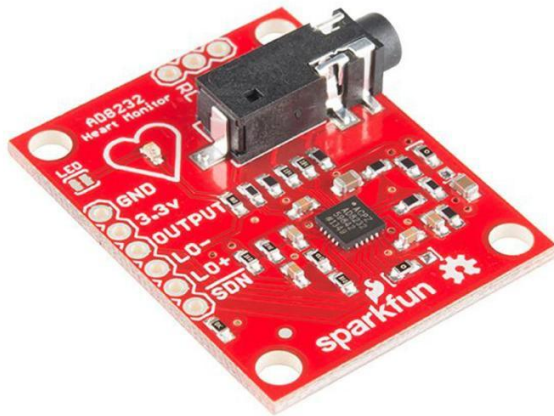


Figure 5.6 AD8232 sensor

1. Key Features:

- **Technology:** ECG amplifier with low power consumption.
- **Input voltage range:** ± 300 mV.
- **Profit:** Adjustable gain up to 1000 V/V.
- **Right Leg Drive (RLD) stimulation:** Improves the quality of the ECG signal.
- **Low consumption:** 170 μ A during operation, ideal for portable devices.
- **Catering:** 2.0V - 3.5V (compatible with ESP32 operating at 3.3V).[29]

2. Connecting AD8232 to ESP32:

The AD8232 is connected to the ESP32 via an analog input. The connection is as follows:

- VDD: Connects to the 3.3V of the ESP32 for power.
- GND: Connects to the GND of the ESP32.
- OUT: Connects to GPIO 34 of the ESP32 to read the ECG signal.
- LO+: Connects to GPIO 33 of the ESP32 for lead-off detection (Lead-Off Detection +).
- LO-: Connects to GPIO 32 of the ESP32 for lead-off detection (Lead-Off Detection -).

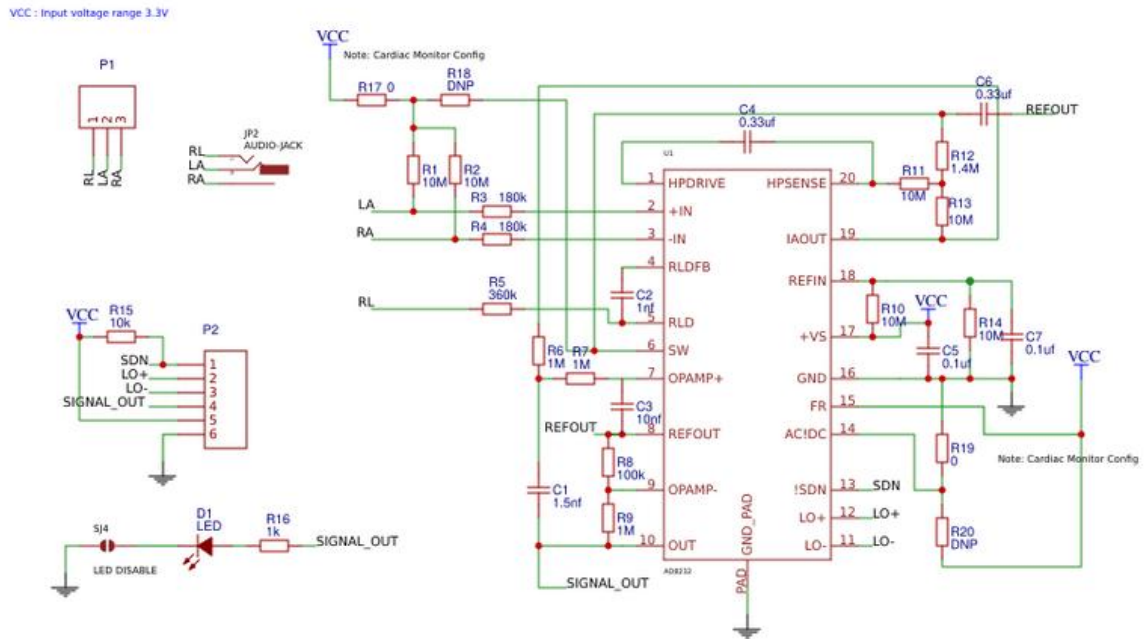


Figure 5.7 AD8232 schematic

5.3.5 ST7789 display

The display offers vivid colors and high brightness, ideal for displaying data such as heart rate, SpO2, temperature and ECG curves in healthcare applications and beyond. The ST7789 controller is used in high-resolution TFT color displays (320x240 pixels) and connects to the ESP32 via SPI for fast communication. The wiring is as follows:

- **GND:** Connects to the GND of the ESP32.
- **VCC:** Connects to the 3.3V of the ESP32 for power.
- **SCL:** Connects to GPIO 18 (SCK) of the ESP32 for the SPI interface clock.
- **SDA:** Connects to GPIO 23 (MOSI) of the ESP32 to transmit data via SPI.
- **RES:** Connects to GPIO 4 of the ESP32 to reset the screen.
- **DC:** Connects to GPIO 2 of the ESP32 for data/command selection.
- **CS:** Connects to GPIO 5 of the ESP32 for display selection (Chip Select).[30][31]



Figure 5.8 ST7789 Display

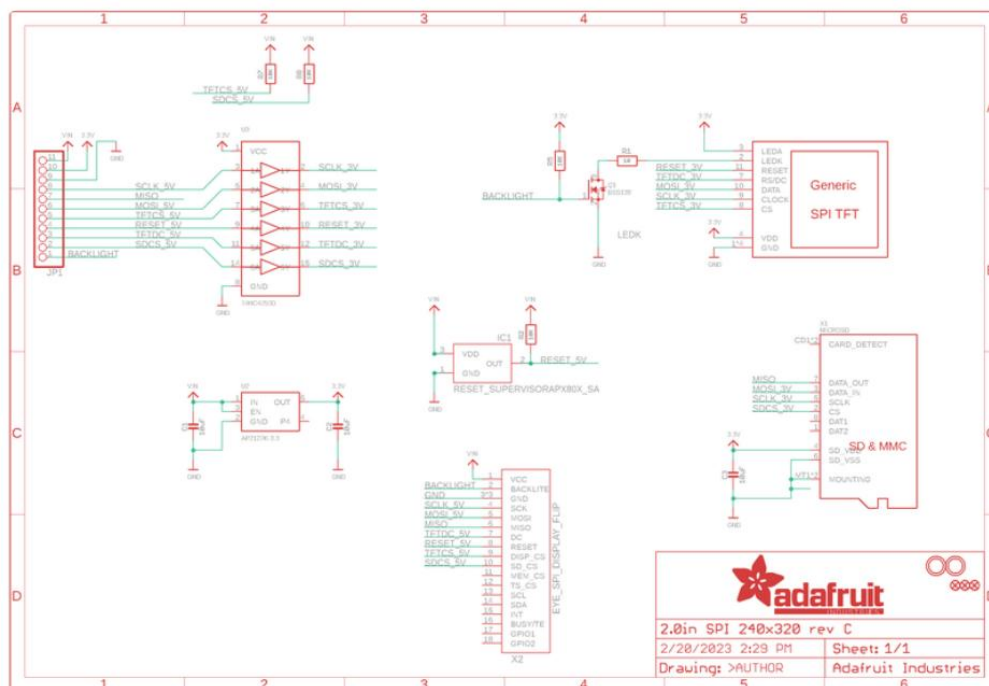


Figure 5.9 ST7789 Display Schematic

5.4 Construction Completion: Selection of Remaining Materials

After the extensive analysis and description of all the sensors and their characteristics, we proceed to the analysis and selection of the remaining materials required to complete the construction of the system. These materials include:

5.4.1 Jumpers

For the connection of the sensors and the ESP32, male-to-male jumpers were used. In the final construction, flat jumpers were chosen, which offer better organization, reduce the required space and facilitate the creation of a compact casing. This ensured ease of assembly and stability in the operation of the system.

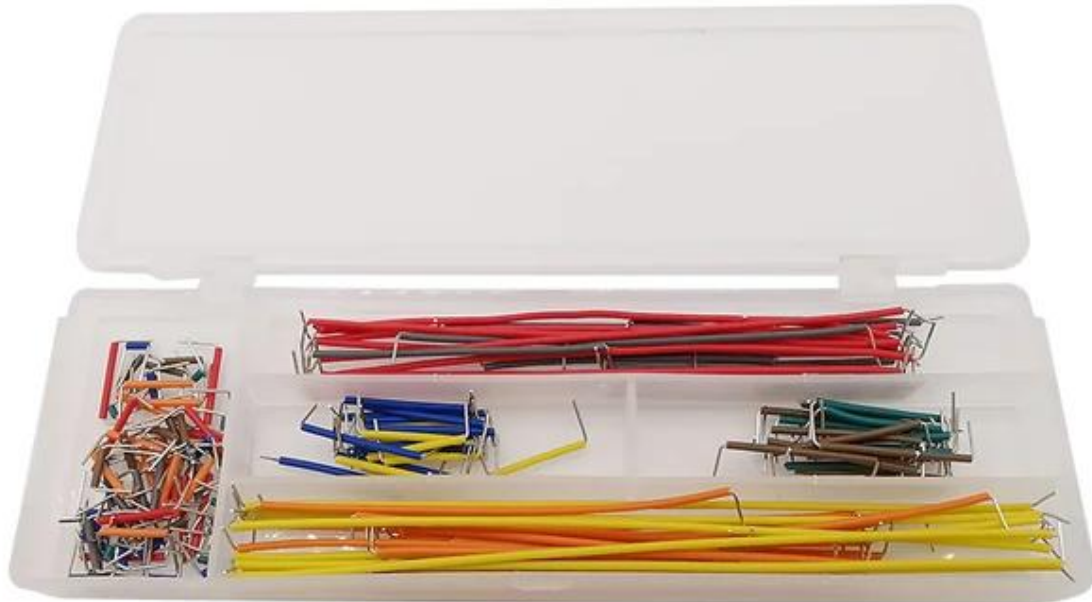


Figure 5.10 Jumpers

5.4.2 Buzzer (Mini Piezo Buzzer)

The Mini Piezo Buzzer is a sound producing device used in electronic circuits for audible notifications. It works based on the piezoelectric effect, where the application of voltage causes vibration and sound production. It is ideal for applications such as:

- Audible alerts in medical devices
- Alarms
- Confirm system functions



5.11 Mini Piezo Buzzer

Key Features:

1. Types:

- Active: Operates with a constant voltage (3.3V/5V), produces a preset sound
- Passive: Requires PWM signal to control frequency and create different sound tones [32]

2. Technical Specifications:

- Operating voltage: 5V (compatible with ESP32)
- Current consumption: <30mA (safe for direct connection to GPIO)
- Frequency range: 2,300 ±500Hz [33]

3. Connections:

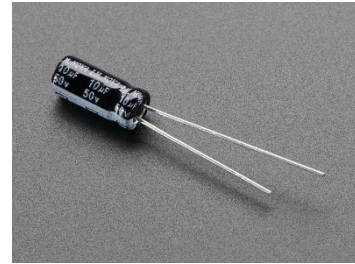
- IN (+): Connects to GPIO 13 of the ESP32
- GND: Connects to the GND of the ESP32.

5.4.3 Capacitor 10μf

The 10μF electrolytic capacitor, placed between the EN (Enable) and GND pins of the ESP32 board, helps to automatically reset the device when starting the code upload.

In detail:

- The positive leg of the capacitor is connected to the EN pin of the ESP32.
- The negative leg is connected to the pin (GND).

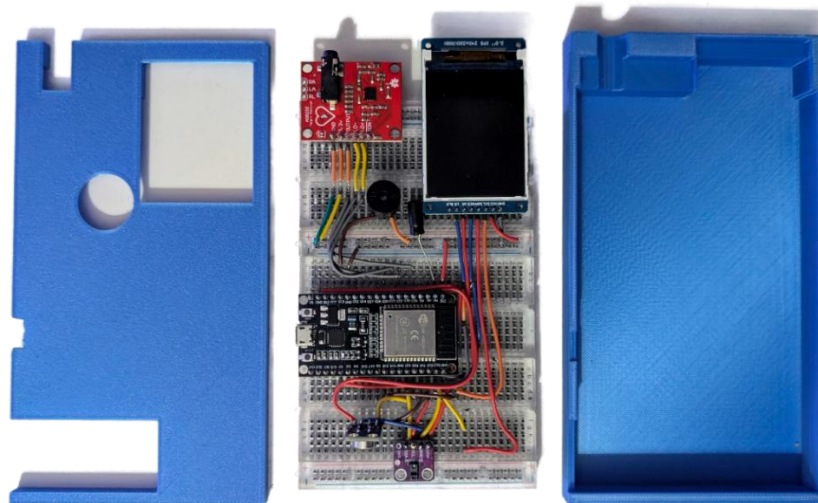


5.12 Capacitor 10µf

When uploading a program via USB, the capacitor causes a short delay in the voltage rise on the EN pin, allowing the ESP32 to enter bootloader mode in time. Thus, the upload is done automatically, without requiring a manual press of the "BOOT" button.

5.4.4 Casing Construction

The casing of the construction was designed with the help of Tinkercad and then printed on a 3D printer with PLA material. In the center there is a circular hole for the buzzer, which ensures that the sound is heard clearly. On the upper left side there is a hole for connecting a cable for the AD8232 electrodes. On the lower left side there is a square hole for connecting a micro USB cable, which is used for powering and programming the ESP32. On the lower side there is a hole for the finger socket, which facilitates the use of the MAX30100 sensor for heart rate and oxygen measurements, as well as the MLX90614 sensor for temperature measurement.



5.13 Construction Casing

Quick Guide to Tinkercad

1. **Creating a Parallelogram Cube:** I used a cube as a base for the casing.
2. **Add Holes:**

- **Circular hole for the buzzer:** I added a cylinder to the center of the casing and made it a "hole".
- **Hole for AD8232 electrodes:** I added a rectangular prism to the top left side and made it a circular "hole" at the bottom of the box.
- **Micro USB hole:** I added a rectangular prism to the lower left side and made it a "hole".
- **Finger hole:** I added a rectangular blank "hole" to the top side of the print to be the slot for the finger.

3. File Export:

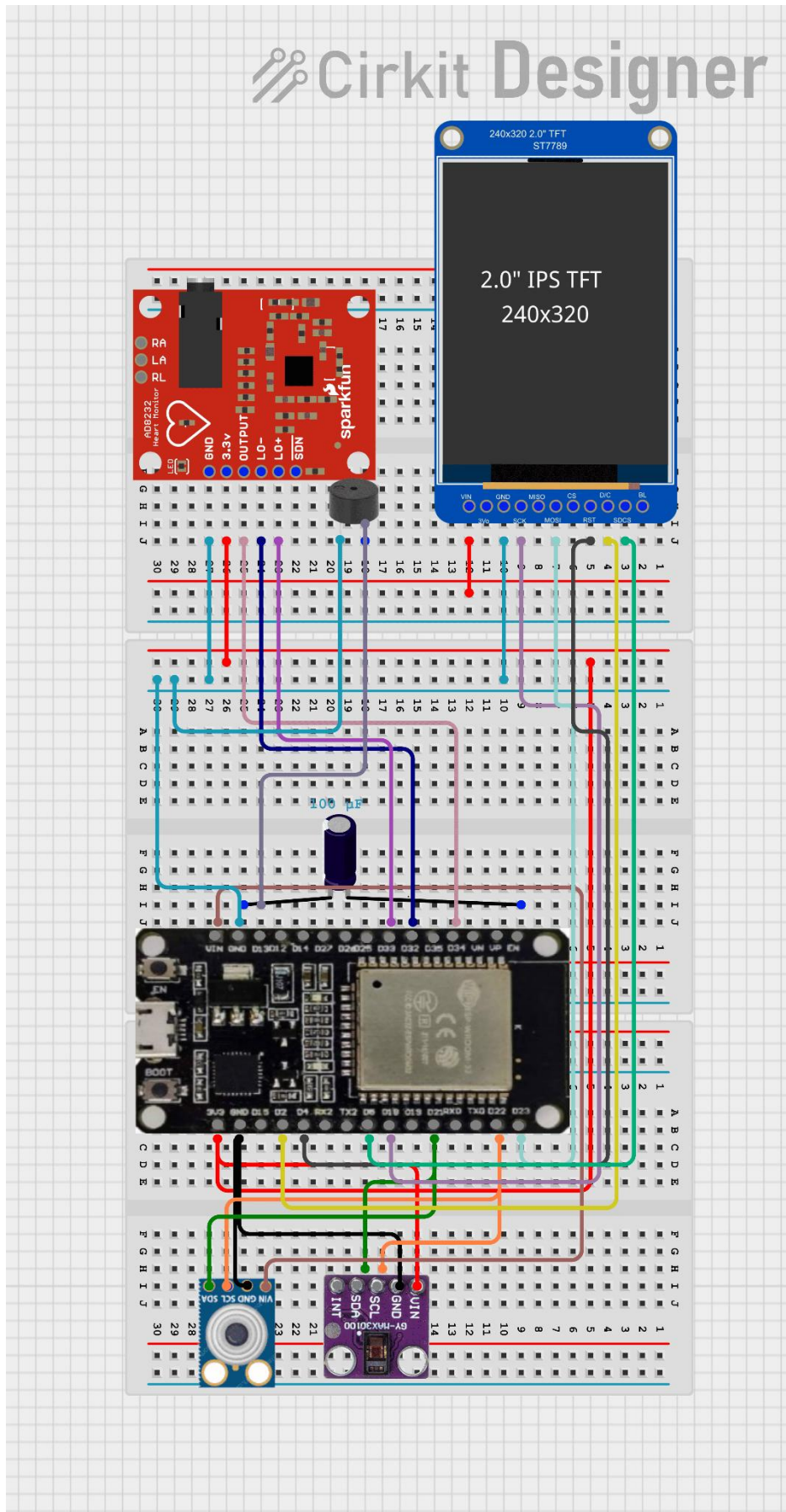
- I exported the design in STL format for 3D printing.

4. Printing:

- I used PLA material to print the casing.

5.5 Epilogue

In this chapter, a detailed presentation of the basic sensors and materials used for the implementation of the system was made, along with their characteristics and operation. After the description of the components has been completed, the circuit wiring follows.



5.14 Circuit Connections

Chapter 6: Code Analysis

6.1 Introduction

This chapter provides a detailed analysis of the code, with emphasis on the operating logic of the system. It includes:

1. Initializations: The steps for starting up the sensors and communication protocols, in chronological order.
2. Processing loops: The main loop routines and their timings (e.g. ECG every 240ms, SpO2 every 3s).
3. Flowchart: A visual representation of the operation at the end of the chapter, for clarity and immediate understanding.

The goal is to present the dynamics of the system — from startup to ongoing interaction with the user and the cloud.

6.2 Analysis and Explanation

The system starts by initializing all the necessary components. First, serial communication is enabled (`Serial.begin(115200)`) for debugging purposes, so that the execution of the code can be monitored. Then, a connection is made to the WiFi network and the Blynk platform through the `Blynk.begin(auth, ssid, pass)` call, which ensures that the system can communicate with the cloud to send data and receive commands. The system sensors are initialized in turn. The MAX30100, which is responsible for measuring the pulse and blood oxygenation, is configured with `pox.begin()`. The MLX90614, which measures the temperature, is enabled with `mlx.begin()`. At the same time, the ST7789 display is prepared with `tft.init()` for displaying the data. In case any of the sensors fails to initialize, the system displays a relevant error message and enters an infinite loop (`while(1)`), interrupting its operation to avoid processing incorrect data. Once initialization is complete, the system enters the main operation loop, where it continuously performs the following operations:

1. Background task management via `yield()`, which ensures that communication processes (WiFi, Blynk) are executed without blocking the main system functions.
2. Reading and processing data from sensors:
 - The electrocardiogram (ECG) is read every 240 ms by the AD8232 sensor (`analogRead(ECG_PIN)`), and its data is displayed as a waveform on the screen, while simultaneously being sent to Blynk via the virtual pin V4.



Figure 6.1 Valid Limits Case

- Pulse and oxygenation measurements from the MAX30100 are taken every 3 seconds. Before processing, a finger presence check is performed to ensure the reliability of the measurements (valid values: pulse 40–180 bpm, SpO2 70–100%). If measurements appear repeated two or more times, the sensor is reinitialized to prevent the use of incorrect data.
- The temperature is measured by the MLX90614 with `mlx.readObjectTempC()`.

The system then performs a safety check on the measurements, according to the predefined safe ranges:

- Pulse: 40–120 bpm
- Oxygenation: >90%
- Temperature: 34–38°C

If the values are within the limits, the buzzer is activated for 100 ms (1000 Hz) as a safe status indication. Otherwise, and if 60 seconds have passed since the last notification, a notification is sent via Blynk (`Blynk.logEvent`) and at the same time an email notification is sent.

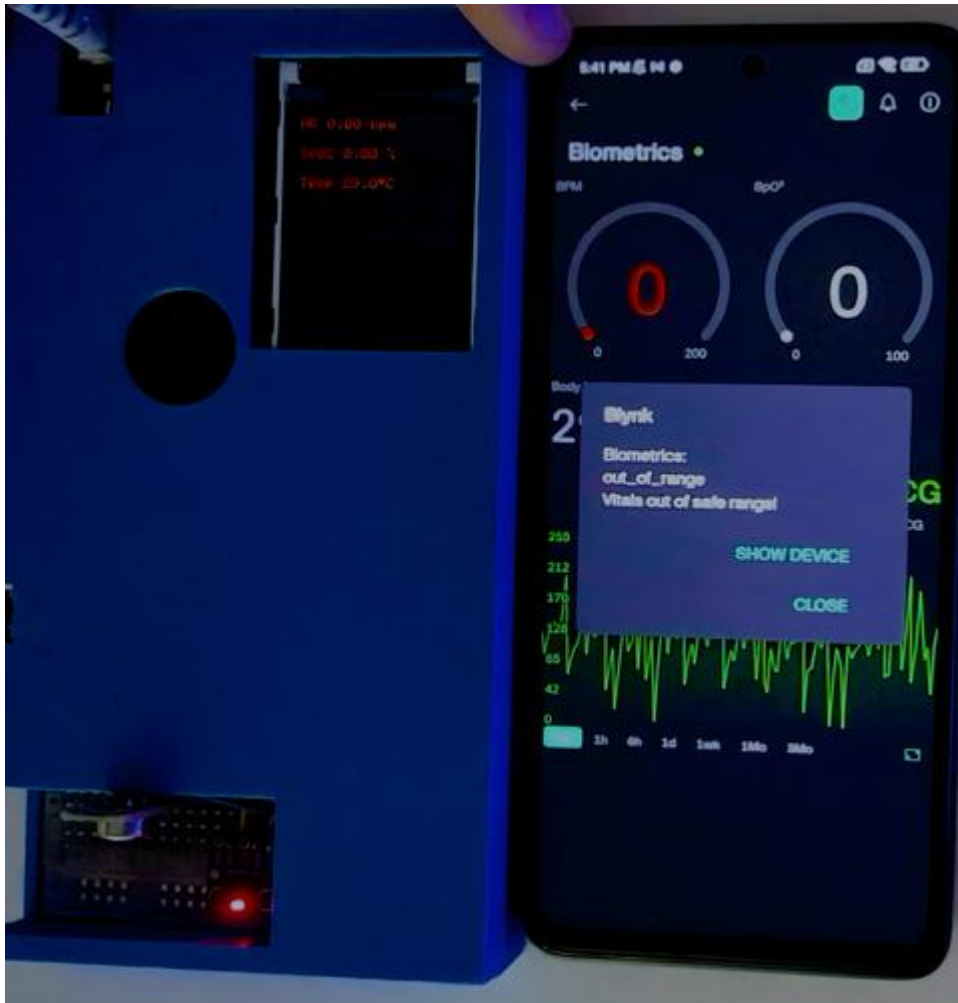


Figure 6.2 Notification Case

The data is displayed in real time on both the ST7789 display and the Blynk app:

- On the screen, values appear in red when they exceed safe limits (e.g. pulse <40 or >120 bpm).
- In Blynk, they are sent through the virtual pins V1 (pulse), V2 (SpO2), V3 (temperature).

The operation of the system can be visualized as an infinite loop that performs the following basic functions in sequence:

1. Running background tasks (WiFi, Blynk).
2. Reading and processing data from sensors.
3. Security check and update of the screen/cloud.

This structure ensures reliable and continuous operation, with real-time capability for monitoring biosignals and immediate detection of risks.

6.3 Flowchart

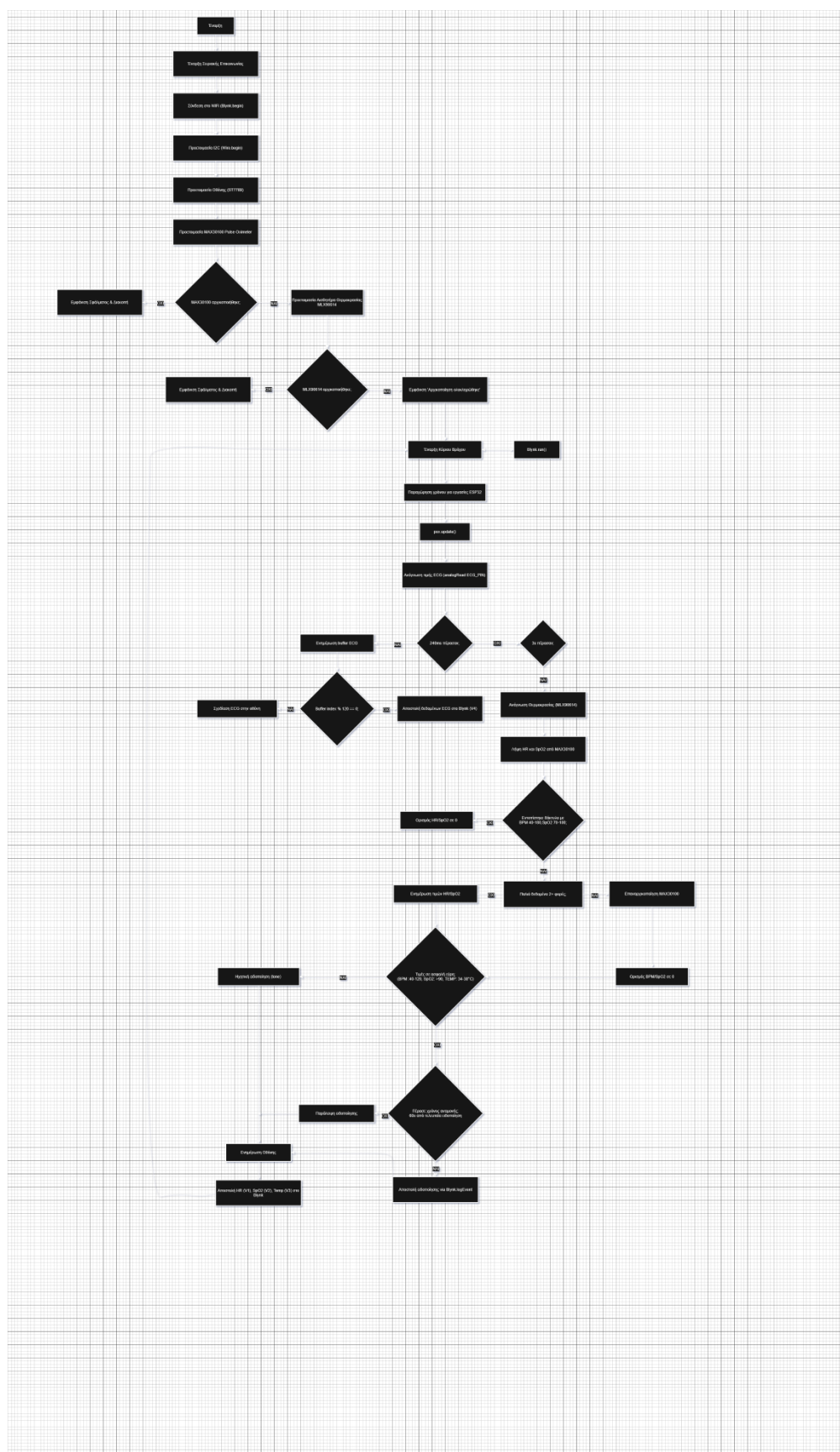


Figure 6.3 Flowchart

6.4 Epilogue

The code analysis showed that the system works reliably in real time, with basic monitoring and notification capabilities. However, as will be discussed in the following section, there are some limitations in terms of accuracy, internet dependency, and latency, which open the way for future improvements.

6.5 Problems and Ways to Improve

- **Problem:** The MLX90614 only measures finger surface temperature

Solution:

- Changing the position of the MLX90614 sensor by placing it 1-3cm from the forehead
- Using a contact sensor (DS18B20) for core body temperature

- **Problem:** Partial Delay ESP32 in continuous operation

Solution:

- Using dual ESP32 (1 for sensors, 1 for communication)
- Connection via UART/I2C
- **Problem:** Cloud/Blynk data limit

Solution:

- Paying for the pro version
- Changing cloud platform (using these does not solve the following problem, which is:)
- **Problem:** Internet addiction

Solution:

- SD Card for offline storage
- Blynk.Local Server for internal network
- **Problem:** High energy consumption

Solution:

- Deep sleep mode between measurements
- Timer for periodic operation.

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ΠΑΡΑΡΤΗΜΑ Α : MATERIALS LIST

Code	Component Description	Source	Quantity	Price
4.3.1	ESP32 DEVKIT V1	Grobotronics	1	9.9€
4.3.2	MAX30100	AliExpress	1	€1.79
4.3.3	MLX90614	AliExpress	1	€6.65
4.3.4	AD8232 ECG Module	AliExpress	1	€4.67
4.3.5	ST7789 monitor	AliExpress	1	€5.41
4.4.1	Jumpers	AliExpress	1	€2.34
4.4.2	Breadboard 400pts	AliExpress	3	7.62€
4.4.3	Casing Construction (estimate)	-	1	0.8€
4.4.4	Piezo Buzzer	AliExpress	1	0.5€
Total Cost:				€39.68

ANNEX B: CODE

```
#define BLYNK_TEMPLATE_ID "TMPL4CgkZQ6NP"
#define BLYNK_TEMPLATE_NAME "Biometrics"
#define BLYNK_AUTH_TOKEN "MPPi6i0Zuh1L7_WgnEtMT2oQJlSCL8Hg"

#include <Wire.h>
#include "MAX30100_PulseOximeter.h"
#include <Adafruit_GFX.h>
#include <Adafruit_MLX90614.h>
#include <Adafruit_ST7789.h>
#include <BlynkSimpleEsp32.h>

#define TFT_CS    5
#define TFT_DC    2
#define TFT_RST   4
#define BUZZER_PIN 13
#define ECG_PIN   34
#define WAVEFORM_HEIGHT 160
#define WAVEFORM_START_Y(200 - WAVEFORM_HEIGHT / 2)
#define BUFFER_SIZE 240

character auth[] = BLYNK_AUTH_TOKEN;
character ssid[] = "Test_Ard"?
character pass[] = "b96hmn6b546xchcp4nam"?

PulseOximeter pox?
Adafruit_ST7789 tft =Adafruit_ST7789(TFT_CS, TFT_DC, TFT_RST);
Adafruit_MLX90614 mlx =Adafruit_MLX90614();

int ecgData[BUFFER_SIZE];
int bufferIndex =0?
unsigned long lastSampleTime =0?
const long sampleInterval =240?
uint32_t tsLastReport =0?
#define REPORTING_PERIOD_MS 3000

float heartRate =0, spO2 =0, objectTemp =0?
unsigned long lastAlertTime =0?
const unsigned long alertCooldown =30000?
int sameReadCount =0?
float lastHR =0, lastSpO2 =0?

void updateWaveformBuffer(int reading) {
    ecgData[bufferIndex] = reading;
    bufferIndex = (bufferIndex +1) % BUFFER_SIZE;
}
```

```

void displayECGWaveform() {
  TFT.fillRect(0, WAVEFORM_START_Y, 240, WAVEFORM_HEIGHT, ST77XX_BLACK);
  for(int i = 1; i < BUFFER_SIZE; i++) {
    int previousIndex = (bufferIndex + i - 1) % BUFFER_SIZE;
    int currentIndex = (bufferIndex + i) % BUFFER_SIZE;
    int y1 = map(ecgData[previousIndex], 0, 4095, WAVEFORM_START_Y,
WAVEFORM_START_Y + WAVEFORM_HEIGHT);
    int y2 = map(ecgData[currentIndex], 0, 4095, WAVEFORM_START_Y,
WAVEFORM_START_Y + WAVEFORM_HEIGHT);
    TFT.drawLine(i - 1, y1, i, y2, ST77XX_GREEN);
  }
}

void setup() {
  Serial.begin(115200);
  Blynk.begin(auth, ssid, password);
  Wire.begin(21, 22, 100000);

  pinMode(BUZZER_PIN, OUTPUT);
  TFT.init(240, 320);
  TFT.setRotation(4);
  TFT.fillScreen(ST77XX_BLACK);
  TFT.setTextSize(2);
  TFT.setTextColor(ST77XX_WHITE);
  TFT.setCursor(10, 10);
  TFT.println("Initializing...");

  if(!smallpox.begin()) {
    Serial.println("Oximeter FAILED!");
    while(1);
  }

  if(!mlx.begin()) {
    Serial.println("MLX90614 Sensor NOT Found!");
    while(1);
  }

  Serial.println("Initialization complete.");
}

void loop() {
  yield();
  unsigned long currentMillis = millis();
  smallpox.update();
  int ecgValue = analogRead(ECG_PIN);

  if(currentMillis - lastSampleTime >= sampleInterval) {
    lastSampleTime = currentMillis;
    updateWaveformBuffer(ecgValue);
  }
}

```

```

    if(bufferIndex %120==0) {
        displayECGWaveform();
    }

    int scaledECG =map(ecgValue,0,4095,255,0);
    Blynk.virtualWrite(V4, scaledECG);
}

if(currentMillis - tsLastReport > REPORTING_PERIOD_MS) {
    objectTemp =mlx.readObjectTempC();

    float newHR =smallpox.getHeartRate();
    float newSpO2 =smallpox.getSpO2();

    boolean hrValid = newHR >40&& newHR <180?
    boolean spo2Valid = newSpO2 >70&& newSpO2 <=100?
    boolean fingerDetected = hrValid && spo2Valid;

    if(fingerDetected) {
        if(newHR == lastHR && newSpO2 == lastSpO2) {
            sameReadCount++;
            if(sameReadCount >=2) {
                Serial.println("Stale MAX30100 data. Resetting...");
                smallpox.begin();//Reinitialize sensor
                heartRate =0?
                spO2 =0?
            }
        }else{
            heartRate = newHR;
spO2 = newSpO2;
            sameReadCount =0?
        }
    }else{
        heartRate =0?
        spO2 =0?
    }
}

lastHR = newHR;
lastSpO2 = newSpO2;

    boolean inSafeRange = (heartRate >40&& heartRate <120&& spO2 >90&&
objectTemp >=34&& objectTemp <=38);
    if(inSafeRange) {
        tone(BUZZER_PIN,1000,100);
    }else{
        if(currentMillis - lastAlertTime > alertCooldown) {
            Serial.println("Vitals out of safe range! Sending alert.");
            Blynk.logEvent("out_of_range","Vitals out of safe range!");
        }
    }
}

```

```

        lastAlertTime = currentMillis;
    }
}

Blynk.virtualWrite(V1, heartRate);
// Display data on screen
TFT.fillScreen(ST77XX_BLACK);

TFT.setCursor(10,10);
TFT.setTextColor((heartRate <40 || heartRate >120) ? ST77XX_RED :
ST77XX_WHITE);
TFT.print("HR:");
TFT.print(heartRate);
TFT.print("bpm");

TFT.setCursor(10,50);
TFT.setTextColor((spO2 <90) ? ST77XX_RED : ST77XX_WHITE);
TFT.print("SpO2:");
TFT.print(spO2);
TFT.print(" %");

TFT.setCursor(10,90);
TFT.setTextColor((objectTemp <34 || objectTemp >38) ? ST77XX_RED :
ST77XX_WHITE);
TFT.print("Temp:");
TFT.print(objectTemp,1);
TFT.print((character)247);
TFT.print("C");

Blynk.virtualWrite(V2, spO2);
Blynk.virtualWrite(V3, objectTemp);

tsLastReport = currentMillis;
}
Blynk.run();
}

```