



Integrated ECG-PPG Wearable for Real-Time Cardiac Care

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ABSTRACT- Cardiovascular diseases are one of the leading causes of health complications worldwide, and early detection of heart-related abnormalities is essential for effective treatment and prevention. Traditional cardiac monitoring systems, such as hospital-based equipment, provide accurate results but are not suitable for continuous, everyday use. To address this limitation, this project proposes an Integrated ECG–PPG Wearable for Real-Time Cardiac Care, a compact and user-friendly device designed to monitor heart activity continuously outside clinical environments.

The wearable integrates two sensing technologies: Electrocardiography (ECG) and Photoplethysmography (PPG). The ECG sensor measures the electrical activity of the heart, providing detailed information about heart rhythm and detecting irregularities such as arrhythmias. The PPG sensor measures changes in blood volume and pulse rate using light-based detection, enabling continuous tracking of cardiovascular performance. By combining these two methods, the system improves monitoring accuracy and provides a more comprehensive understanding of heart health.

The collected physiological signals are processed in real time to calculate heart rate and identify abnormal patterns, allowing timely alerts and medical consultation if required. The device is designed to be lightweight, wearable, and cost-effective, making it suitable for daily use without discomfort. This

system aims to support preventive healthcare by enabling continuous monitoring, early diagnosis, and better management of cardiac conditions, ultimately improving patient outcomes and reducing dependence on periodic hospital visits.

The integration of ECG and PPG signals improves the accuracy and reliability of cardiac monitoring compared to individual sensing methods. The system is designed to be compact, low-cost, and user-friendly, making it suitable for continuous monitoring in daily life. This project demonstrates the effectiveness of wearable technology in healthcare by providing real-time, non-invasive cardiac monitoring. It has potential applications in hospitals, home healthcare, fitness tracking, and telemedicine, contributing to early detection and better management of heart-related conditions.’



1. INTRODUCTION

1.1 Problem Statement

Cardiovascular diseases often go undetected due to the lack of continuous and real-time monitoring systems. Existing monitoring solutions face several challenges:

- Traditional ECG machines are not portable and require hospital visits.
- PPG-based devices (like smartwatches) may lack accuracy when used alone.
- Most wearable devices monitor only a single parameter, leading to incomplete analysis.
- Delayed detection of heart abnormalities can result in serious health complications.
- High cost and complexity limit accessibility for common people.
- Therefore, there is a need for a cost-effective, portable, and reliable wearable system that integrates ECG and PPG signals to provide continuous, real-time cardiac monitoring and early detection of potential health risks.

1.2 Objectives

The main objective of this project is to design and develop an integrated ECG–PPG wearable system for real-time cardiac monitoring. The project aims to combine both electrical and optical sensing techniques to improve the accuracy of heart health analysis.

This system is intended to continuously monitor vital cardiac parameters and provide real-time feedback to users and healthcare professionals. Another objective is to design a compact, portable, and low-cost device that can be easily worn by users in their daily life.

1.3 Importance of Study

This study is important for several reasons:

- **Early Detection of Heart Diseases:** Helps identify cardiac abnormalities at an early stage, reducing risk of severe complications.
- **Real-Time Monitoring:** Provides continuous tracking of heart activity anytime and anywhere.
- **Improved Accuracy:** Combining ECG and PPG signals offers more reliable and comprehensive data than using a single method.
- **Portable and User-Friendly:** Enables patients to monitor their health without frequent hospital visits.
- **Cost-Effective Healthcare Solution:** Makes cardiac monitoring accessible to a wider population

2. LITERATURE REVIEW

• In recent years, significant research has been carried out in the field of wearable healthcare devices, especially for real-time cardiac monitoring using ECG and PPG signals. Various studies highlight the importance of combining these two sensing techniques to improve accuracy, reliability, and usability in continuous health monitoring systems.

• Several research works focus on Photoplethysmography (PPG)-based wearable devices, which are widely used due to their simplicity, low cost, and non-invasive nature. PPG sensors measure blood volume changes and are commonly used in smartwatches and fitness trackers to monitor heart rate and oxygen saturation. Studies show that PPG technology enables continuous monitoring and can provide valuable cardiovascular information such as pulse rate, blood pressure trends, and cardiac output.

• Additionally, literature highlights that wearable devices using ECG and PPG signals are not only useful for cardiac monitoring but also for applications such as stress detection, emotion recognition, and remote healthcare. These systems enable continuous monitoring outside clinical settings, making healthcare more accessible and efficient.

• Despite these advancements, several challenges remain, including signal noise, motion artifacts, power consumption, and data accuracy. Researchers continue to work on improving sensor design, signal processing algorithms, and integration techniques to overcome these limitations and enhance the performance of wearable cardiac monitoring systems.

• The rapid advancement of wearable healthcare technologies has significantly transformed cardiovascular monitoring, particularly through the integration of electrocardiography (ECG) and photoplethysmography (PPG). These modalities provide complementary insights into cardiac function, enabling continuous, non-invasive, and real-time assessment of physiological parameters. The literature highlights a growing interest in combining ECG and PPG signals within wearable systems to enhance diagnostic accuracy and enable early detection of cardiovascular diseases (CVDs).

• Early developments in wearable cardiac monitoring primarily focused on ECG-based systems. These devices allowed continuous tracking of the heart's electrical activity and were widely used for arrhythmia detection and heart rate monitoring. However, standalone ECG systems are limited in providing hemodynamic information, such as blood flow and vascular characteristics. To address this



limitation, researchers introduced PPG sensors, which measure blood volume changes in peripheral circulation using optical techniques.

3. CHALLENGES AND LIMITATIONS

3.1 Challenges

1. Signal Acquisition Issues

- Difficulty in capturing accurate ECG and PPG signals due to noise and interference.
- External disturbances affect the quality of signals.
- Proper sensor placement is required for reliable data collection.

2. Motion Artifacts

- Body movements such as walking or hand motion introduce distortions in signals.
- PPG signals are highly sensitive to motion, causing inaccurate readings.
- Removing motion noise in real-time is a complex process.

3. Power Consumption

- Continuous monitoring leads to high battery usage.
- Limited battery life affects long-term operation.
- Designing low-power systems while maintaining performance is challenging.

4. Data Processing Complexity

- Simultaneous processing of ECG and PPG signals requires efficient algorithms.
- Real-time analysis without delay is difficult to achieve.
- Handling large volumes of continuous data is challenging.

5. Device Design Challenges

- Integrating multiple sensors into a compact wearable device is difficult.
- Ensuring comfort, durability, and lightweight design is necessary.
- Balancing size, performance, and cost is a major challenge.

3.2 Limitations

1. Limited Clinical Accuracy

- The device does not provide the same level of accuracy as hospital-grade ECG machines.
 - It is mainly suitable for monitoring purposes, not for complete medical diagnosis.
- Possibility of false positives or false negatives in detecting abnormalities
- Possibility of false positives or false negatives in detecting abnormalities.

2. Dependency on Battery Life

- Continuous monitoring leads to high battery consumption.
- Requires frequent charging, which may interrupt usage.
- Limited battery capacity restricts long-term continuous operation.

3. Sensitivity to Motion

- Accuracy decreases during physical activities like walking or running.
- Movement causes distortion in ECG and PPG signals.
- Difficult to obtain stable readings in active conditions.

4. Sensor Placement Issues

- Proper placement of ECG electrodes is essential for accurate readings.
- Incorrect positioning leads to inconsistent data.
- Users may find it difficult to maintain correct placement continuously.

5. Environmental Limitations

- External factors such as temperature, humidity, and lighting affect performance.
- PPG sensors are sensitive to ambient light interference.
- Sweat and skin conditions can reduce signal quality.

4. SYSTEM OVERVIEW

The proposed system consists of ECG and PPG sensors connected to a microcontroller. The ECG sensor is used to detect the electrical signals generated by the heart. These signals provide detailed information about heart rhythm and electrical conduction. The PPG sensor, on the other hand, uses light-based technology to measure blood volume changes in the body, which helps in determining pulse rate and oxygen levels. Both sensors send their signals to the microcontroller, which acts as the central processing unit. The microcontroller processes the input signals, filters noise, and calculates important parameters such as heart rate. The processed data is displayed on a screen such as an LCD or OLED display, allowing the user to view real-time information. Additionally, a wireless communication module like Bluetooth or Wi-Fi transmits the data to a smartphone or cloud platform. This enables remote monitoring by healthcare professionals.

4.1 Block Diagram Explanation

The proposed system for an integrated ECG-PPG wearable device consists of multiple functional blocks that work together to monitor cardiac activity in real time.

1. ECG Sensor Block

The ECG sensor is responsible for measuring the electrical activity of the heart. It uses electrodes placed on the body to detect electrical signals generated during each heartbeat. These signals help in analyzing heart rhythm and identifying abnormalities such as irregular heartbeats.

2. PPG Sensor Block

The PPG sensor measures blood volume changes in the body using light-based technology. It typically uses infrared or red light to detect variations in blood flow. This sensor is useful for calculating pulse rate and can also be used to estimate oxygen saturation levels.

3. Microcontroller Block

The microcontroller acts as the central processing unit of the system. It receives analog or digital signals from both ECG and PPG sensors and processes them. The microcontroller filters noise, analyzes the signals, and calculates important parameters such as heart rate and pulse rate. It also controls data flow to other components.

4. Display Unit

The display unit, such as an LCD or OLED screen, is used to show real-time cardiac data. It provides immediate feedback to the user by displaying values like heart rate, pulse rate, and other relevant parameters.

5. Wireless Communication Block

The wireless module enables the system to transmit data to external devices. Technologies like Bluetooth or Wi-Fi are used to send the processed data to a smartphone or cloud platform. This allows remote monitoring and easy access to health information.

6. Mobile/Cloud Monitoring System

The mobile or cloud system receives the transmitted data and displays it in a user-friendly format. Healthcare professionals or users can monitor the data in real time, store historical records, and analyze trends for better diagnosis and treatment.

project, ELM is used for efficient classification of intrusion data, reducing training time while maintaining good accuracy. It is particularly useful for large-scale IoT datasets.

5. HARDWARE COMPONENTS

The integrated ECG–PPG wearable system is built using several hardware components that work together to acquire, process, and transmit physiological data. Each component plays an important role in ensuring accurate and real-time cardiac monitoring.

5.1 ECG Sensor Module (AD8232)

The ECG sensor module is used to measure the electrical activity of the heart. It consists of electrodes that are attached to the human body to capture bioelectric signals generated during heartbeats. The AD8232 module amplifies and filters these weak signals to produce a clear ECG waveform. It is widely used due to its low power consumption and compact size, making it suitable for wearable applications.

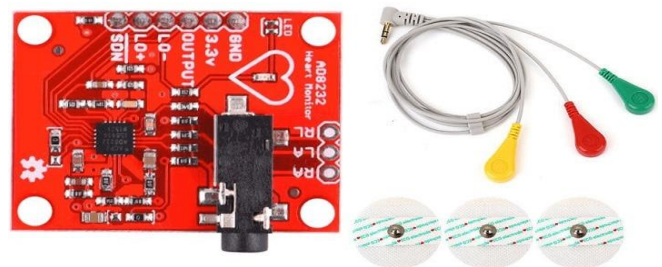


Fig 4.1 ECG Sensor Module (AD8232)

5.2 PPG Sensor Module (MAX30100 / MAX30102)

The PPG sensor is an optical sensor that measures changes in blood volume using light. It emits infrared or red light into the skin and detects the amount of light absorbed or reflected by blood vessels. The MAX30100 or MAX30102 modules are commonly used as they can measure pulse rate and oxygen saturation (SpO₂). These sensors are small, efficient, and ideal for wearable devices.

5.3 Microcontroller (Arduino / ESP32)

The microcontroller acts as the brain of the system. It collects signals from the ECG and PPG sensors and processes them. It performs signal conditioning, filtering, and calculation of parameters such as heart rate and pulse rate. Arduino is easy to use for beginners, while ESP32 offers additional features like built-in Wi-Fi and Bluetooth for wireless communication.

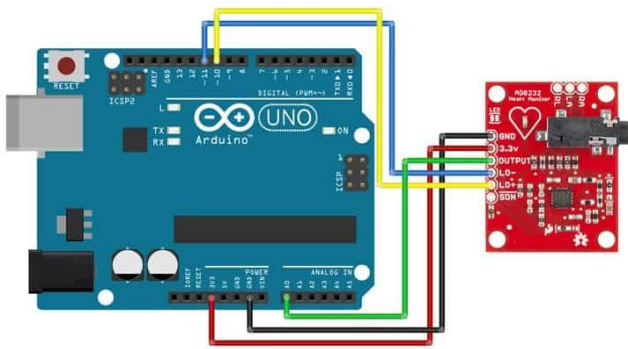


Fig: 4.3 Microcontroller (Arduino / ESP32)

5.4 Display Unit (LCD / OLED Display)

The display unit is used to show real-time data to the user. It displays parameters such as heart rate and pulse rate clearly. LCD (16×2) and OLED displays are commonly used due to their low power consumption and readability.

5.5 Wireless Communication Module (Bluetooth / Wi-Fi)

This module enables the system to transmit data wirelessly to external devices such as smartphones or cloud platforms. Bluetooth modules like HC-05 are used for short-range communication, while Wi-Fi modules like ESP8266 or ESP32 allow internet-based data transfer for remote monitoring.

5.6 Electrodes

Electrodes are used with the ECG sensor to detect electrical signals from the body. They are placed on specific parts of the body (such as chest or arms) to capture accurate heart signals. Good electrode placement is essential for reliable ECG readings.

5.7 Power Supply (Battery)

A battery is used to power the entire system, making it portable and wearable. Rechargeable batteries are commonly used to ensure continuous operation without frequent replacement.

5.8 Breadboard and Connecting Wires

A breadboard is used for assembling and testing the circuit without soldering. Connecting wires are used to establish electrical connections between all components. As shown in fig about the breadboard and connecting wires to a human body.

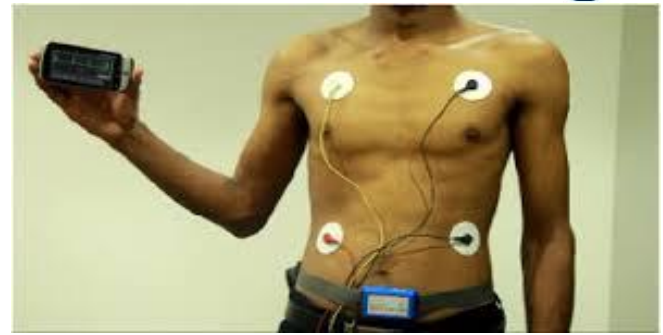


Fig: 5.8 Breadboard and Connecting Wires

6. SOFTWARE DESIGN

The software design of the integrated ECG–PPG wearable system focuses on acquiring sensor data, processing signals, calculating cardiac parameters, and displaying as well as transmitting the results in real time. The system is developed using embedded programming on a microcontroller platform.

6.1 Programming Environment

The software for this project is developed using the Arduino IDE or similar embedded development platforms. The programming language used is Embedded C/C++, which allows efficient control of hardware components and real-time data processing.

6.2 Data Acquisition

The first step in the software design is data acquisition. The microcontroller continuously reads input signals from the ECG and PPG sensors. The ECG sensor provides analog signals, which are converted into digital form using an Analog-to-Digital Converter (ADC). The PPG sensor provides digital or analog output depending on the module used.

6.3 Signal Processing

The acquired signals often contain noise due to body movement, external interference, or environmental conditions. Therefore, signal processing techniques are applied to improve accuracy.

- Filtering is used to remove noise and unwanted frequencies.
- Smoothing techniques help in obtaining stable signals.
- Peak detection algorithms are used to identify heartbeats from ECG and PPG signals.



6.4 Parameter Calculation

After processing the signals, the software calculates important cardiac parameters such as:

- Heart rate (beats per minute)
- Pulse rate
- Oxygen saturation (SpO₂) (if supported by the PPG sensor)

These calculations are based on detecting peaks in the signal and measuring the time interval.

6.5 Display Function

The processed data is displayed on an LCD or OLED screen. The software updates the display continuously to show real-time values such as heart rate and pulse rate, making it easy for users to monitor their health status.

6.6 Wireless Data Transmission

The system uses Bluetooth or Wi-Fi modules for wireless communication. The software sends the processed data to a mobile device or cloud platform. This allows remote monitoring and storage of health data for future analysis.

6.7 System Control and Integration

The microcontroller software integrates all modules and ensures smooth operation. It manages:

- Sensor data reading
- Signal processing
- Display updates
- Data transmission

The program runs in a continuous loop to ensure real-time monitoring.

6. WORKING PRINCIPLE

The integrated ECG–PPG wearable system works by continuously collecting, processing, and analyzing physiological signals from the human body to monitor cardiac activity in real time. The system combines electrical and optical sensing techniques to provide accurate and reliable heart health information.

Initially, the ECG sensor is attached to the body using electrodes placed at specific positions. This sensor detects the electrical signals generated by the heart during each

cardiac cycle. These signals represent the depolarization and repolarization of heart muscles and are essential for analyzing heart rhythm and detecting abnormalities.

7.1 Algorithms

The integrated ECG–PPG wearable system uses a set of algorithms to acquire signals, process data, detect heartbeats, and calculate cardiac parameters. These algorithms ensure accurate and real-time monitoring of heart activity.

7.2 ECG Signal Processing Algorithm

This algorithm is used to process the ECG signal and detect heartbeats.

Steps:

1. Start the system and initialize the ECG sensor and microcontroller.
2. Read analog ECG signal from the sensor.
3. Convert the analog signal into digital form using ADC.
4. Apply a bandpass filter to remove noise and interference.
5. Smooth the signal to reduce fluctuations.

7.3 PPG Signal Processing Algorithm

This algorithm processes the PPG signal to calculate pulse rate and related parameters.

Steps:

1. Initialize the PPG sensor.
2. Read PPG signal data continuously.
3. Remove noise using filtering techniques.
4. Identify peaks in the PPG waveform.
5. Measure time interval between peaks.

7.4 Integrated ECG–PPG Analysis Algorithm

This algorithm combines ECG and PPG data for better accuracy.

Steps:

1. Acquire ECG and PPG signals simultaneously.
2. Synchronize both signals using timestamps.
3. Detect R-peaks from ECG and pulse peaks from PPG.
4. Calculate Pulse Transit Time (PTT) as the time difference between ECG and PPG peaks.



5. Analyze combined data for improved accuracy of heart rate.

7.5 Data Transmission Algorithm

This algorithm handles wireless communication.

Steps:

1. Initialize Bluetooth/Wi-Fi module.
2. Establish connection with mobile device or cloud.
3. Format sensor data into readable form.
4. Transmit data periodically.
5. Check for transmission errors.

7.6 Display Algorithm

This algorithm updates the display with real-time data.

Steps:

1. Initialize display module.
2. Receive processed data from microcontroller.
3. Update heart rate, pulse rate, and other values.
4. Refresh display at regular intervals.

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8. IMPLEMENTATION

8.1 Hardware Implementation

In the hardware setup, all called according to system design. Electrodes are placed on the user's body (such as chest or arms) to capture heart signals accurately. The PPG sensor is connected using digital communication protocols such as I2C. It is placed on the fingertip or wrist to measure blood flow. Proper positioning of the sensor is important to obtain accurate readings. The display unit (LCD or OLED) is interfaced with the microcontroller to show real-time results. A wireless communication module, such as Bluetooth or Wi-Fi, is connected to enable data transmission. All components are powered using a battery, making the system portable and suitable for wearable applications. Connections are initially tested on a breadboard, and once verified, they can be implemented on a compact PCB for better stability and usability.

8.2 Software Implementation begins

The software is developed using the Arduino IDE or a similar embedded platform. The program is written in Embedded C/C++ and uploaded to the microcontroller. The software by initializing all hardware components, including sensors, display, and communication modules. The microcontroller continuously reads data from the ECG and PPG sensors. Signal processing techniques are applied to filter noise and improve signal quality. Algorithms are implemented to detect peaks in both ECG and PPG signals, which are then used to calculate heart rate and pulse rate. The calculated parameters are displayed on the screen and also transmitted wirelessly to a mobile device or



cloud platform. The system runs in a continuous loop to ensure real-time monitoring.

9. TESTING AND RESULT

9.1 Testing

Initially, all hardware components were checked individually to ensure proper functioning. The ECG sensor was tested by placing electrodes on the body and observing the waveform output. Similarly, the PPG sensor was tested by placing it on the fingertip to monitor pulse signals. After verifying individual components, the complete system was assembled and tested. The microcontroller was programmed, and real-time data from both sensors were monitored through the display and serial output. The wireless module was also tested to confirm successful data transmission to a mobile device.

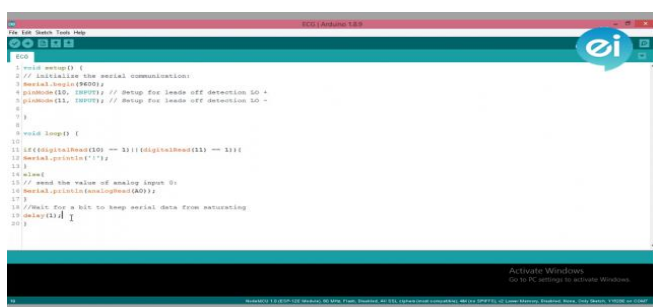
Different conditions were considered during testing, such as:

- Resting condition (normal state)
- Slight body movement
- Continuous monitoring for a period of time

This helped evaluate the stability and reliability of the system.

Uploading Sketch to Arduino:

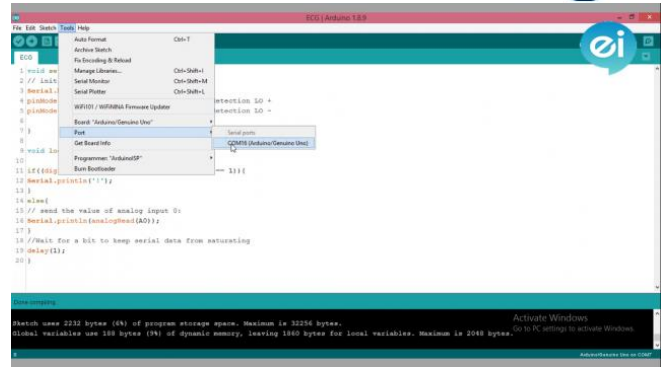
Take a new Arduino sketch, Copy and paste the above code.



Select the Arduino UNO board from Tools>>Board>>Arduino/Genuino UNO

Computer Hardware

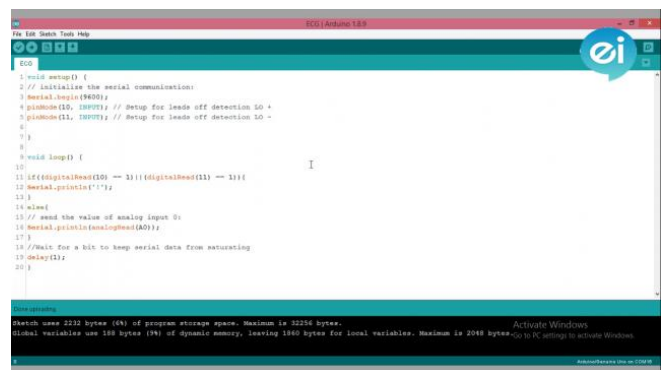
Select the port: Tools>> Port>> COMXX (Mine is COM16)



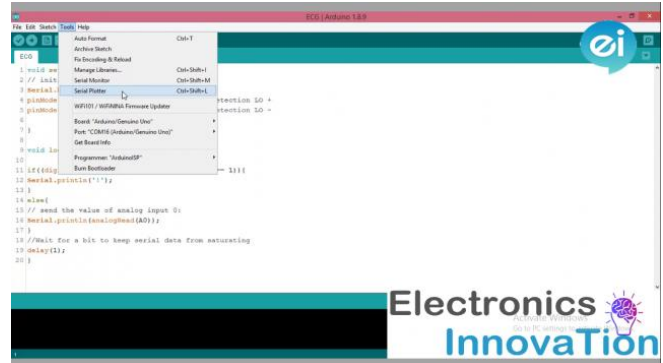
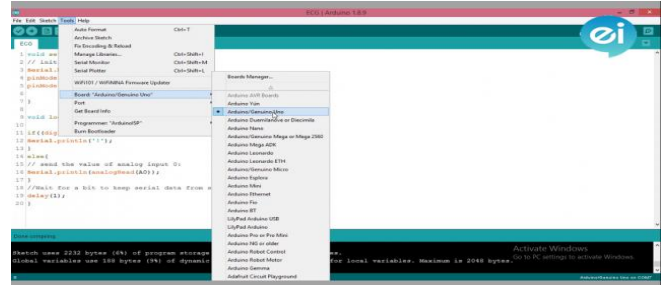
Tap on upload button:



Wait till the uploading process is done.



Open Serial Plotter: Tools>> Serial plot





9.2 Results

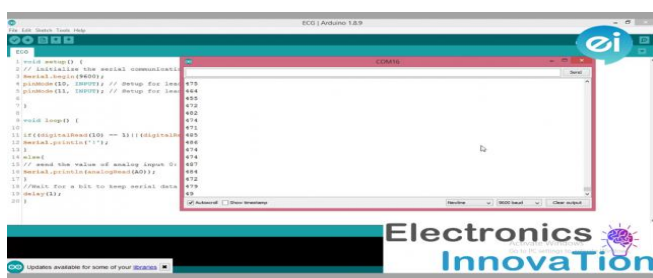
The system successfully measured and displayed heart rate and pulse rate in real time. The ECG sensor produced clear waveforms representing heart activity, while the PPG sensor provided stable pulse signals under normal conditions. The calculated heart rate values were found to be within a reasonable range when compared with standard measurements. The integration of ECG and PPG signals improved the accuracy of detection. The wireless module successfully transmitted the data to a mobile device, enabling remote monitoring. The display unit showed continuous updates without significant delay.

Here we have successfully interfaced AD8232 with Arduino and Derived the ECG waveform.

Medical Devices & Equipment



Let's see the same values on the serial monitor. Here we are getting 3 digits no. These 3 digits no are plotted on the serial plotter according to the time.



This is all about Low-cost AD8232 based ECG & Heart monitoring system using Arduino.

10.CONCLUSION

The integrated ECG–PPG wearable system developed in this project provides an effective solution for real-time cardiac monitoring. By combining Electrocardiography (ECG) and Photoplethysmography (PPG) technologies, the system is capable of measuring both electrical and physiological aspects of heart activity, resulting in improved accuracy and reliability.

The project successfully demonstrates the design and implementation of a compact, portable, and cost-effective wearable device. It is capable of continuously monitoring important cardiac parameters such as heart rate and pulse rate, and displaying them in real time. The inclusion of wireless communication further enhances the system by enabling remote monitoring, which is highly beneficial for modern healthcare applications.

Although the system has certain limitations such as sensitivity to motion and dependence on proper sensor placement, it still proves to be a valuable tool for basic cardiac monitoring. The results obtained during testing indicate that the system performs effectively under normal conditions and can be used for continuous health tracking.

Overall, this project highlights the importance and potential of wearable technology in healthcare. It provides a foundation for future developments in smart health monitoring systems, contributing to early detection of heart-related problems and improved patient care. The project successfully demonstrates the design of a portable and user-friendly device capable of continuously monitoring vital cardiac parameters such as heart rate and pulse rate. The use of a microcontroller for signal processing and a wireless module for data transmission enables real-time monitoring and remote access to health data.

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We would thank my parents and all the faculty members who have contributed to our progress through the course to come to this stage.



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