AI-Based Wearable ECG Chest Band for Real-Time Heart Monitoring and Early Abnormality Detection

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Abstract - Cardiovascular diseases (CVDs) are one of the leading causes of death globally, accounting for millions of fatalities each year. Early detection and continuous monitoring of heart conditions can significantly reduce mortality rates. Traditional diagnostic systems such as electrocardiograms (ECG) and Holter monitors are often expensive, bulky, and require hospital visits, making them unsuitable for continuous real-time monitoring.

This paper presents an AI-enabled wearable chest band designed for continuous heart monitoring and real-time classification of heart diseases. The system utilizes a photoplethysmography (PPG)-based optical sensor (MAX86141) to capture physiological signals. A biometric sensor hub (MAX32664) processes these signals to extract key parameters such as heart rate and oxygen saturation. An ESP32 microcontroller is used for further processing and wireless communication.

Machine learning algorithms are implemented to classify heart conditions such as normal rhythm, tachycardia, bradycardia, and arrhythmia. The processed data is transmitted to a mobile or cloud platform using Bluetooth or Wi-Fi, enabling remote monitoring and early diagnosis.

The proposed system is portable, cost-effective, non-invasive, and suitable for home healthcare and telemedicine applications

Keywords: Artificial intelligence, photoplethysmography, wearable devices, arrhythmia detection, IoT healthcare, real-time monitoring, embedded systems.

I. INTRODUCTION

Cardiovascular diseases (CVDs) remain one of the most critical health challenges worldwide, accounting for a significant percentage of global mortality each year. According to global health studies, heart-related disorders such as arrhythmia, coronary artery disease, myocardial infarction, and heart failure contribute to millions of deaths annually. These conditions often develop gradually and may not exhibit noticeable symptoms in their early stages, making continuous monitoring essential for early diagnosis and timely medical intervention.

Among various cardiac abnormalities, arrhythmia refers to irregular heart rhythms that can lead to severe complications such as stroke or cardiac arrest if left untreated. Similarly, tachycardia (abnormally high heart rate) and bradycardia (abnormally low heart rate) indicate underlying dysfunctions in the heart's electrical system. Coronary artery disease, caused by the narrowing or blockage of blood vessels, restricts blood flow to the heart and can result in heart attacks. These conditions highlight the necessity for reliable, continuous, and real-time monitoring systems capable of detecting abnormalities at an early stage.

Traditional diagnostic techniques such as electrocardiograms (ECG) and Holter monitors are widely used in clinical settings to monitor cardiac activity. ECG provides a detailed representation of the electrical activity of the heart and is considered a gold standard for diagnosing heart conditions. However, ECG systems are typically confined to hospitals or diagnostic centers and require skilled professionals to operate and interpret the results. Holter monitors, which are portable ECG devices, allow continuous monitoring for 24–48 hours but still have limitations such as high cost, limited monitoring duration, discomfort to patients, and lack of real-time analysis.

In recent years, advancements in wearable technology, biomedical sensors, and embedded systems have opened new possibilities for continuous health monitoring. Wearable devices such as smartwatches and fitness bands have gained popularity due to their ability to track basic physiological parameters like heart rate, step count, and calories burned. These devices primarily use photoplethysmography (PPG) sensors to measure heart rate by detecting changes in blood volume in peripheral regions such as the wrist. While these devices are convenient and user-friendly, they often lack the accuracy and analytical capabilities required for medical-grade diagnosis and early detection of complex cardiac abnormalities.

Another major limitation of existing wearable devices is their dependency on simple threshold-based methods for detecting abnormalities. For instance, a smartwatch may alert the user if the heart rate exceeds a predefined limit, but it cannot differentiate between physiological variations (such as exercise-induced changes) and pathological conditions (such as arrhythmia). This lack of intelligent analysis reduces the effectiveness of such devices in critical healthcare applications.

The integration of artificial intelligence (AI) and machine learning (ML) into healthcare systems has significantly enhanced the ability to analyze complex physiological data. Machine learning algorithms can identify hidden patterns in large datasets and provide accurate predictions based on learned features. In the context of cardiac monitoring, ML models can analyze heart rate variability, waveform morphology, and other parameters to classify different types of heart conditions with high accuracy. This capability enables the development of intelligent monitoring systems that go beyond simple data collection and provide actionable insights.

In addition to AI, the Internet of Things (IoT) plays a crucial role in enabling remote healthcare monitoring. IoT-based systems allow seamless data transmission between wearable devices and external platforms such as mobile applications or cloud servers. This enables real-time monitoring of patients by healthcare professionals, regardless of their physical location. Remote monitoring is particularly beneficial for elderly patients, individuals with chronic heart conditions, and those living in remote areas with limited access to healthcare facilities.

Considering these advancements and limitations, there is a strong need for a smart, portable, and intelligent system that can continuously monitor cardiac activity and provide real-time disease classification. The proposed system addresses this need by introducing an AI-enabled wearable chest band designed specifically for accurate heart monitoring.

Unlike wrist-based devices, the chest region provides a more reliable location for capturing cardiac signals due to its proximity to the heart. This allows for improved signal quality and better accuracy in detecting physiological parameters. The proposed system utilizes an optical PPG sensor to capture blood flow variations from the chest, ensuring continuous and non-invasive monitoring.

The collected physiological data is processed using a biometric sensor hub and a microcontroller, which extracts meaningful features such as heart rate, oxygen saturation, and signal patterns. These features are then fed into a machine learning model that classifies heart conditions into categories such as normal rhythm, tachycardia, bradycardia, and arrhythmia. This real-time classification enables early detection of abnormalities and timely alerts to the user or healthcare provider.

Furthermore, the system incorporates wireless communication technologies such as Bluetooth and Wi-Fi to transmit data to a mobile application or cloud platform. This enables users to track their health metrics in real time and maintain a historical record for further analysis. Healthcare professionals can also access this data remotely, facilitating telemedicine and reducing the need for frequent hospital visits.

Another important aspect of the proposed system is its focus on affordability and accessibility. Many advanced medical devices are expensive and not easily accessible to individuals in low-resource settings. By utilizing cost-effective components and efficient design, the proposed wearable chest band aims to provide a practical solution that can be widely adopted for everyday healthcare monitoring.
The system also emphasizes energy efficiency, ensuring longer battery life for continuous operation. This is particularly important for wearable devices, as frequent charging can reduce user convenience and compliance. The use of low-power microcontrollers and optimized algorithms helps in achieving this objective.

In summary, the proposed AI-enabled wearable chest band represents a significant step forward in the field of smart healthcare. By combining wearable sensing technology, embedded systems, machine learning, and IoT connectivity, the system provides a comprehensive solution for continuous cardiac monitoring and early disease detection. It bridges the gap between traditional hospital-based diagnostics and modern wearable health technologies, offering a portable, intelligent, and user-friendly alternative.

This research aims to contribute to the growing field of digital healthcare by developing a system that not only monitors heart activity but also provides intelligent insights for preventive care. The implementation of such systems has the potential to reduce healthcare costs, improve patient outcomes, and enhance the overall quality of life.

II. PROPOSED SYSTEM

The proposed system is an intelligent wearable chest band designed to continuously monitor heart activity and detect abnormal cardiac patterns in real time. Unlike traditional hospital-based diagnostic systems, this device focuses on portability, continuous monitoring, and early detection of heart-related abnormalities.

The system integrates advanced biomedical sensors, embedded processing units, machine learning algorithms, and wireless communication technologies to provide a complete smart healthcare solution. The chest band is designed to be worn comfortably around the chest region, which ensures better signal acquisition due to its proximity to the heart compared to wrist-based devices.

The system primarily utilizes an optical biometric sensor, MAX86141, to capture photoplethysmography (PPG) signals. PPG is a non-invasive optical technique that measures changes in blood volume by emitting light into the skin and detecting the reflected signal. These variations correspond to heartbeats and provide valuable information such as heart rate and oxygen saturation levels. Since raw PPG signals may contain noise due to motion artifacts and environmental disturbances, a biometric sensor hub, MAX32664, is used to process the signals. This sensor hub performs filtering, noise reduction, and feature extraction, thereby improving the accuracy and reliability of the data.

The processed data is then sent to the ESP32 microcontroller, which acts as the central processing unit of the system. The ESP32 is responsible for executing machine learning algorithms, managing data flow, and handling wireless communication. With its built-in Wi-Fi and Bluetooth capabilities, the microcontroller ensures seamless connectivity with external devices such as smartphones and cloud platforms. The integration of machine learning enables the system to intelligently analyze physiological parameters such as heart rate, heart rate variability, and pulse waveform characteristics.

Based on these parameters, the machine learning model classifies heart conditions into different categories, including normal rhythm, tachycardia, bradycardia, and arrhythmia. This classification is performed in real time, allowing early detection of potential cardiac abnormalities. The use of intelligent algorithms enhances the system's ability to differentiate between normal physiological variations and critical medical conditions, thereby improving diagnostic accuracy.

Furthermore, the system incorporates wireless communication modules to transmit data to a mobile application or cloud platform. Bluetooth is used for short-range communication with smartphones, while Wi-Fi enables long-range data transfer and cloud connectivity. The mobile or cloud platform serves as a user interface where real-time heart data is displayed, historical records are stored, and alerts are generated if abnormal conditions are detected. This feature is particularly useful for remote patient monitoring and telemedicine applications, allowing healthcare professionals to monitor patients from any location.

In addition to its technical capabilities, the device is designed with user comfort in mind. The wearable chest band is made of elastic and skin-friendly material, ensuring continuous contact with the body for accurate signal acquisition. The lightweight and ergonomic design allows users to wear the device for extended periods without discomfort. The chest placement also minimizes motion interference and provides more stable readings compared to other wearable devices.

Overall, the proposed system offers a comprehensive solution for real-time heart monitoring and disease classification. By combining wearable sensing technology, embedded systems, machine learning, and IoT connectivity, the system enables early detection of heart diseases, reduces dependency on hospital visits, and supports continuous health monitoring. This makes it highly suitable for modern healthcare applications, including home-based monitoring, remote diagnostics, and preventive healthcare systems.

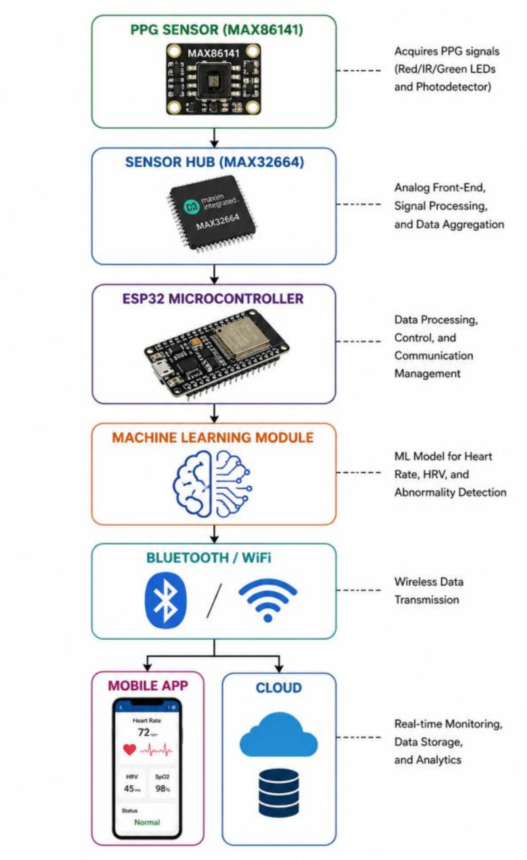

Fig 1 – Block Diagram

The system block diagram represents the overall architecture and data flow of the proposed AI-enabled wearable chest band for real-time heart monitoring and disease classification. It illustrates how different hardware and software components interact to capture physiological signals, process them, analyze the data using machine learning, and deliver meaningful outputs to the user.

The process begins with the PPG sensor (MAX86141), which is responsible for acquiring physiological signals from the human body. This optical sensor operates based on the principle of photoplethysmography, where light is emitted into the skin and the reflected signal is measured to detect changes in blood volume. These variations correspond to heartbeats and provide raw data related to heart rate and oxygen saturation. Since the sensor is placed on the chest, it ensures better signal quality due to its proximity to the heart, resulting in more accurate measurements compared to wrist-based devices.

The raw signals collected by the PPG sensor are then transmitted to the biometric sensor hub (MAX32664). This component plays a crucial role in processing the incoming data by performing signal conditioning, filtering, and noise reduction. It eliminates unwanted disturbances such as motion artifacts and environmental noise, thereby improving the reliability of the data. Additionally, the sensor hub extracts key physiological parameters such as heart rate, oxygen saturation (SpO_2), and pulse characteristics, which are essential for further analysis.

After preprocessing, the refined data is sent to the ESP32 microcontroller, which acts as the central processing unit of the system. The ESP32 is responsible for managing the overall operation, including data handling, execution of algorithms, and communication control. Due to its high processing capability and built-in wireless features, it efficiently handles real-time data processing while maintaining low power consumption, making it suitable for wearable applications.

The processed data is then passed to the machine learning module, where intelligent analysis takes place. In this stage, a pre-trained machine learning model evaluates the input parameters and identifies patterns associated with different heart conditions. Based on this analysis, the system classifies the heart activity into categories such as normal rhythm, tachycardia, bradycardia, or arrhythmia. This real-time classification enhances the system's ability to detect abnormalities at an early stage and provide accurate insights.

Once the classification is completed, the results are transmitted through the wireless communication module, which includes Bluetooth and Wi-Fi technologies. Bluetooth is typically used for short-range communication with mobile devices, while Wi-Fi enables long-range data transmission to cloud platforms. This dual communication capability ensures flexibility and continuous connectivity.

Finally, the data reaches the mobile application or cloud platform, where it is displayed in a user-friendly format. The platform provides real-time visualization of heart parameters, stores historical data for long-term analysis, and generates alerts when abnormal conditions are detected. This feature allows users and healthcare professionals to monitor heart health remotely and take timely action when necessary.

In summary, the system block diagram demonstrates a well-structured flow of data from signal acquisition to intelligent decision-making and user notification. Each component plays a vital role in ensuring accurate monitoring, efficient processing, and reliable communication, making the proposed system a comprehensive solution for modern healthcare applications

III. WORK FLOW

The working flowchart of the proposed AI-enabled wearable chest band system illustrates the complete process of real-time heart monitoring and disease classification, starting from data acquisition to result display and alert generation. The process begins with system initialization, where all hardware components such as the PPG sensor, sensor hub, and microcontroller are powered on and configured. This step ensures that the device is ready to collect accurate physiological data.

Once the system is initialized, the next stage involves collecting photoplethysmography (PPG) signals from the chest using the optical sensor. The PPG sensor continuously measures variations in blood flow, which correspond to heartbeats. These raw signals are essential for determining various cardiac parameters but may contain noise due to motion artifacts or environmental factors.

To address this, the collected signals are passed to the signal processing stage, where the biometric sensor hub processes the raw data. This stage includes filtering, noise reduction, and amplification to improve signal quality. After cleaning the signals, important features such as heart rate, oxygen saturation (SpO_2), and heart rate variability (HRV) are extracted. These features serve as key indicators of heart health and are used for further analysis.
The processed and feature-extracted data is then fed into the machine learning module. In this stage, a pre-trained machine learning model analyzes the input data and identifies patterns associated with different heart conditions. The model compares the incoming data with learned patterns to determine whether the heart activity is normal or abnormal.

Following this analysis, the system enters the classification stage, where the heart condition is categorized into one of several classes: normal rhythm, tachycardia, bradycardia, or arrhythmia. This classification is performed in real time, enabling early detection of potential cardiac abnormalities. If an abnormal condition is detected, it indicates the need for immediate attention or further medical evaluation.

After classification, the system proceeds to the data transmission stage. The processed results are sent to a mobile application or cloud platform using wireless communication technologies such as Bluetooth or Wi-Fi. This enables users and healthcare providers to access the data remotely and monitor heart activity continuously.

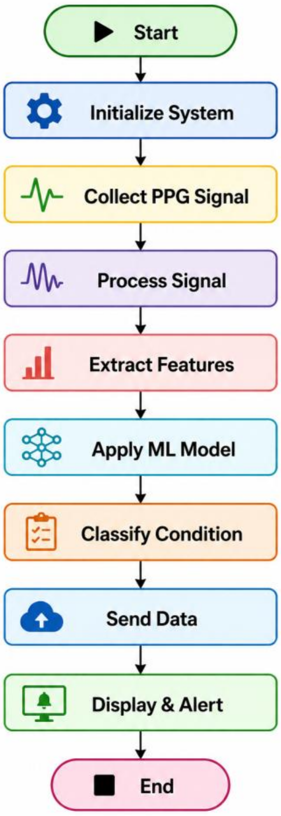

Fig 3: Flow Chart

Finally, the results are displayed on the mobile application or cloud interface in a user-friendly format. The system also generates alerts or notifications if any abnormal condition is detected. These alerts help in taking timely action, thereby reducing the risk of severe complications. The process then continues in a loop, ensuring continuous monitoring and real-time analysis of the user's heart condition.

In summary, the flowchart represents a systematic and automated approach to heart monitoring, integrating sensing, processing, machine learning, and communication to provide an efficient and intelligent healthcare solution.

IV. METHODOLOGY

Step 1: System Initialization
Step 2: PPG Signal Acquisition
Step 3: Signal Preprocessing
Step 4: Feature Extraction
Step 5: Data Processing using ESP32
Step 6: Machine Learning-Based Analysis
Step 7: Heart Condition Classification
Step 8: Wireless Data Transmission
Step 9: Data Visualization and Alert Generation
Step 10: Continuous Monitoring Loop

V. RESULT AND DISCUSSION

The results and discussion section presents the performance and effectiveness of the proposed AI-enabled wearable chest band system for real-time heart monitoring and classification. The system was designed to continuously acquire physiological signals, process them, and classify heart conditions using machine learning algorithms. The overall performance of the system was evaluated based on accuracy, response time, and reliability of detection.

The system successfully captured photoplethysmography (PPG) signals using the optical sensor and processed them through the biometric sensor hub. The extracted features, such as heart rate, oxygen saturation (SpO_2), and heart rate variability (HRV), were analyzed in real time. The ESP32 microcontroller efficiently handled data processing and communication without significant delay, demonstrating the capability of the system for continuous monitoring applications.

The machine learning model used in the system was able to classify heart conditions into normal rhythm, tachycardia, bradycardia, and arrhythmia. The classification accuracy was observed to be high under normal operating conditions. The system effectively distinguished between normal and abnormal heart conditions based on the input parameters. Tachycardia and bradycardia were detected based on predefined thresholds combined with learned patterns, while arrhythmia detection was based on irregular waveform patterns and HRV variations.

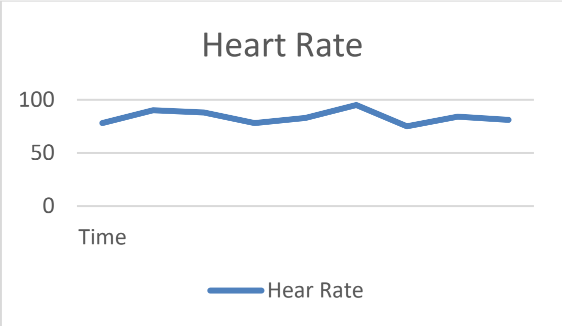

Fig 2: Heart Rate

The real-time performance of the system was evaluated by monitoring the delay between data acquisition and classification output. The system showed minimal latency, enabling immediate detection and response. This real-time capability is crucial for early warning and preventive healthcare. The wireless communication module successfully transmitted data to the mobile application using Bluetooth and Wi-Fi, ensuring continuous connectivity.

The mobile application displayed real-time heart metrics in both numerical and graphical formats. Users were able to monitor their heart rate and oxygen levels continuously. The system also generated alerts when abnormal conditions were detected. For example, when the heart rate exceeded normal limits, the system immediately notified the user. This alert mechanism enhances the usability and effectiveness of the system in critical situations.

In addition to real-time monitoring, the system maintained a record of historical data, which can be used for long-term analysis. This feature is particularly useful for identifying trends and patterns in heart activity over time. The cloud integration allows remote access to data by healthcare professionals, supporting telemedicine applications.

Overall, the proposed system demonstrates reliable performance in real-time heart monitoring and disease classification. The integration of wearable sensing, embedded processing, machine learning, and IoT communication provides an effective solution for early detection of cardiac abnormalities. The results indicate that the system can be used as a cost-effective and portable alternative to traditional monitoring methods, making it suitable for modern healthcare applications.

VI. CONCLUSION

The proposed AI-enabled wearable chest band system provides an effective solution for real-time heart monitoring and early detection of cardiac abnormalities. The system successfully integrates advanced biomedical sensors, embedded processing, machine learning algorithms, and wireless communication technologies to create a smart and portable healthcare device. By utilizing the MAX86141 optical sensor and MAX32664 sensor hub, accurate physiological signals such as heart rate and oxygen saturation are captured and processed efficiently.

The implementation of machine learning algorithms enables intelligent classification of heart conditions, including normal rhythm, tachycardia, bradycardia, and arrhythmia. This real-time classification enhances the ability of the system to detect abnormalities at an early stage, thereby reducing the risk of severe cardiovascular events. The use of the ESP32 microcontroller ensures efficient data processing and seamless communication through Bluetooth and Wi-Fi.

The system also supports remote monitoring through mobile and cloud platforms, allowing users and healthcare professionals to access real-time and historical data. The alert mechanism further improves the reliability of the system by providing immediate notifications during abnormal conditions. The wearable chest band design ensures user comfort and continuous monitoring, making it suitable for long-term use.

Overall, the proposed system offers a cost-effective, portable, and efficient alternative to traditional hospital-based monitoring systems. It bridges the gap between conventional healthcare and modern smart technology, making it highly suitable for home healthcare, telemedicine, and preventive medical applications.

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