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Affordable Real-Time Heart Rate, ECG & SpO_2 Monitoring System Using Internet of Things (IoT)

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Abstract: The healthcare industry now has an incomparable platform thanks to the Internet of Things technology, making it possible to quickly and effectively deal with challenges concerning healthcare. There has been a steady rise in the number of deaths due to sudden cardiac arrest (SCA) cases in developing countries and a lack of widespread use of an AED in these countries. The purpose of this study is to create an affordable Automated External Defibrillator (AED) that can be connected to IoT and can overcome certain drawbacks of the current AEDs. In the first phase of implementation, we attempt to create a Heart Monitoring System that can read Beats Per Minute (BPM), Electrocardiogram (ECG), and Saturation of Peripheral Oxygen (SpO2) using off-the-shelf sensors and display the data on a smartphone app. These sensors are connected to a Raspberry Pi 3b+, a single-board computer (SBC), which controls the entire system. The implementation of the system is successful, transmitting heart vitals to a smartphone app in real time. Further, the limitations of the system and future improvements are also discussed. The study builds a Heart Monitoring System under $67 with a few drawbacks. Further studies with better equipment are required to make the system accessible and less error-prone.
Keywords: Sudden Cardiac Arrest, Heart Monitoring System, Automated External Defibrillator, Heart Rate, Beats Per Minute (BPM), Electrocardiogram (ECG), Saturation of Peripheral Oxygen (SpO_2), Raspberry Pi 3b+, MAX30100 Pulse Oximeter, AD8232 ECG Sensor.

I. INTRODUCTION

Around 7 lakh individuals lose their life to Sudden Cardiac Arrest in India annually. If a cardiac arrest occurs, prompt treatment with a medical device known as an Automated External Defibrillator (AED) can save a person's life. An AED is a portable device that checks the heart rhythm and can deliver an electric shock to the heart to try to restore a normal rhythm. AEDs are used to treat sudden cardiac arrest (SCA). Sudden cardiac arrest happens when the heart abruptly and unexpectedly stops beating. When this happens, the blood supply to the brain and other essential organs stops. Sudden cardiac arrest can be fatal if not treated promptly. However, if it is treated within a few minutes, there is a significant chance of survival. AEDs are designed for use by laypeople with no medical training and can be found in a variety of public places, such as airports, shopping malls, and office buildings. Sudden cardiac arrest (SCA) is a medical emergency that needs to be treated right away. The lack of awareness in identifying the symptoms of SCA can lead to delays in seeking medical help, which can be fatal. Cardiopulmonary Resuscitation (CPR) is a life-saving technique that everyone should be aware of. It is a simple and easy-to-learn process that can mean the difference between life and death in an emergency like SCA. There are many reasons why people refrain from purchasing an AED, despite knowing that it could save a life. The high cost of an AED is often a deterrent, as is the lack of education on how to use the device. In addition, many people are simply unaware of the potential benefits of an AED and how it could potentially save a life.

In the US, sudden cardiac arrest is one of the leading causes of mortality. According to the American Heart Association, SCA kills more than 350,000 Americans every year. The majority of SCA victims have no prior symptoms and die within minutes. SCA is so abrupt and unexpected that bystanders are generally the only ones who can assist. CPR (cardiopulmonary resuscitation) is a life-saving technique that can be used on victims of SCA. However, CPR is only effective if it is performed immediately after the victim collapses. The use of an AED can also be lifesaving in SCA cases. An AED is a portable device that delivers an electric shock to the heart, which can stop an irregular heartbeat and restore normal heart rhythm. However, AEDs are often not used in SCA cases because they are expensive and many people do not know how to use them. As per the market research conducted by us, we have concluded that the market price of a good AED sums up to around ₹70,000 - ₹1,00,000. But this is not the only cost you need to incur to buy an AED. There are other costs too, which we will discuss in this post. Many costs need to be considered while buying an AED, apart from the market price of the AED itself: the cost of batteries, the cost of carrying a case, the cost of electrodes, and the cost of maintenance.

Your AED doesn't work without batteries. The batteries of an AED can last for 1 – 2 years, depending on the number of times the AED is used. Hence, it is important to consider the cost of batteries while deciding the overall cost of buying an AED. So, the project aims to develop a low-cost AED. Our project is an affordable version of an AED which is made at a fraction of the current cost.

The project is based on a microprocessor (SBC) – Raspberry Pi. It is interfaced with the sensors. The sensors are used to detect the heart rate. If the heart rate is abnormal, then Raspberry Pi sends a signal to the defibrillator. The defibrillator will then give a shock to the patient.

The project consists of two main parts: the hardware and the software. The hardware part consists of the circuitry and the sensors. The software part consists of the firmware which is programmed into the microprocessor. An affordable AED system can be a valuable tool in developing countries where access to emergency medical care may be limited. AEDs can be used to provide prompt treatment for sudden cardiac arrest, which is a life-threatening condition. By providing access to an affordable AED system, more people in developing countries can be trained in how to use these devices and be prepared to respond in an emergency.

II. LITERATURE SURVEY

1) *"Sudden cardiac death"* – A fluctuation in heart rhythm results in a sudden, unexpected death, referred to as sudden cardiac death (SCD). It is the leading cause of natural death in the United States, accounting for about 325,000 deaths each year. The paper notes that an implanted ECG or a ventricular electrogram recorded from an implanted device at the time of death can provide definitive information regarding the death. In many cases, SCD is caused by an abnormal heart rhythm called ventricular fibrillation (VF). VF is a chaotic, disorganized firing of the heart's electrical impulses that causes the ventricles to quiver uselessly instead of pumping blood. If VF is not treated immediately, it will lead to death within minutes. An implanted ECG can help doctors diagnose the cause of SCD. The electrical activity of the heart is examined through the use of an ECG check. It is often used to diagnose heart problems. An implanted ECG is a small device that is placed under the skin. It records the electrical activity of the heart and can be used to diagnose arrhythmias (abnormal heart rhythms). A ventricular electrogram (VEG) is a recording of the electrical activity of the heart from an implanted device. The device is usually a cardioverter-defibrillator (ICD), which is a device that is implanted into the chest and monitors the heart for abnormal rhythms. If an abnormal rhythm is detected, the ICD will deliver a shock to the heart to try to restore a normal rhythm. The ventricular electrogram is used to help the physician determine if the ICD is functioning properly and to help diagnose heart rhythm problems. [1]
2) *"Open-source automated external defibrillator"* – An automated external defibrillator (AED) is a portable device that delivers an electrical shock to the heart to treat sudden cardiac arrest (SCA). AEDs are accessible and may be located in plenty of public locations, including airports, workplaces, and educational institutions. An AED is a device used to deliver an electrical shock to the heart to restore its normal rhythm. It is a life-saving tool that can be used by anyone, regardless of their medical training. The AED has two main components: the battery and the electrodes. The battery provides the power for the AED, and the electrodes are placed on the patient's chest. The AED will automatically deliver a shock to the heart if it detects that the heart is in a life-threatening rhythm. The AED will also provide visual and auditory prompts to guide the user through the process of delivering the shock. The AED is a safe and easy-to-use device that can be the difference between life and death in a cardiac emergency. The Open-source automated external defibrillator (O-AED) is a low-cost AED that can be built using open-source hardware and software. The O-AED is designed to be easily assembled, and its software is based on the open-source AED software platform, which is freely available. The O-AED has been validated by third-party organizations, and its performance is comparable to that of commercial AEDs. The O-AED is a cost-effective solution for communities in need of AEDs, to save lives. [2]
3) *"Machine Learning Approach for Sudden Cardiac Arrest (SCA) Prediction Based on Optimal Heart Rate Variability (HRV) Features"* – There is no one best machine learning approach for predicting sudden cardiac arrest. The choice of machine learning approach should be based on the available data and the objectives of the prediction. The study found that support vector machines (SVMs) had the highest mean Sudden Cardiac Arrest prediction rate of 96.36%. This was significantly higher than the other prediction models studied which had mean prediction rates between 87.07% and 94.64%. The other methods used were k Nearest Neighbors (KNN), Decision Trees, and Naive Bayes. SVMs have several advantages over other methods, including the ability to handle nonlinear problems and the ability to scale to large datasets. [3]

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4) *"Real-Time System Prediction for Heart Rate Using Deep Learning and Stream Processing Platforms"* – The heart is an essential organ that circulates blood throughout the body. It is important to monitor the heart rate because an irregular heartbeat can be a sign of health problems. Rapid technological advancement has allowed healthcare sectors to consolidate and analyze massive health-based data to discover risks by making more accurate predictions. The proposed system consists of two phases: an offline phase, during which a model is developed using different forecasting techniques to find the lowest root mean square error; and an online phase. The Medical Information Mart for Intensive Care (MIMIC-II) was used to obtain the heart rate time-series dataset. Heart rate time series are subjected to the application of recurrent neural network (RNN), long short-term memory (LSTM), gated recurrent units (GRU), and bidirectional long short-term memory (BI-LSTM). The best-built model has been utilized to estimate the heart rate in advance for the online phase using Apache Kafka and Apache Spark. The GRU with three layers had the highest performance, according to the experimental findings. Consequently, heart rate has been predicted five minutes in advance using GRU with three layers. [4]
5) *"IoT-based System for Heart Rate Monitoring"* – The Heart Rate Monitoring system was created with the use of IoT technology with the aim of sensing the patient's heartbeat in order to track both the regular check-ups and the risk of a heart attack. To ensure that our health is in top shape, body health monitoring is crucial to us. The heart rate is an essential metric for the equipment under consideration (HR). The project outlines the development of a portable, low-cost heart rate monitoring device based on Bluetooth technology. The Bluetooth module, Android application, and Heart Rate module are only a few of the components that make up the overall system. The Heart Rate (HR) module collects heart rate data from the subject (patients) using a non-invasive method called Photoplethysmography and transmits it wirelessly to a computer or an Android application using a Bluetooth module. This system can be used in conjunction with other telemedicine components. The heart rate module's data can be stored and accessed for future medical applications. The results from the prototype of this device can be applied to a variety of clinical studies because the Bluetooth signal can be transmitted up to 20 meters. [5]
6) *"Advanced System for Heart Rate Monitoring Based on Internet of Things (IoT)"* – Monitoring heart rate is crucial for keeping the heart healthy. Age-specific heart rate thresholds, optimal, and minimum values are present in humans, and the heart rate control system is sufficiently compatible to address this issue. The article discusses a hardware system with a pulse sensor and an Internet of Things-based device that can track the heartbeat using sensor output data. Additionally, a warning system is integrated to send alerts when the pulse crosses a predetermined threshold or level. A programmed cell phone delivers the warning message to the doctor. This tool system will enable doctors to remotely monitor the patient's pulse data. Medical workers working at the hospital, such as nurses or doctors, will keep a close eye on the patient's heart rate. The database stores the patient's pulse and other private information that can be utilized to further monitor the patient's health. [6]
7) *"A Study on Heart Rate Monitoring Systems Using IoT"* – The sound of a person's heartbeat is made when the heart's valves contract or explain as they force blood to different parts of the body. Your heart performs a vital job in your cardiovascular system. A Heart Rate Monitor (HRM) should be a serious consideration if you want to maintain a better check on your general fitness. From wrist wearables to chest straps and more, we have included the top HRM. The article gives a thorough overview of the numerous heartbeat sensors and newly developed Internet of Things sensor devices (IoT). [7]
8) *"LDIAED: A lightweight deep learning algorithm implementable on automated external defibrillators"* – Automated External Defibrillator (AED) ability to distinguish between shockable and non-shockable Electrocardiogram (ECG) signals would enhance the effectiveness of resuscitation (AED). This study uses a Deep Neural Network (DNN) method to quickly classify shockable signals from non-shockable signals in 1.4-second segments. The suggested method has a 99.1% accuracy rate and is frequency-independent. It is trained using signals from a variety of patients taken from the MIT-BIH Malignant Ventricular Ectopy Database (VFDB), the Creighton University Ventricular Tachyarrhythmia Signals Database (CUDB), and MIT-BIH. The model's optimized version is then loaded onto the Raspberry Pi minicomputer. The implemented model was evaluated using unseen ECG signals, and the results showed that it met the IEC 60601-2-4 criteria with an average latency of 0.845 seconds. [8]
9) *"Realtime Heart Attack Detection System with AED Device Alert System"* – Health-related concerns and issues are of paramount importance to man in terms of existence and influence. Different systems that can collect and keep track of changes in health factors have been developed. This paper research describes real-time remote monitoring of heart rate. The heart rate can be monitored through this system's alert and LCD display. This study describes the implementation of a wireless module-based heart rate detection and alert system that is affordable, effective, and flexible. The heart rate is sensed and measured by the sensors, and the signals that are picked up are transferred to the control unit for further processing. The controller shows the heart rate on the LCD, followed by the alert system. [9]

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III. METHODOLOGY

A. Objective

Covid-19 has had a profound impact on the world, causing widespread panic and upheaval. One of the most visible effects of the pandemic has been the sudden increase in the price of pulse oximeters. Pulse oximeters are small devices that measure the oxygen level in your blood. They are commonly used by doctors and nurses to check the health of their patients and are essential for people with heart problems. During the Covid-19 pandemic, the price of pulse oximeters skyrocketed, leaving many people with heart problems stranded without access to this vital piece of equipment, while people with heart ailments were left stranded in long queues for an ECG test. Our system seeks to address this problem by making single-lead ECG testing available to the masses. Our system is simple to use and affordable and can be used by people without any special training. By making ECG testing more accessible, we can help to reduce unnecessary crowding at hospitals and allow more people to test themselves at home. This will help to relieve the pressure on the healthcare system and ensure that people with heart problems get the treatment they need.

B. Implementation

The proposed system relies on the use of two sensors to measure various physiological parameters of the patient. The first sensor is the MAX30100, which is used to measure the blood oxygen level and pulse rate of the patient. The second sensor is the AD8232, which is used to measure the electrocardiogram (ECG) of the patient. The data from these sensors is processed by the Raspberry Pi 3b+ and is then relayed to the Blynk IoT app. The Blynk app is used to visualize the data and to make decisions about the treatment of the patient.

The MAX30100 is a sensor that is used to measure the blood oxygen level and pulse rate of the patient. The sensor works by shining a light on the finger of the patient and then measuring the amount of light that is absorbed. The amount of light that is absorbed is then used to calculate the blood oxygen level and pulse rate of the patient. The MAX30100 sensor uses the I2C protocol to start the sensor and transfer data to the Raspberry Pi. (Refer to Fig. 1 and Fig. 2)

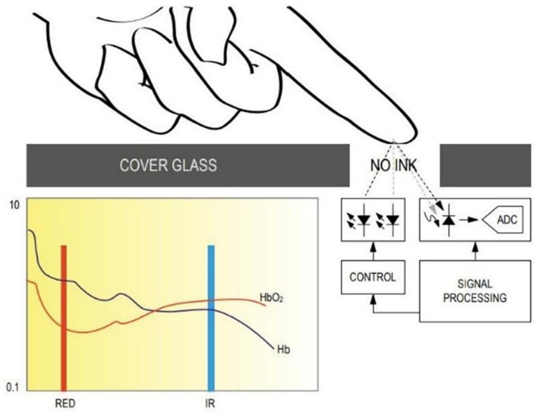

Fig. 1 Block diagram of MAX30100 pulse oximeter sensor

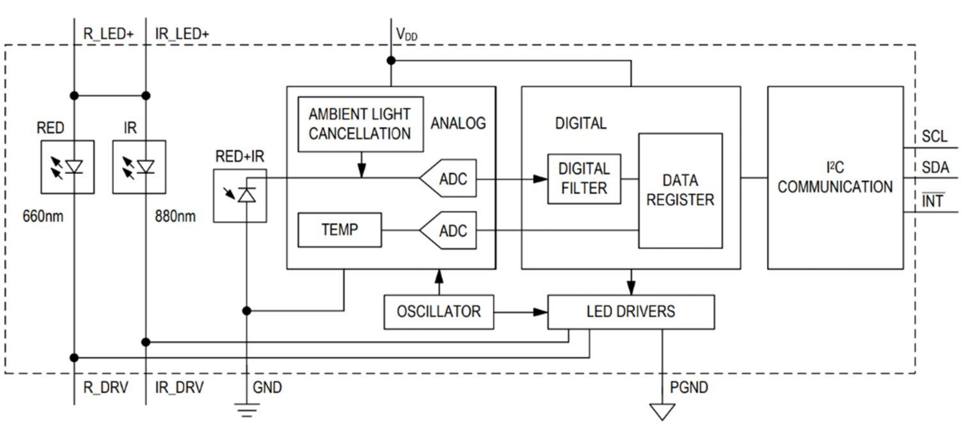

Fig. 2 Architectural diagram of MAX30100 pulse oximeter sensor

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The AD8232 is a sensor that is used to measure the ECG of the patient. The sensor works by measuring the electrical activity of the heart. The data from the sensor is then used to calculate the heart rate of the patient. As the AD8232 outputs only the analog data it was not compatible with the Raspberry Pi 3b+. This required a new module, MCP3008, an analog-to-digital converter to convert the analog data and transfer it to the Raspberry Pi using the SPI interface.

The data from the sensors is processed by the Raspberry Pi 3b+. The Data coming from the ECG machine is first validated by the pins LO- and LO+ for correction of erroneous data while the implementation of the MAX30100 sensor uses an average of values and max to handle outliers in the data and filter them out.

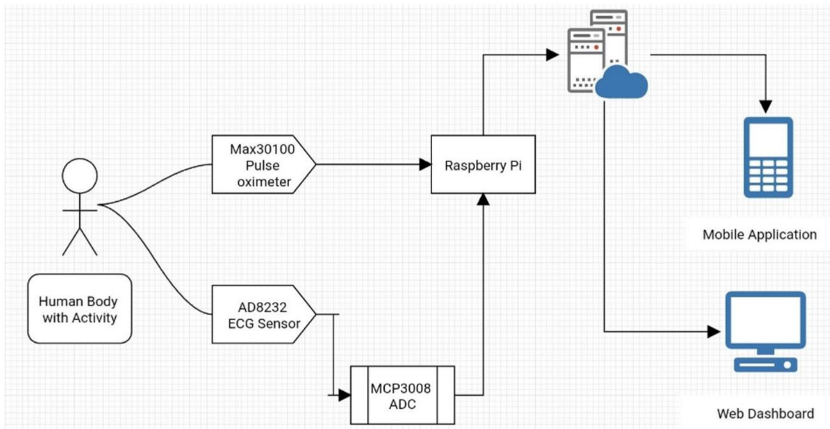

Fig. 3 System top-level architecture

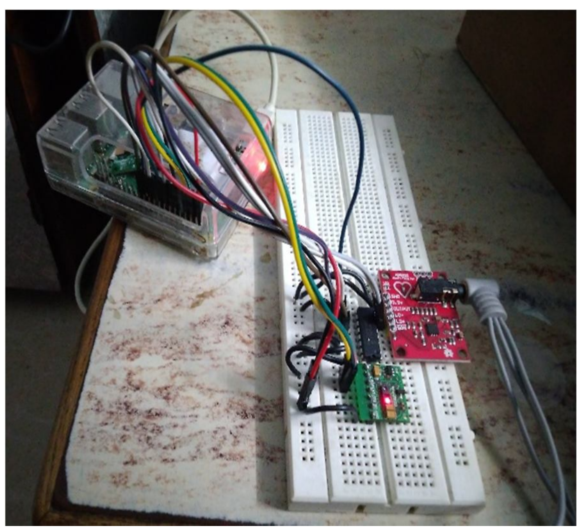

Fig. 4 System implementation

One of the challenges faced using the AD8232 sensor is to keep the Raspberry Pi reading the signal when the ECG pulse is detected by the sensor and related to the SBC. The AD8232 sensor is an analog sensor with no buffer to store data. This was problematic during the first implementation of the system when the inputs from the sensors would be taken and uploaded to the cloud in a cyclic order one at a time. This led to a loss of data from both sensors. This problem is overcome using multithreading on the Raspberry Pi. Three threads are created, the first one for reading the AD8232 sensor, the second for reading the MAX30100 sensor, and the third thread for managing all other tasks and uploading all the data. The data from the sensors is then stored inside a global array which is accessible to all the threads.

The data is then pushed to the Blynk Cloud via the API provided. This data is visualized on devices with the Blynk app or the Blynk web dashboard. Using a multithreaded system greatly increases the system throughput as the AD8232 and MAX30100 sensors transferred data at higher speeds while the speed for uploading the data is comparatively slow in nature. Rewriting the code and using multithreading helps with getting more consistent results from the system. (Refer to Fig. 3)

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IV. SYSTEM REQUIREMENT

A. The following hardware components are required for implementing the system –

1) ECG Sensor AD8232
2) Pulse Oximeter MAX30100
3) Raspberry Pi 3b+
4) MCP3008 analog to digital converter
5) Smartphone

B. The following software and firmware are required for implementing the system –

1) Raspberry Pi OS
2) Blynk IoT App
3) Python 3.7

V. RESULT

As seen in Fig. 5, the readings during the first implementation were underwhelming and not fit to be used to infer any medical conditions. The erroneous data due to the cyclic read method of sensor data was clearly the problem plaguing the system.

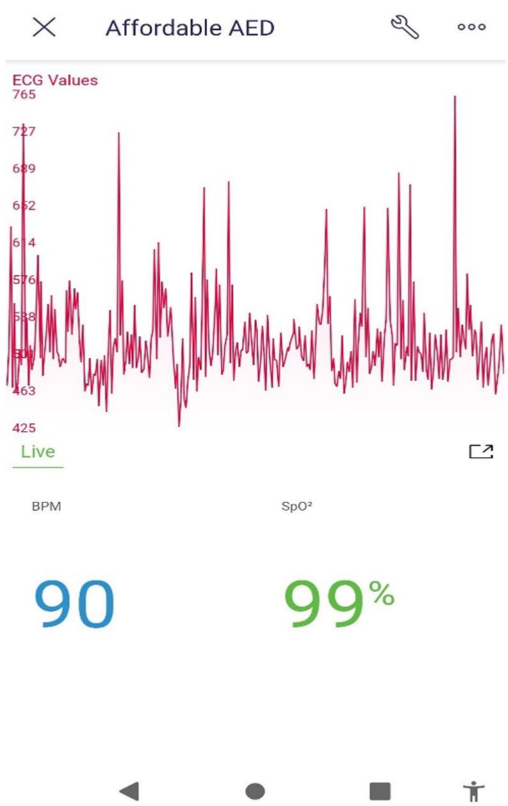

Fig. 5 Readings from the first implementation

Overcoming these issues, the second implementation reads data without any major problems. This implementation does a better job of getting and presenting the data. The SpO_2 data coming from the MAX30100 sensor has most of the errors in the data filtered out. This leads to a very accurate SpO_2 reading when compared to a medical-grade oximeter. However, the same cannot be said about the ECG data. Even after filtering the data from the AD8232 sensor, the readings are sometimes inaccurate. The sensor is susceptible to errors due to talking or the movements of the test subject and loose contact among the wires and cables used in the system. Yet these ECG readings are more consistent and reliable as compared to the readings of the first implementation. (Refer to Fig. 6)

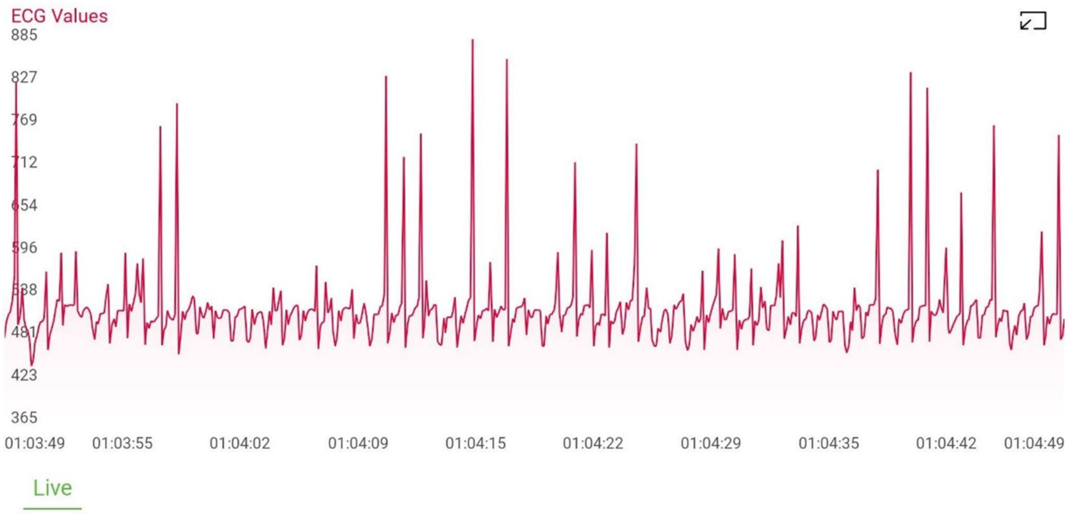

Fig. 6 ECG readings from the second implementation

As these sensors are non-destructive testing in nature, they are highly susceptible to errors due to external factors. In the case of the MAX30100 sensor, the excess ambient light causes the sensor to provide faulty readings, and nail paint and dirty hands also cause errors. Excessive sweating, involuntary movements or even talking causes errors in ECG data. It was a major challenge to create a system immune to these errors. The current system, based on the readings, accounts for these errors and filters them to a certain extent.

VI. LIMITATIONS

While working on the system we identified the following limitations of our current implementation –

1) The MAX30100 sensor is susceptible to external factors such as sunlight or ambient light. It also requires that the patient doesn't apply any nail paint on their nails for accurate readings.
2) The AD8232 sensor has 3 electrodes and can theoretically form 6 leads by changing the polarity of the electrodes. However, the sensor performs only a single lead.
3) The ECG reading from the sensor is inaccurate and a better filter is required to solve this issue.
4) External factors such as body hair and sweat also add errors in the ECG data.
5) The system is also affected by internet connectivity and upload speeds.
6) As the speed of data being read and the data being uploaded and displayed is not the same there can be instances where the reading displayed might be a previous reading and be confused with the current reading.
7) The system aims to also implement an SCA detector using the ECG values and a pulse mechanism but the ECG readings were not reliable enough to implement such a system.

VII. FUTURE ENHANCEMENTS

The following improvements are expected to take place in future implementations –

1) Better filter for the ECG data.
2) Implementation of an SCA detector using the ECG values using ML.
3) Implementation of a pulse delivery mechanism using ML.
4) A new enclosure for the system to reduce errors due to external factors.
5) PCB implementation of the system, as the current implementation uses a breadboard and jumper cables and is susceptible to loose contact.
6) A data storage system to store and share ECG data with medical professionals.

VIII. CONCLUSION

Correct detection of ECG is important in the first place, which allows medical experts and emergency services to respond quickly to save patients' lives. In this project, we attempt to create a better version of the existing AED in the current market.

Covid19 had a profound impact on the prices of healthcare equipment prices. In the first phase, we created a heart monitoring system that successfully sent BPM, SpO_2, and ECG data to the smartphone via a cloud platform. This system is an attempt to bring critical medical equipment to households at an affordable rate, thereby reducing crowding at hospitals. The entire system was made for under 5000 INR (67 USD. Oct 2021).

The drawbacks of the system can be overcome with better sensors and filtering techniques. Studies in the future and improved sensors will be able to rectify these problems.

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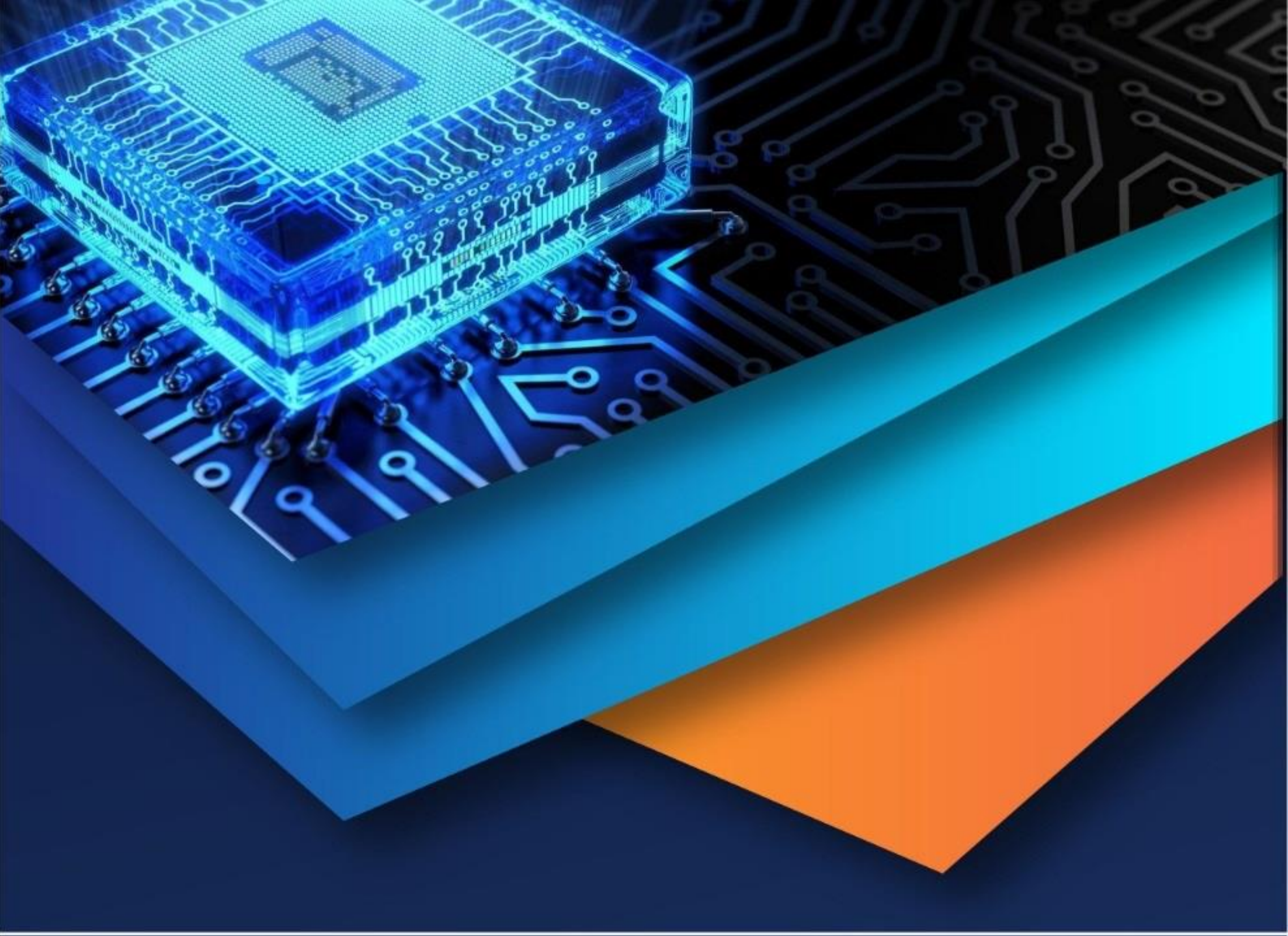

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