A Wireless Early Prediction System of Cardiac Arrest through IoT

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***Abstract*- The increase in popularity for wearable technologies has opened the door for an Internet of Things (IoT) solution to healthcare. One of the most prevalent healthcare problems today is the poor survival rate of out-of-hospital sudden cardiac arrests. The objective of this study is to present a multisensory system using IoT that can collect physical activity heart rates and body temperature. For this study, we implemented an embedded sensory system with a Low Energy (LE) Bluetooth communication module to collect ECG and body temperature data using a smartphone in a common environment. This study introduces the use of signal processing and machine learning techniques for sensor data analytics for sudden cardiac arrest and or heart attack prediction.**

Keywords- IoT, ECG, Heart-rate, Smartphone, Heart attack.

I. INTRODUCTION

The increase in popularity for wearable technologies has opened the door for an Internet of Things (IoT) solution to healthcare. One of the most prevalent healthcare problems today is the poor survival rate of out-of-hospital sudden cardiac arrests. All existing systems for predicting cardiac arrest in the elderly mainly consider the heart rate parameters. By 2050, it is estimated that more than one in five people will be of age 65 or over [1, 15]. Heart diseases in the elderly seem to be a very common occurrence, and approximately, one-third to one-half of the elderly population experiences heart attack or cardiac arrest repeatedly on a yearly basis [2]. Our research tries to address this problem by focusing on ECG signals' analysis and detection that will eventually lead to a risk prediction. Since abnormal ECG patterns can lead to a heart attack, our system uses the identification of an abnormal heart-rate to alert the user regarding a potential heart attack.

In an aging society, heart attacks have huge consequences since they tend to cause tremendous concerns as related to deterioration in the quality of life and an increase in the cost of healthcare. Although there has been a great deal of research on automatic heart attack detection, the area of risk of heart attack prediction is still lacking in study and investigation. The need to identify all the possible patterns that can lead to a heart attack is very challenging.

Historically, seniors living all around the world have been known to be late adapters to the world of technology compared to their younger neighbors, but their movement into digital life is continuing to expand. Today, 59% of seniors report that they go online, and 47% say they have a high-speed broadband connection at home. In addition, 77% of them have a phone and among that number, 18% are using smartphone devices [3, 17]. With recent developments, smartphones have increased processing capabilities and are equipped with several built-in multimodal sensors, including accelerometers, gyroscopes, and GPS interfaces. As self-contained devices, smartphones present a common commodity and software environment for developing various cardiac arrest or heart attack detection systems. Smartphone-based heart risk detection systems can function almost everywhere since mobile phones are highly portable. Ideally, integrated sensors along with the ECG can automatically detect a risk of injury due to heart variability [4]. Due to these and several other advancements in mobile technology, the elderly may increase their smartphone use.

However, these existing cardiac arrest and heart attack detection systems [4] can detect a risk only after it has already occurred, following which the system sends an alarm to the caregivers. The ideal way to reduce the number of risks is to alert the users about their abnormal heart rate and bring to their attention that they are at a risk of a potential heart attack. If abnormal ECG patterns can be accurately identified using automated processes, the elderly may be able to avoid injury from a potential heart risk.

Therefore, our focus is on heart risk prediction rather than detection. The objective of this study is to present a multisensory system that can collect heart rates and body temperatures. For this study, we implemented an embedded sensory system with a Low Energy (LE) Bluetooth communication module to collect ECG and body temperature data using a smartphone in a common environment. This study introduces the use of signal processing and machine learning techniques for sensor data analytics for sudden cardiac arrest and or heart attack prediction. Our proposed system will be useful not only to the elderly, but also has a scope in identifying heart disease among children, adults and stroke patients, physical rehabilitation patients, and human behavior analysis research.

A. Major Contributions

In this paper, we propose to use smartphones as the platform for developing an embedded system for predicting heart attacks; because they naturally combine the detection and communication components. Our major contributions are as follows:

- *developed a multisensory embedded IoT system for heart attack prediction.*
- *proposed a smartphone-based heart assistance system with a wearable ECG and temperature sensor for elderly people as a novel application for predicting cardiac arrest.*

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- *designed, developed, and implemented a self-heart assistance system which analyzes heart rate and body temperature.*

The rest of the paper is organized as follows: in the next section, we describe the relevant related work. In this section, we also discuss the difference between our system and the existing ones. Then, we discuss the details of the proposed system. This section is followed by the evaluation of our smartphone-based prototype system. Finally, we conclude the paper with some future research directions.

II. RELATED WORK

Risk identification using ECG patterns with embedded sensors has been the subject of much study over the past decade. Most of the previous approaches regarding heart rate recognition utilize ECG sensors attached to the subject for gathering data. Therefore, they have very limited accuracy in predicting cardiac arrest.

There has been a lot of work done that we can relate to. It's important for us to learn about related work to see what aspects we can improve on. EHealth is a very common topic for research and many companies have taken advantage of that by designing systems that connect patients with doctors around the world. "PatientsLikeMe" have launched its first online community in 2006 and its main goal was to listen to patients to identify outcome measures, symptoms, and treatments. It is mainly focused on helping patients answer the question: "Given my status, what is the best outcome I can hope to achieve, and how do I get there?" [5]. They answered patient questions in several forms like having patients with similar conditions connect to each other and share their experiences.

"DailyStrength" is a social network centered on support groups, where users provide one another with emotional support by discussing their struggles and successes with each other. The site contains online communities that deal with different medical conditions or life challenges [6]. Two major differences between "PatientsLikeMe" and "DailyStrength" is that "DailyStrength" does not involve research institutes and does not have a mobile application. However, they are both global platforms that are very helpful for patients with health problems. "PatientsLikeMe" is more of a platform where patients share experiences of same symptoms while "DailyStrength" gives patients the option to talk to doctors.

Everyday IoT systems produce content relating to health and wellness [7-10]. Even though a large number of companies provide health services, none of them have the feature of providing hardware devices that can be used by patients to monitor their everyday activities and alert them when needed. There are a lot of heart monitors out there that provide users with their ECG signals so they can keep track of their condition but none of which who alert the users upon emergencies. "Qardiocore" [11-12] is a very well-known and high quality heart monitor that tracks a user's complete heart health and displays it on smartphones. The device yields very accurate results and is one of the best products in the market in terms of showing real time graphs of ECG and EKG. However, it only allows users to share data with their doctors upon receiving it in an offline manner, it does not give them the option of alerting them in real time when their heart is at a serious condition and it certainly does not predict heart attacks. Neither of the above systems have the capability of predicting heart attack.

To address the drawbacks of the above-mentioned research, in this paper, we propose an embedded IoT system for cardiac arrest prediction. Our system is designed to address directly some of the drawbacks of the existing systems and potentially yield good prediction results. The most important aspect of our system is the warning that allows the user to prevent an injury before it actually happens. To the best of our knowledge, our system is the first smartphone-based heart assistance which uses an embedded IoT system for predicting heart related injuries.

III. ARCHITECTURE OF THE SYSTEM

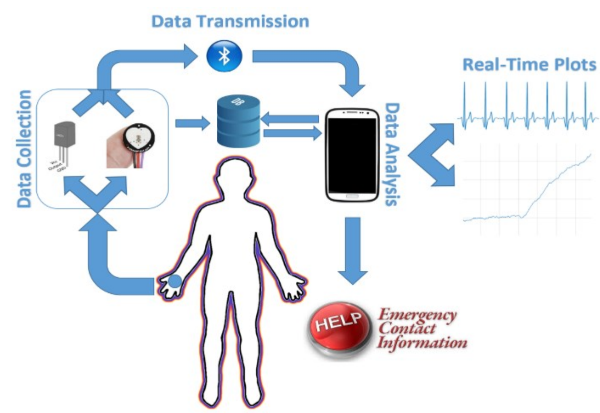


Figure 1. System architecture of the system

The strength of our proposed architecture is relying on existing wireless communications to provide a low power with maximum freedom of movement to users in their physical activity. In addition, we have used small, light-weight devices that are user friendly.

To integrate the sensors, we will use output of the embedded sensors to perform an extensive set of experiments for evaluating and discriminating between normal and abnormal heart rate patterns. Subjects will wear the embedded sensors, and carry their smartphone in their pockets or hold it in their hands. The embedded ECG and temperature sensors will constantly collect the heart parameters while the subject is living a normal life. After receiving the data through a low energy (LE) Bluetooth communication, the smartphone will process the data to classify whether the user's condition is normal or abnormal. A quantitative heart-rate analysis will be performed on the Android platforms which will give the user the option of viewing his/her real-time plots of their ECG signal and body temperature [17].

To determine abnormal heart patterns, we first will establish a criterion for normal heart-rate. Quantitative analysis of heart rate stability and pulse symmetry will yield a series of parameters, like elevated ST and heart rate. An early warning system will be designed that will monitor these parameters for a subject's signs of cardiac arrest during an activity. Though the system will continuously monitor ECG patterns, the planned design will only trigger a warning if the ECG patterns or body temperature of the user reaches a certain point where the user might face a potential heart attack. At that moment, the system will send out a warning to the user in the form of an audio message or a vibration alert. If the condition is too serious it will also send an alert to the emergency contact that the user has listed since the user might not be able to approach help while having a heart attack.

Figure 1 shows the basic flow of the system's architecture. All the components will be discussed in detail in the next section but mainly the IoT device constantly collects data from the users and sends it via Bluetooth to the application as shown in the Figure. The application is where all the processing and data analysis take place. As mentioned, the user has the option to view his/her real-time plots which will give him/her a basic idea of his/her body's status. The user does not have to keep track of his/her data to make sure that s/he is okay since the application's job is to alert the user upon an emergency. Finally, when the application senses an abnormality it either alerts the user or sends an alert to the emergency contact depending on how serious the condition is.

A. Design Overview

In the system, the ECG and temperature sensors are used to collect the raw ECG patterns and body temperature while the user is walking. Then, the resultant outputs are processed inside the mobile phone to identify the user's ECG pattern. Though the system continuously monitors for ECG patterns and body temperature, it only triggers a warning if the ECG pattern and body temperature of the user reaches a certain threshold where the user might face a potential heart attack. At that time, the system warns the user with a message and vibration to alert them about an imminent cardiac arrest.

B. Physical Implementation

IV. HARDWARE

The IoT system consists of a pulse sensor, a temperature sensor, an Arduino, and a Low Energy (LE) Bluetooth which are listed in Figure 2. A smartphone is used to collect sensors data.

The Arduino is used as an analog to digital converter (ADC) [19]. The Arduino will be programmed to read an analog signal from the ECG and temperature sensors and create a data packet to convert the signal into digital form. Subsequently it will send those packets to the phone as a response to the data sending request. It will also manage the Bluetooth communication by coordinating with the LE Bluetooth chip. The Bluetooth chip basically equips the Arduino with the ability to connect to the smartphone application.

The data read from the sensors is always an analog value between 0 and 5 volts since that's the operating voltage of the microcontroller. The Arduino then maps those voltage values to digital values ranging from 0 to 1023. The idea is to read the sensor value from the Arduino through analog pin 0 and then multiply it by five and divide it by 1023 to get the correct voltage value. This only applies to the pulse sensor since the expected output from the temperature sensor is in degrees Celsius. Similarly, we read the sensor value through an analog pin and use an equation to get the temperature in Celsius.

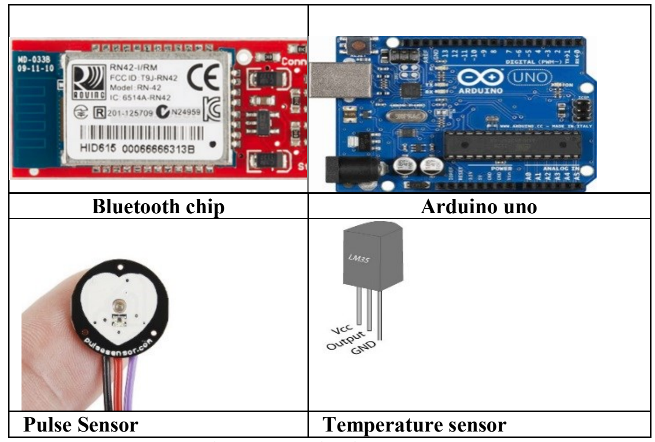


Figure 2. IoT hardware components

To avoid reading inaccurate values from the Arduino, we not only need a delay between each reading but also need to read from the same analog pin twice. So basically, we read the temperature data from the sensor twice and send the second reading, then do the same for the pulse sensor. Of course, we need to send different symbols before the sensor readings to be able to parse the data at the receiving end (android application) [18].

V. EVALUATION OF THE SYSTEM

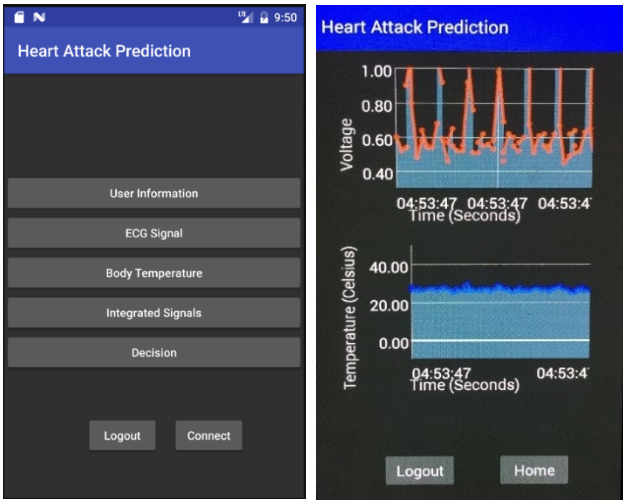
To evaluate our proposed system, we have developed a prototype application and investigated its performance. We evaluated the prototype with extensive experiments. In this section, we first introduce how the data is collected. Then we present how the data is analyzed and performance is measured.

A. Experimental Setup

To test the effectiveness of our proposed model, we collected data from ECG and temperature sensors using a smartphone. We used multiple subjects and collected data for different events of user daily activity. Data for each subject was collected from a smartphone placed in the subject's hand or a pocket.

B. Data Collection

The screenshots of the prototype application are shown in Figure 3. In Figure 3(a), the sensors data collection interface is shown while walking which is used to collect users' ECG pattern and body temperature for a period of time. We can also monitor temperature variation and ECG patterns with graphical representation on a smartphone which is shown is Figure 3(b). We have used our prototype application for data collection and for evaluating our system.



(a) Sensors data collection interface

(b) Real-time ECG and temperature monitoring on a smartphone

Figure 3. Screenshots of system prototype

We collected data for different test subjects in different environments for 160 samples in per second. Each segment is 25 seconds long. The collected sample data is shown in Figure 4. We collected sensor data for sitting, walking, and climbing upstairs.

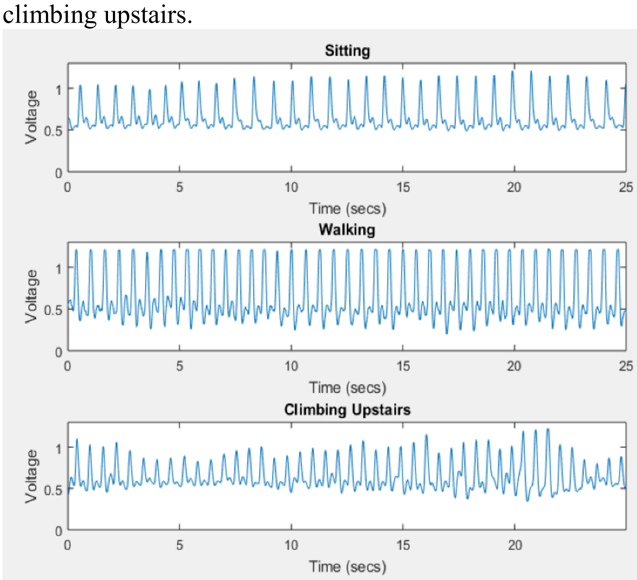


Figure 4. Heart rate variations of a test subject while sitting, walking and climbing upstairs

We first used these datasets for training our system. Later we used the trained system with real people to verify the detection accuracy of the proposed system.

TABLE I. STATISTICS ABOUT SUBJECTS PARTICIPATING IN OUR DATA COLLECTION.

Gender	Age [yrs.]	Height [cm]
F: 3	21-24: 3	150-159: 4
M: 7	25-30: 4	160-169: 2
	30-35: 3	170-179: 2
		180-200: 2

Since we cannot test potential heart attack or cardiac arrest with the people who have experienced heart attacks, we recruited 10 participants from both genders including a variety of age groups, and a range of heights (see Table I for statistics).

The IoT device components used for data collection are shown in Figure 5.

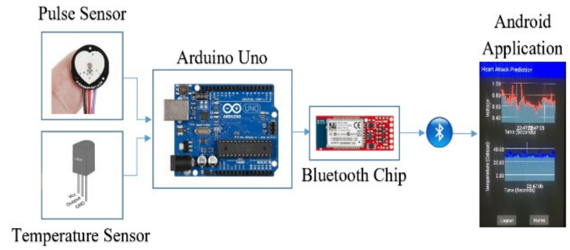


Figure 5. Sensor' data collection interface

C. *Result Analysis*

In this section, we discuss the performance of the proposed smartphone-based embedded IoT system.

In signal processing, noise is a general term for unwanted alterations that a signal may suffer during collecting, storing, transmitting, or processing [20-21]. In our system, we are collecting data from analog sensors and transmitting them via a low energy Bluetooth communication channel. The readings can be affected through the process of the transmission. Therefore, we need data enhancement techniques before we can start analyzing the data. The reason why this is very important is because a noisy signal has information that doesn't accurately describe the signal which can very much affect the decision. Since temperature values don't usually have many fluctuations, we are more concerned about the enhancement of the ECG signals. For temperature plots, we smooth them to give them a better visual representation but other than that, all the data analysis techniques are focused on ECG signals.

Baseline Wander Removal

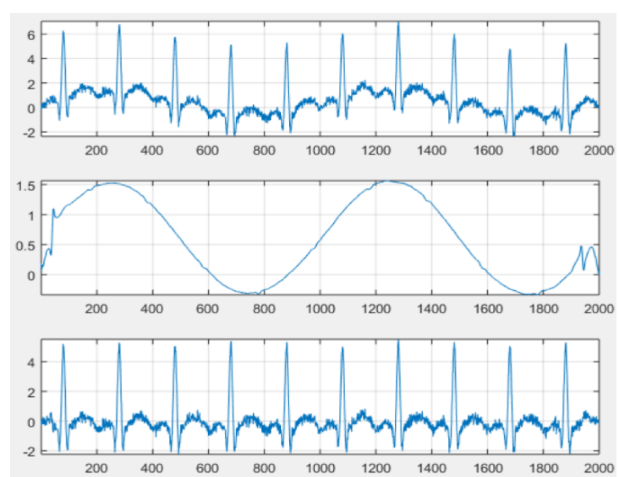


Figure 6. Noise reduction from ECG signal by removing the baseline wander

Baseline wander is a problem that shows ECG signals in a wavy fashion rather than being consistent. Reasons for that may be due to respiration or motion of the patients or the instruments. The technique that has been proven to work best with this is applying a high pass filter. This works because removing the low frequency component from the signal removes the sine-like pattern of the baseline which is shown clearly in Figure 6. The Figure is divided into three subplots, the first one shows the original signal, the second one shows the low frequency component that needs to be removed, and the third one shows the result after removing that low frequency component. Removing the baseline gives us a better signal which can help us process data more accurately.

The mathematical equation for the operation of high pass filtering can be done using Equation 1 where w_c is the cut off frequency and N is the filter order:

$$|H\ (\omega)|^2 = \frac{1}{1+\left(\frac{\omega_c}{\omega}\right)^{2N}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 1$$

We used two simultaneous equations to remove the baseline wander. First we smooth the signal using the MATLAB built in function 'smooth', which gives us that sin-wave-like signal, then subtract that sin-wave-like (low frequency component) from the original signal.

High-Frequency Component Removal

A high-frequency noise can reduce the detection accuracy that would need a low pass filter rather than a high pass filter. The time domain operation of a low pass filter for signals is the mathematical operation called the moving average (often addressed to as smoothing). Figure 7 shows a signal distorted with high frequency components that result in major fluctuations that alter the details of the original signal and the enhanced version of it. The enhanced version was achieved by applying low pass filter that as you can see worked perfectly. The key when using high pass or low pass filters is to choose the correct cutoff frequency. Choosing the wrong cutoff frequency can result in huge reduction in detection/prediction accuracy.

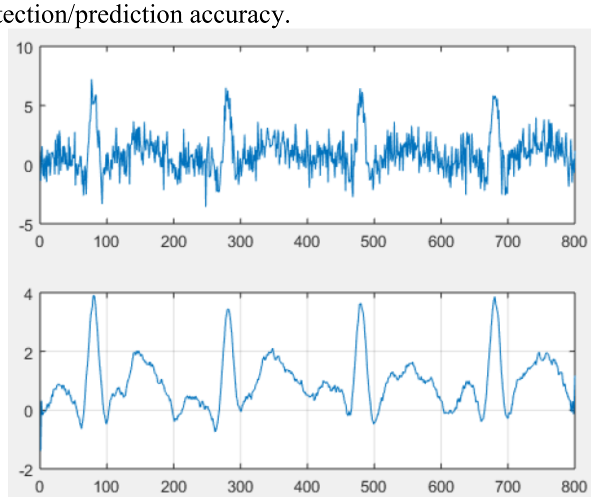


Figure 7. Noise reduction from ECG signal using smoothing

The mathematical equation for the operation of low pass filtering can be done using Equation 2 where w_c is the cutoff frequency and N is the filter order:

$$|H\ (\omega)|^2 = \frac{1}{1+\left(\frac{\omega}{\omega_c}\right)^{2N}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 2$$

We apply a moving average which is achieved by using the smooth function in MATLAB. Using the correct window for smoothing is essential as it can affect the signal's expected output.

Heart Rate

One major feature that we extracted from ECG signals is a person's heart rate or beats per minute. This can be calculated using several techniques including taking number of QRS peaks in a given time, using autocorrelation, or using Fourier transform. The first technique can sometimes yield inaccurate results, however, when a signal has no baseline wander problem, this technique should work perfectly fine. Autocorrelation and Fourier transform techniques yield very accurate results.

We can determine the heart rate from the autocorrelation of an ECG signal by a series of simple steps. Figure 8 shows a plot of the autocorrelation of an ECG signal. First we calculate the difference between two peaks which gives use the length of one period in data points. Dividing that number of data points by the sampling frequency gives us the time in seconds of one period. Inversing that and multiplying it by 60 gives us the total beats per minute.

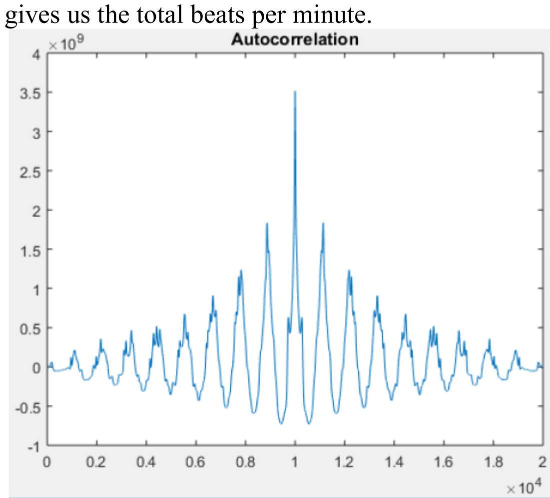


Figure 8. Autocorrelation of an ECG signal

The mathematical equation for the autocorrelation function for signal processing is shown below:

$$R(k) = \sum_{n=N1}^{N2-k} x(m) * x(m+k) \dots\dots\dots\dots\dots\dots..3$$

Prediction Algorithm

After extracting all features from the sensors, we combine the analyzed results and apply a prediction algorithm. Our prediction process is divided into two major approaches. First we plan to use a thresholding technique where we make sure that the patient's body temperature and heart rate are within the normal range. If the patient's temperature and heart rate are normal, the algorithm will focus on detecting fluctuations in the ECG signal like ST elevations or abnormal peak values. If the user's body temperature or heart rate are abnormal, the smartphone application will generate an alert message to warn the user about an imminent heart attack. We are still working on our algorithm and prediction accuracy.

VII. CONCLUSIONS

In this paper, we have developed an embedded IoT system to monitor heart rates and body temperatures using smartphones. We use an ECG sensor system and the real-time detection of abnormality in users' ECG patterns. The results from sensors' data are also presented to show that this approach provides a high rate of classification correctness in distinguishing between normal and abnormal ECG patterns. The system may also find multiple applications in heart behavior detection for people with various disabilities who are at a high risk of cardiac arrest.

To test the permanence and long-term feasibility of our approach in the future, we plan to test our system with data from elderly people who suffer from chronic heart problems. Additionally, the system can be used in smart home monitoring systems for future wireless technologies.

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