Driver-centered pervasive application for heart rate measurement

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ABSTRACT

People spend a significant amount of time daily in the driving seat and some health complexity is possible to happen like heart-related problems, and stroke. Driver's health conditions may also be attributed to fatigue, drowsiness, or stress levels when driving on the road. Drivers' health is important to make sure that they are vigilant when they are driving on the road. A driver-centered pervasive application is proposed to monitor a driver's heart rate while driving. The input will be acquired from the interaction between the driver and embedded sensors at the steering wheel, which is tied to a Bluetooth link with an Android smartphone. The driver can view his historical data easily in tabular or graph form with selected filters using the application since the sensor data are transferred to a real-time database for storage and analysis. The application is coupled with the tool to demonstrate an opportunity as an aftermarket service for vehicles that are not equipped with this technology.

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1. INTRODUCTION

The global market for automotive active health monitoring systems is anticipated to grow significantly because of technological breakthroughs and advances and collaboration between the automotive and health industries. Even though the technology is still in its infancy, the trend is expected to acquire substantial popularity in the next years where electronics and microelectronics developments are increasingly being employed as monitoring instruments [1]. The widespread use of the internet of things (IoT) and advancements in sensor technology is anticipated to provide real-time, accurate, and trustworthy diagnostic data for drivers and healthcare organizations working with insurance companies [2].

Moreover, the increase in the number of global traffic accidents due driver unhealthy state contributes to the demand for driver health monitoring systems [3], [4]. Accidents are more likely to occur when the driver is feeling unwell, drowsy, monotonic driving, influenced by alcohol or under sedative drugs which may be indicated by changes in the driver's heart rate. Recently, 20.4% of people between ages 15 to 40 had died in accidents in Malaysia and 15.6% of the accidents were cause by heart problems [5].

One of the most important indications of a person's health is their respiratory rate which has a direct positive link to a person's heart rate. A normal respiratory rate of less than 12 breaths per minute (bpm) or greater than 25bpm has been proven to be a significant predictor of health problems such as asthma, anxiety, pneumonia, lung illness, heart disease, and drug overdose [6]. According to the findings of the study by [7], aggressive driving induced an increase in heart rate, capable of increasing it by up to 2.5 and 3 percent beats per minute.

In a clinical environment, a person’s heart rate is normally measured from an electrocardiogram (ECG) graph which measures how well the heart is operating. It basically records the heartbeats' regularity and frequency which can reveal crucial information of a person’s health. However, majority of people do not schedule annual routine health check-up due to time and increasing cost of healthcare services [8]. This may put them at risk when they are in the driver’s seat. Hence, heart rate detection monitors based on in-vehicle sensors and cameras are gaining popularity worldwide, particularly for vehicles of the society of automotive engineers (SAE) autonomous levels 0 to 3. These systems are used to detect health problems and anomalies in the driver's state, such as attention, workload, or arousal level, while driving. The driver's heart rate is normally detected by an ECG which measures how well the heart is operating by basically recording the heartbeats' regularity and frequency. When a heart attack, suspected coronary artery constriction, or an irregular pulse are detected, it can reveal crucial information [9].

Furthermore, the health of drivers can be at risk due to diseases such as cardiovascular, respiratory, and brain disease, impacting their daily lives. Hence, it is vital to learn and implement innovative strategies which allows drivers to monitor their health conditions when they are driving on the road [2]. This may be prevented by installing a health monitoring system application, which tracks the driver's heart rate and can immediately notify and alert the driver when his or her heart rate is not within the normal range. In addition, the system can be mandated for monitoring occupational drivers’ status from the labour management point of view [9], [10]. Vital health indicators like heart rate, respiratory rate, SpO2, and blood pressure can conveniently be monitored using wearable devices and unobtrusive sensing technologies [11]. Several different experiments for monitoring the driver's status have been undertaken utilizing non-contact-based physiological data such as heart rate (HR), respiration rate (RR), and inter-beat interval (IBI), but they are limited to obtaining physiological data with no classification [12]. These systems are mainly categorized into steering-type, seat-type, seat-belt-type, portable device-type, and camera-type systems [9].

For example, authors in [13] evaluated the ECG signals acquired from electrodes placed on the steering wheel to estimate an average and instantaneous heart rate as well as the driver's breathing rate using innovative spectro-temporal processing of the acquired signals. The experimental results reveal that ECG signals collected from the steering wheel have the same quality as those obtained from a benchmark chest ECG equipment, and that they can monitor both average and instantaneous heart rates, as well as breathing rate. The same approach of placing sensors on the steering wheel can be applied to monitor a driver’s drowsiness and mental workload level. According to [14], the average heart rate (bpm) decreased gradually with longer driving time and if a driver’s heart rate is more than 78 bpm, the driver is experiencing high mental workload level [15]. Likewise, Essers *et al.* [16] created a steering-type system with an infrared sensor fitted inside. The sensor can identify the driver's facial expression, which is combined with data received from sensors that detect the driver's hands on the steering wheel. By merging the pulse with other assessment indicators, the system evaluates the driver's state. On the other hand, Arakawa *et al.* [17] created a steering-type measuring system which detects heartbeats using the capacitive pulse approach. This technology can monitor pulse waves consistently regardless of the driver's movement while driving. Nevertheless, the system does demand that the driver grasp the steering wheel firmly when driving, whether one-handed or two-handed, which limits the driver's movement significantly.

Besides the steering wheel, windscreen is also used to mount in-vehicle camera for the sake of monitoring the driver. For instance, Zheng *et al.* [6] developed an intelligent system that performs monitoring activities utilizing a COTS impulse radio installed on the windscreen called V2iFi. The system is capable of accurately detecting the driver's vital signs while driving and in the presence of passengers, possibly inferring associated health conditions using wireless fidelity (Wi-Fi) channel state information (CSI). Pandya *et al.* [8] creates a system that remotely monitors blood oxygen saturation and pulse rate, using wearable and non-invasive sensors. The system implements an IEEE1855-2016 algorithm and fuzzy-as-a-service cloud-based framework. However, the system is aimed for elderly users in a home environment. Meseguer *et al.* [7] studied the correlation between driver heart rate and driver behavior.

A data collection from accelerometers implanted in a vehicle seat that comprises ten persons sitting in a moving automobile's passenger seat, as well as surface ECG data from each user to give ground truth of the heartbeat. Despite the presence of significant levels of noise from automobile motion, human motion, and the car engine, this data may be utilized to examine the heart activity of persons in cars [18]. Additionally, authors in [19] suggests using a microwave sensor on a car seat backrest to monitor the driver's heart rate. The heartbeat signal is learned as a template while the car is idling, and then correlation is calculated with observed signals. The method amplifies the heartbeat signal and reduces road noise, and an experiment on an actual road at low speed showed over 90% accuracy compared to a contact-based system for measuring heart rates. Alternatively, Leicht *et al.* [20] introduced a safety belt sensor device for detecting breathing and cardiac activity. The experiments demonstrated that optical sensors can be applied for measuring heart activity and a magnetic induction (MI) sensor for breathing monitoring. However, special care needs to be considered regarding compliance with the safety standard of seat belts.

In another approach, a study was carried out in two states, i.e., rest and during a mathematical arithmetic task to assess the mental workload of the driver. A sensor system was used to gather the threshold value of mental workload, and if the heart rate reading exceeds the safe driving maximum threshold, the buzzer will emit a sound [15]. Wang *et al.* [21] used a convolutional neural network (CNN) and a long short-term memory (LSTM) network to extract features from the ECG signals and predict the heart rate. The system achieved high accuracy in detecting the driver's heart rate, even under noisy and dynamic driving conditions. Moreover, fusion techniques may be applied to incorporate multiple sensors and multiple models or channels, such as visual, audio, environmental, and physiological signals where specific aspects of sensor fusion applications have been studied in the literature [22].

A pervasive mobile application provides value to the driver by providing a highly personalized driving experience compared to traditional application. The application responds to context changes in real time by using geolocation, phone sensors, external sensors, surrounding data [8]. It seamlessly integrates into the user's daily life and provide a rich and interactive user experience that is always available and accessible [10]. In a driving scenario, the driver’s personal wellness which evolved from the driving situation will be the focus. Hence, the main contributions of this work are as follows: i) A pervasive application which monitors a driver’s heart rate and classifies the heart rate, and ii) A sensor-based system which is non-wearable and implemented using the internet-of-things approach.

The remainder of this paper is structured as follows: Section 2 focuses on related work that has been performed to monitor heart rate using sensors. Section 3 elaborates the methodologies used in this work. Section 4 elucidates the experimental results that are performed in this study. Section 5 concludes the study with scope for future work.

2. METHOD

2.1. Working principle

The pervasive application proposed in this study is guided by the IoT life cycle [23] which consists of four stages i.e., capture, communicate, act and analyze. In the first stage of the cycle, MAX30102 sensors are placed on the steering wheel. The system is dependent on the activation of the vehicle and automatically starts when the driver starts the engine and shuts down once the engine is shut off.

Figure 1 shows the working principle of the system. Two MAX30102 sensor which is a combination of heart rate monitor and pulse oximetry were placed inside a steering cover. To mount the sensors, two holes were cut out for the subjects to place their fingers. The sensors are linked to a microcontroller board which is integrated with other components and packaged in a box. The box was temporarily attached to the steering arm using tape. Once the driver placed his fingers on both sensors, blue light-emitting diodes (LEDs) will light up on both sides of the steering wheel. The Bluetooth low energy (BLE) was utilized for ESP32 to communicate and acquire the heart rate from both sensors before transmitting the mean heart rate value (in bpm) to the application.

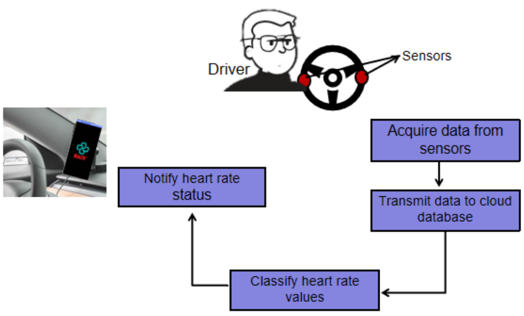


Figure 1. Working principle of the system

The sensors data will be synchronized with the cloud database when connectivity is available. The application will classify the value and display the status as either good, average, or poor. In addition, a red LED will light up if the heart rate is not normal. The driver is encouraged to attach his mobile phone to a phone holder mounted to the car dashboard if he wishes to monitor the readings continuously when he is driving. This will also enable the driver to view the notification when the readings are not within the normal range. In addition, if normal readings are detected, the system will synchronize with the cloud storage i.e., firebase and loop back to the correct data process.

2.2. Participants

This study has been approved by the institution's Ethical Research Committee (approval code EA0812022). Calls for voluntary participants were made a week before the actual experiment took place. On the experimental day, all participants were briefed on the experimental setup and processes. Afterwards, they were asked to read and sign a consent form, which they only signed if they agreed to take part in the experiment as approved by the organization's Ethical Committee. The participants were asked to determine if they were unfit which would cause them to be not suitable to participate. Out of 24 volunteers, 20 of them (10 male and 10 female) agreed to participate and complete the experiment. 4 of the volunteers had to be declined since they are feeling stressed and claimed not feeling well which may affect the data collection.

In addition, in a brief preliminary questionnaire, all participants reported no history of heart related problems including shortness of breath, asthma or experienced tight chest. The subjects were asked about their food and beverage intake before data recording and exercise regimen that they practiced. The mean temperature of the room was about 25 °C.

During the experimental process, the subject was required to launch the pre-installed health^{+} application on a tablet and register an account before their normal heart rate was recorded. The subject was also required to put on a headset to exclude them from the surrounding noise and hold the steering at 9-3 position where the sensors were placed for 5 minutes while watching a driving video on a laptop screen, mimicking a closed environment in a vehicle cabin. During this period, their heart rate was acquired from the sensors (in bpm). The participants were also encouraged to try and restrict their movements during the data recordings. The readings will be used to calculate each subjects resting heart rate.

Next, subjects were required to perform tasks using the switch ring fit game for 2-3 minutes. This is to induce light activity heart rate which resembles driving heart rate. Their heart rate was recorded and classified by the application. At the end of the process, the subject was requested to fill-up a Google Form to rate the application based on the system usability score.

2.3. Heart rate classification

In this study, we classified the heart rate status for drivers based on a reference range for normal resting heart rate and target heart rate during driving, and then compare a driver's heart rate measurements to these reference ranges to determine their heart rate status. Figure 2 shows the age-gender specific heart rate chart. The normal resting heart rate is usually 60-100 beats per minute. The target heart rate during driving is less than 20 beats per minute above resting heart rate. Based on this reference, a driver's heart rate status can be classified as follows:

a. Excellent: Resting heart rate falls within the 60-100 bpm range and heart rate during driving is less than 20 bpm above resting heart rate.
b. Average: Resting heart rate is above 100 bpm and/or heart rate during driving is consistently above 20 bpm above resting heart rate.
c. below average/poor: Resting heart rate is consistently below 60 bpm and/or heart rate during driving is consistently lower than expected for the individual.

Resting Heart Rate Chart

Men (beats per minute)

Age	18 - 25	26 - 35	36 - 45	46 - 55	56 - 65	65 +
Athlete	49 - 55	49 - 54	50 - 56	50 - 57	51 - 56	50 - 55
Excellent	56 - 61	55 - 61	57 - 62	58 - 63	57 - 61	56 - 61
Great	62 - 65	62 - 65	63 - 66	64 - 67	62 - 67	62 - 65
Good	66 - 69	66 - 70	67 - 70	68 - 71	68 - 71	66 - 69
Average	70 - 73	71 - 74	71 - 75	72 - 76	72 - 75	70 - 73
Below Average	74 - 81	75 - 81	76 - 82	77 - 83	76 - 81	74 - 79
Poor	82 +	82 +	83 +	84 +	82 +	80 +

Women (beats per minute)

Age	18 - 25	26 - 35	36 - 45	46 - 55	56 - 65	65 +
Athlete	54 - 60	54 - 59	54 - 59	54 - 60	54 - 59	54 - 59
Excellent	61 - 65	60 - 64	60 - 64	61 - 65	60 - 64	60 - 64
Great	66 - 69	65 - 68	65 - 69	66 - 69	65 - 68	65 - 68
Good	70 - 73	69 - 72	70 - 73	70 - 73	69 - 73	69 - 72
Average	74 - 78	73 - 76	74 - 78	74 - 77	74 - 77	73 - 76
Below Average	79 - 84	77 - 82	79 - 84	78 - 83	78 - 83	77 - 84
Poor	85 +	83 +	85 +	84 +	84 +	85 +

Figure 2. Age-gender specific resting heart rate

However, if the normal heart rate for the driver is not available, the system will refer to the age-gender specific resting heart rate as in [24]. The heart rate value and status are sent to the health+ application. The status, i.e., excellent, average, below average or poor will be displayed with options to view either the data table or the graph.

3. RESULTS AND DISCUSSION

In this section, it is explained the results of research and at the same time is given the comprehensive discussion. Results can be presented in figures, graphs, tables and others that make the reader understand easily [25], [26]. The discussion can be made in several sub-sections.

3.1. System functionalities

To use the application, the user must be a registered user. User needs to provide his name, email, password, gender, birthdate and self-declare either he is an athlete or active sportsman. This is to enable the identification of the threshold values for individual users. Once registered, user can access the system normally using his or her email and password method. Another option, user may register using his or her Google account. If the user forgets his password, he can click on the forget password and one email will be sent to his email account to let him reset his password. The main screen will be displayed upon successful login as in Figure 3. Figure 4 shows example of notifications to driver where Figure 4(a) shows the average status and Figure 4(b) shows the below average status of drivers from different profiles.

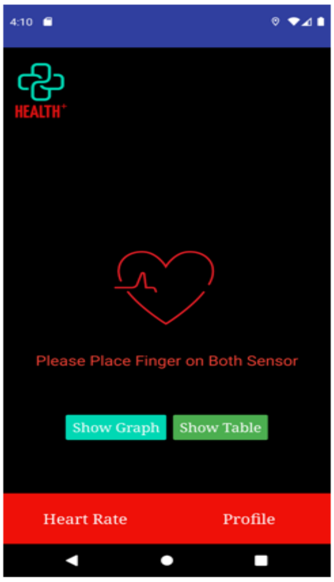


Figure 3. Health+ main screen

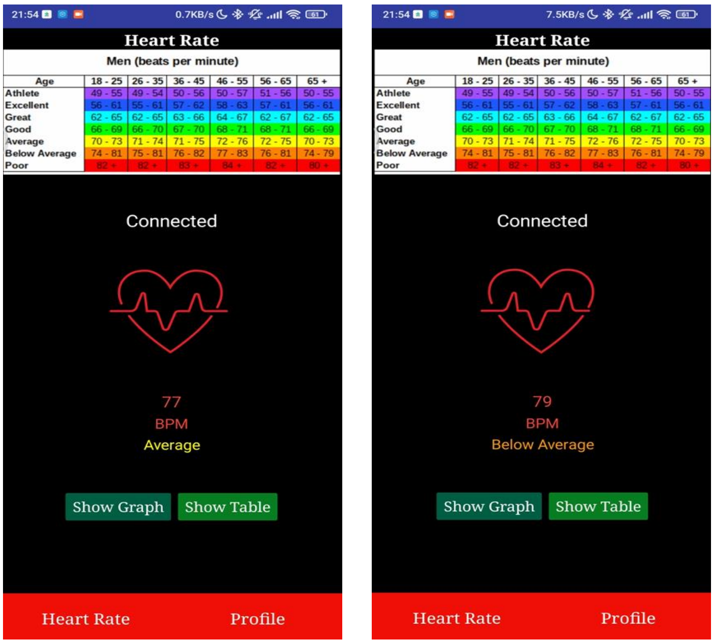
Apart from that, users also have the option to view their historical heart rate values either in tabular form or in a graph form Figure 5. Specific date, start time (1-24), end time (1-24) and duration of the graph either for 5, 10, 30 or 60 minutes may be specified based on individual purposes as shown in Figure 5(a). Moreover, the heart rate values may be filtered based on the date, start time (1-24), end time (1-24) and the heart rate status either excellent, average, or poor as shown in Figure 5(b).

3.2. System usability

System usability score is a trustworthy instrument for evaluating usability. The participants were required to provide ratings i.e., strongly disagree (1), disagree (2), neutral (3), agree (4) and strongly agree (5) based on 10 statements to assess the usability of the system [27]. Given X is the sum of the points for all odd-numbered statements minus 5, and Y is 25 minus the total points for all even-numbered statements, the system usability scale (SUS) score was calculated based on the formula:

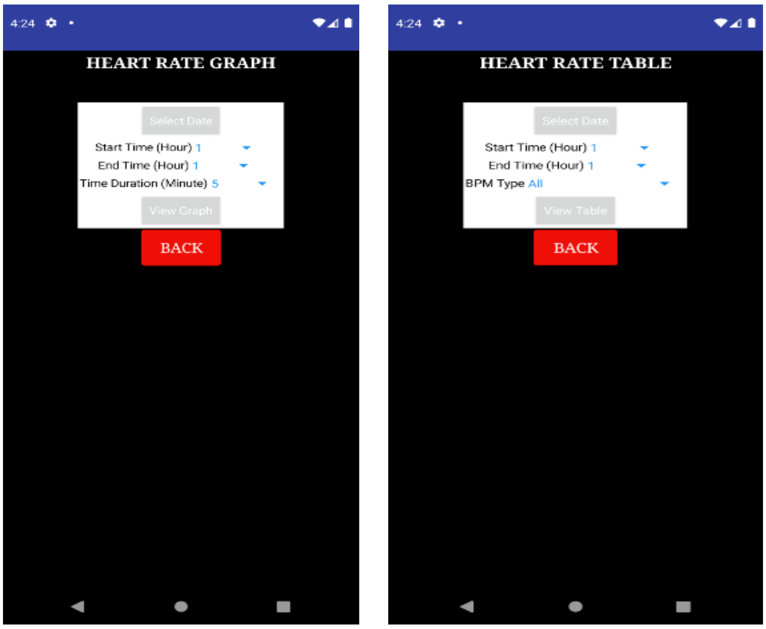
$$SUS\ score = (X + Y) \times 2.5$$

A SUS score higher than 67 would be considered above average. In this study, the calculated SUS score is 78 which is considered good. Majority of the testers (50%) agreed that they would like to use the system regularly to monitor their heart rate. The system functions are clear and easy to use. They do not require technical assistance or special training to help them use the system. They also found that the system is simple and provide easy to comprehend output. They were able to know their heart rate classification directly and based on stored data. However, there are a few participants who feel that they need more time to understand and appreciate the system functions. Hence, a user manual or simple tutorial may be beneficial for this group of participants.



(a) (b)

Figure 4. Example of notification to driver based on heart rate status (a) average and (b) below average



(a) (b)

Figure 5. Historical data view (a) graph and (b) tabular form

4. CONCLUSION

A driver-centered pervasive application for monitoring a driver's heart rate can provide a range of benefits that enhance safety, comfort, and health. Since most people spend time driving on the road, continuous monitoring of a driver's heart rate can provide a wealth of valuable data that can be used to identify changes and abnormalities that may indicate potential health issues. For example, if a driver's heart rate suddenly spikes, it could be an indicator of a heart attack or other serious cardiovascular problems. Hence, this study focused on the development of an IoT device that utilizes a low-energy consumption microcontroller unit (MCU) and a sensor. This design choice makes the device not only cheap but also portable and suitable for use in real-life scenarios. The system can easily be integrated into the steering wheel of a vehicle, where the driver is only required to place their finger on the sensor for it to function. This approach minimizes any possible inconvenience or distraction that may arise from using the device.

Moreover, the system is not standalone, as it is connected to an android application. This app can provide real-time heart rate feedback to the driver while driving. This feature is especially crucial as it helps the driver to monitor their heart rate and identify any abnormality while driving, which may suggest potential health issues. By alerting the driver to any problems, it can encourage them to take appropriate action, such as pulling over or seeking medical assistance. Detecting these issues early on can be critical for receiving prompt medical attention and preventing serious health consequences. Moreover, if the application detects an increased heart rate, it could indicate that the driver is feeling stressed, anxious, or fatigued. The collected data can be valuable for the driver's own health and well-being by enabling the driver to track their heart rate over time, giving them insights into their general health and any patterns that may emerge. In addition, it can also be used by researchers and healthcare professionals to gain insights into the relationship between driving and cardiovascular health.

To improve the system in the future, the connectivity between sensors and mobile application needs to be improved to remove noise. Additional features such as an emergency contact button and data extraction can be added to the application to enable drivers to contact their designated emergency contacts in case of accidents or health issues. The data extraction feature can also facilitate consultations between doctors and drivers. The security of the application can be improved by implementing double-authentication functions such as one-time password (OTP) and password. Additionally, the application should be designed for iOS devices to broaden its user base.

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