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ORIGINAL ARTICLE

Enhanced Brady-Tachy Heart Automotive (BT-Heartomotive) Device for Heart Rate Monitoring during Driving

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ABSTRACT – Driving with brady-tachy syndrome is one of the main causes of car accidents. In order to prevent drivers from brady-tachy driving, there is a strong demand for driver monitoring systems. Other than problems in driving attitudes and skills, road accidents are also caused by uncontrollable factors such as medical conditions and drowsiness. These factors can be avoided by having early detection. Therefore, the brady-tachy heart automotive so-called BT-Heartomotive device is developed. This BT-Heartomotive device can detect early signs of drowsiness and health problems by measuring the heart rate of the drivers during driving. The device also could use the data to send an alert to the passengers that they're in precaution. The device shows a good accuracy in the detection of the heart rate level. The device comprised three main components; wristband, monitor and integrated mobile applications. Heart rate measurement can reveal a lot about the physical conditions of an individual. The BT-Heartomotive device is simple, easy to use and automated.

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Brady-tachy; Heart rate; Automotive; Medical device; Driving; Car accident.

INTRODUCTION

The causes of road accidents vary between two groups of drivers: young and old drivers. Young drivers tend to be involved in road accidents due to the lack of experiences, risk-taking behaviours, over-speeding as well as alcohol and drug influence. Most of the accidents among older drivers are due to medical problems such as stroke, heart disease and psychoactive medications [1]. Another main factor contributing to road accidents is drowsiness which is due to the brady-tachy syndrome. The brady-tachy syndrome is where the heart sometimes beats too slowly (brady) and sometimes beats too quickly (tachy). 21% of fatal road accidents were due to drowsiness according to the AAA Foundation for Traffic Safety between the year 2009 to 2013 [2] and 54% of adult drivers' despite in the state of sleepiness [3]. According to a study done by Abdul Rahim et al. [4], there is a big difference in the heartbeat between normal and drowsy states. In a normal, relaxed state, the heartbeats in the range of 70 to 100 bpm but, the abnormal only in the range of 45 to 65 bpm early drowsiness state. Other than drowsiness, the measurement of heart rate can reveal information about the health state of an individual such as the risk of having cardiovascular disease [5,6], undetected heart attack, blood pressure condition as well as the level of blood electrolyte [7].

Current studies propose that physiological procedures such as heart rate may be optimal candidates to perceive increasing levels of mental capability. In the existing study by Durantin et al. [8], for occurrence, participants implemented a computer-based piloting task in which they were asked to track an active target with their aircraft. A numeral of physiological metrics containing heart rate was measured. A constructive relationship between task exertion and heart rate capriciousness was found so that as the task became more problematic heart rate became more flexible. Another appropriate phase of heart rate is that it tends to decrease with ageing. In the study by Christou and Seals [9], the authors considered the consequence of ageing on a typical heart rate. Results presented that older contributors 65-year-old had an inferior average heart rate compared to young contributors 25-year-old. Comparable results were established in the study by Anselmi et al. [10] in which the effect of age, gender variances and body weight on heart rate variability were studied. Results exhibited that heart rate inconsistency simultaneous with age and gender such that older contributors and women indicated a concentrated heart rate variability related to their particular complements. Due to the current prevention, they do not have any effective device, especially in avoiding the car accident on the road.

In this study, BT-Heartomotive device is developed to address the road safety issue among old drivers, people with medical problems and drowsiness [4]. Our main objective is to develop the BT-Heartomotive device purposely can detect early signs of drowsiness and health problems by measuring the heart rate of the drivers during driving. The mechanism of action of BT-Heartomotive is based on the measurement of the heart rate by a sensor [11]. Many information can be extracted from the heart rate data. The most important data is the state of drowsiness. The BT-Heartomotive can also monitor blood pressure and blood oxygen saturation level (SpO_2) level. The degree of haemoglobin binding to oxygen (lung factor), haemoglobin concentration (anaemic factor) and cardiac output (cardiac factor) are the three factors that can affect the quantity of oxygen transported throughout the body. Oxygen saturation is the ratio of the amount of

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oxygenated haemoglobin compared to the amount of haemoglobin in the blood, which indicates the sufficiency or insufficiency of oxygen in our body. The level of healthy SpO_2 ranges from 96% to 99%. The level decreases significantly for patients with pulmonary or cardiovascular chronic diseases [12,13]. Currently, we are working on the functional prototype to improve the consistency and reliability [14,15] of the data so that it can be used for the intended purpose. Essentially, the data could be stored and always reliable and usable.

METHODOLOGY

Design and Development

The BT-Heartomotive device is intended using SolidWorks 2017. Each part and component of the device is designed and drawn with a precise dimension as the real size. The device consists of three main components; wristband, monitor and mobile applications, as shown in Figure 1.

Wristband

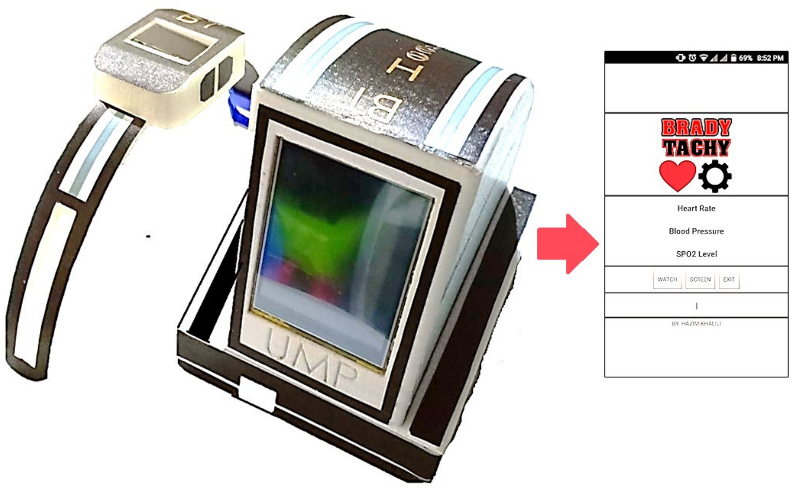
Wearables offer great opportunities to intensify our driving experience. Wearable devices like smart wristband or smartwatches are mainly used to enhance the driver's experience and improve safety. More specifically, Mercedes, BMW, and Nissan have built special applications that monitor the speed and fuel efficiency via onboard sensors and even the driver's fatigue level via heart rate sensors. Ford S-Max concept provides the ECG heart rate monitoring seat, which continuously monitors and records the driver's heart rate. The wristband component consists of the MAX30100 sensor, integrated pulse oximetry and solution of heart-rate monitor sensor that combines one optimised optics, low-noise signal processing, photo-detector and two LED to perceive heart-rate signal and pulse oximetry which detector for the heart rate, blood pressure and SpO_2 level can be obtained.

Monitor

The monitoring system for the device displayed the three important parameters; heart rate, blood pressure and SpO_2 level of the driver after receiving the value from the microcontroller and Bluetooth system. The alarm notification also placed in this monitoring system [16,17].

Mobile application

The mobile app was developed to record the heart rate, blood pressure and SpO2 data-trend of the driver. The data keep in the storage system as a black-box function. These data will use as the emergency tread record or research activity. The details of the overall process flow of the proposed device shown in Figure 2.



(a) (b) (c)

Figure 1. The prototype design of BT-Heartomotive device with (a) wristband, (b) monitor, (c) mobile application.

Figure 3 and Figure 4 show the system configuration, which comprised of an oximeter sensor, a micro-controller unit, a Bluetooth transmitter, a smartphone (mobile application), and a monitor. The oximeter sensor incorporates Arduino Nano and a Bluetooth module and can be attached to the driver's wrist-hand. The outputs from the oximeter sensor are transmitted wirelessly via Bluetooth communications to a smartphone by mobile app that extracts the heart rate and SpO2 by time series. After this, the smartphone (Transmission Control Protocol (TCP) client) transmits the output signals to an external monitor display for feature generation, feature selection, and classification. Finally, the arrangement outcome is a reaction to a responsive customer interface for activating the alarm and passenger or self-monitoring for the driver.

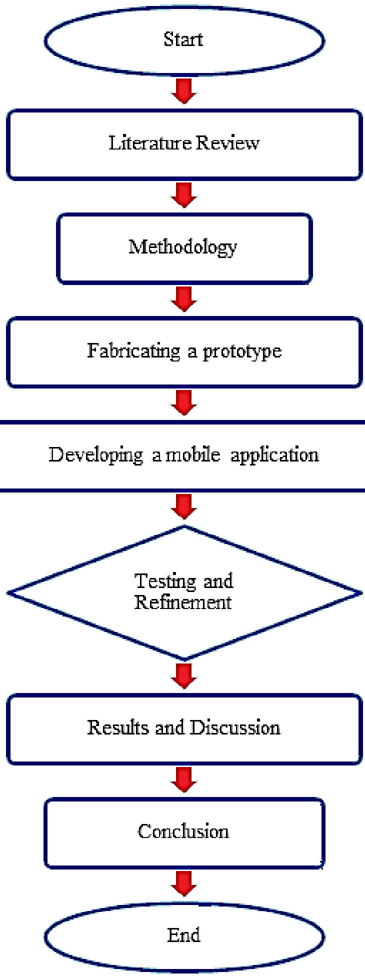


Figure 2. The overall process flow of the proposed device.

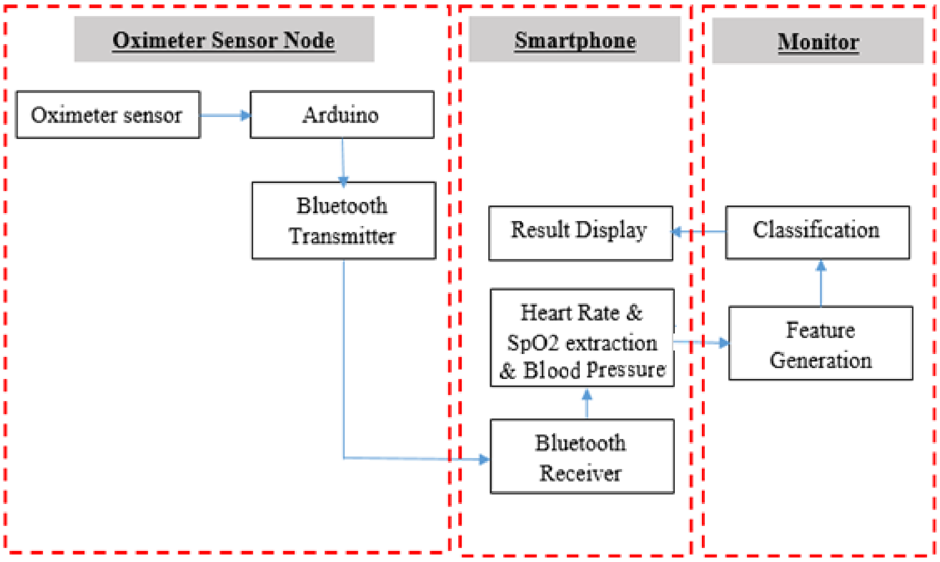


Figure 3. Block diagram of the proposed device with BT-Heartomotive detection system.

Materials and Specification

To accomplish the research objective, the materials selected must be planned. The Magma Flex TPU transparent filament (thermoplastic elastomer) was used in this prototype study to create a flexible and transparent on wristband shown in Figure 1(a). This is a type of plastics that can be melted and moulded via the FDM process and has similar characteristics to rubber. This type of filament was chosen to fulfil the flexibility due to high elongation at break, high strength, and elasticity (easy to bend). For the monitor casting, the polylactic acid (PLA) was used, as shown in Figure 1(b). Table 1. shows the specification of the materials used.

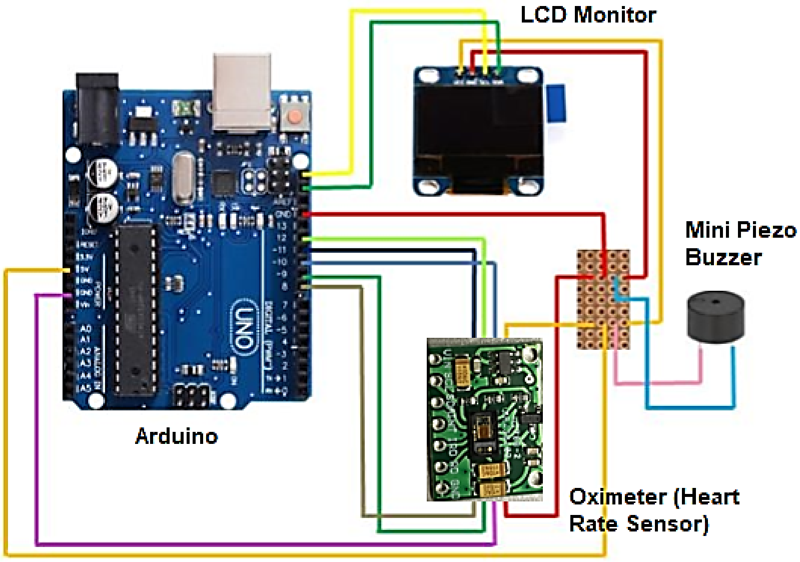


Figure 4. Schematic diagram of the proposed BT-Heartomotive device.

Table 1. Material specification.

Material	Flexible TPU
Print Temperature	200-230ºC
Length	335mm
Diameter	1.75mm +/- 0.03mm
Recommended printing speed	20/60 mm/s
Material	SUNLU PLA
Print Temperature	190-220ºC
Length	330mm
Diameter	1.75mm +/- 0.05mm
Recommended printing speed	20/60 mm/s

BT-Heartomotive operation

In the present device, the Arduino Uno microcontroller is used. The Arduino is intended for making an interactive surface. As shown by integrated Arduino and oximeter in Figure 5, the value of heart rate in beats per minute (bpm) based on the photoplethysmograph (PPG) data from MAX30100 is obtained. When the driver's situation becomes or close to the Brady-Tachy syndrome, the monitor is activated to awaken/alert the driver. One of the direct information about the heart rate (heartbeat) is obtained by using an oximeter sensor involved in the driver's wristband. In this case, the sensor may be pretentious by some electrical noises caused by many electric instruments in the existing car. The system seems to be attractive by its contact-free property, but the effect of active sensing to driver's health is not clear. Since many factors for designing a heart rate detection system, we recommend a system based on wrist-hand sensing.

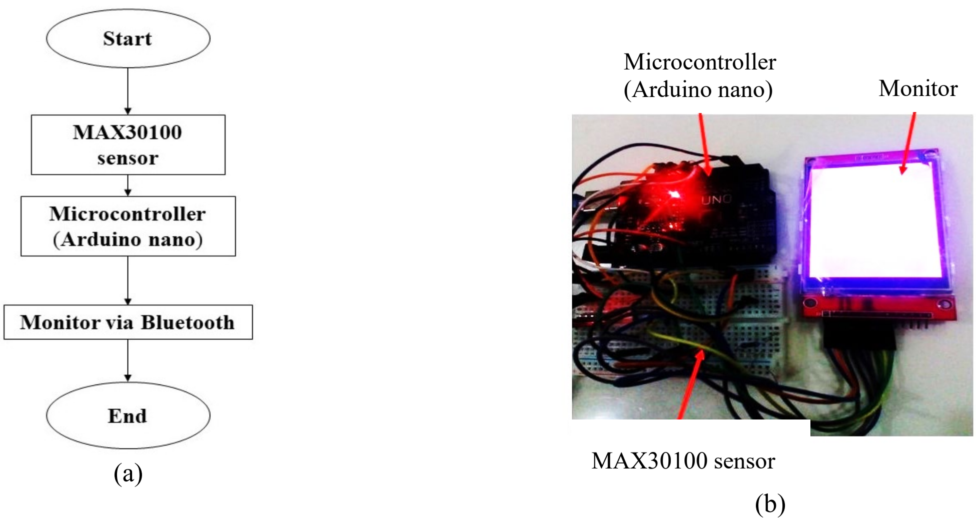


Figure 5. Representative (a) flowchart for the operation of BT-Heartomotive device, and (b) setup of BT-Heartomotive device.

RESULTS AND DISCUSSIONS

Integrated Concept of Measurement System

The BT-Heartomotive device [18,19] considers the driver's heart rate monitoring problem to choose the heart rate level for safe driving. This integrated concept of the measurement system is to perceive the heart rate of the driver by adopted the wristband (oximeter) sensors. This system involves three parts as sensing, analysis, and feedback, as shown in Figure 6. The sensing part measures the driver's physiological data and environment. The analysis part excerpts the heart rate of the driver form the noisy data and controls whether the driver is an early stage of brady-tachy or not.

(a) (b) (c)

Figure 6. The integrated concept of measurement system between; (a). mobile app, (b). wristband and (c). monitoring system.

Functionality Validation

To validate the functionality of the proposed device, the prototype has been manmade, as presented in Figure 1. A preliminary study has been completed concentrating on assessing the operation of device parameters obligatory for appropriate functional use of the designed BT-Heartomotive device. The device well reproduced the subject feels, thus demonstrating repetitive device handling. Figure 7 shows out of 8 drivers presented a comfortable feeling, and only two complained of discomfort when using the BT-Heartomotive device. Figure 8 shows four drivers complained badly in handling the BT-Heartomotive device. The same tests conducted on women drivers confirmed that BT-Heartomotive device shows very well handling during active driving. The subjects did not feel any discomfort or applied interaction forces obligatory by the device and could efficiently work with the device.

Preliminary Test On Early Detection of Brady–Tachy (BT) Syndrome

The abnormal heart rhythm problem is often seen in people who have been diagnosed with atrial fibrillation. Both conditions are extremely dangerous for the driver, and others were sharing the road with them. Due to this problem, the BT-Heartomotive is tried to solve this driving threat. The preliminary test on early detection of BT syndrome is conducted in two hours driving. The results in Figure 9 shows that the device was successfully detected the heart rate of the driver wherein the normal condition heart rate become moderate between 67 bpm to 87 bpm. However, when the device detected the value of the heart rate reached to 100 bpm, which is in the brady-tachy condition, the device will automatically give the alarm notification.

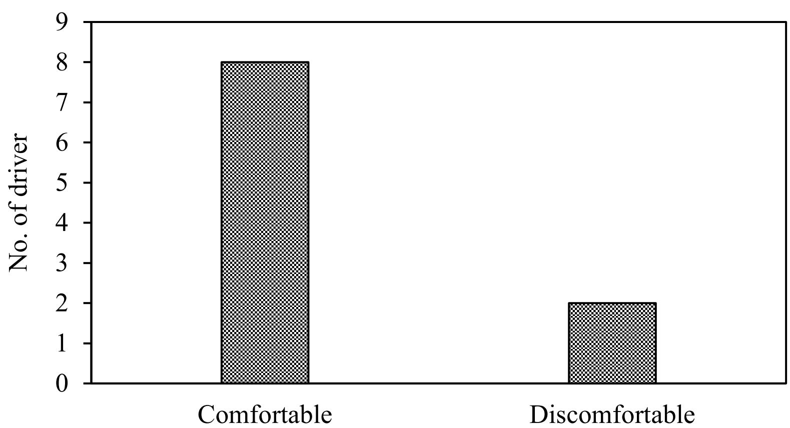


Figure 7. The comfortable and discomfort feel of the driver when used the BT-Heartomotive device.

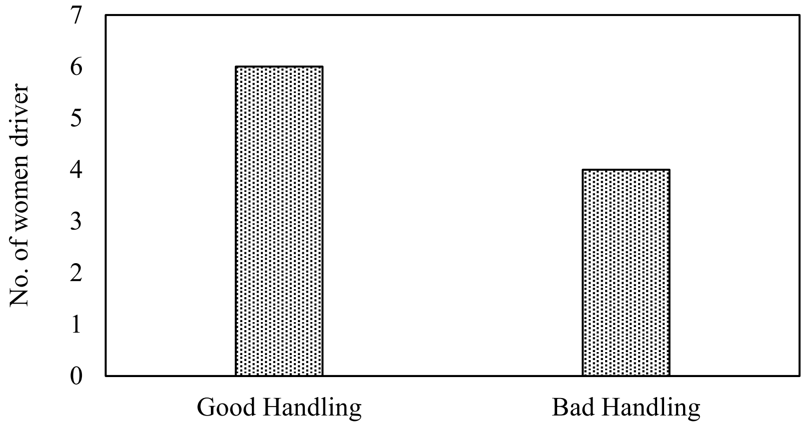


Figure 8. Women driver compliant handle of the BT-Heartomotive device.

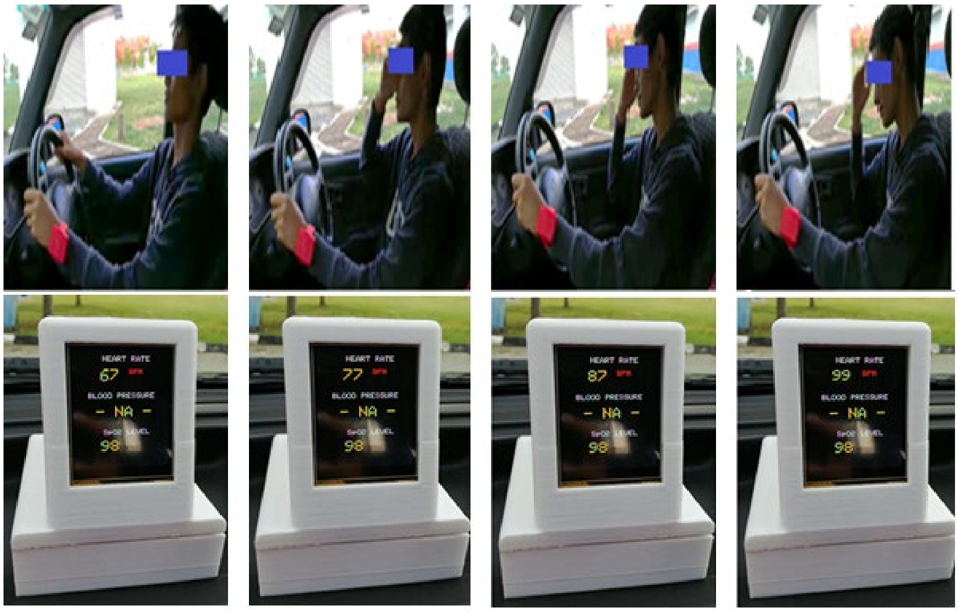


Figure 9. The condition of the driver's feeling before and after Brady-Tachy (top) and the trend of heart rate value during brady-tachy condition (bottom).

Frequency Domain

The evaluation of software processing was used in the experiment to accumulate the frequency band in both phases, which is normal and in the abnormal (brady-tachy) state. The experiment was conducted, whereas the two subjects were driving the simulation within two hours. In the two hours in simulation driving, the data was collected and verified every 10 minutes and premeditated the ratio of the low-frequency band over the high-frequency band (LF/HF). The data is shown in Table 2.

In Figure 10, the outcomes illustration clear pulse rate signal (frequency wave) can be achieved by the frequency domain of the subject's heart rate time series from low to high-frequency LF/HF ratio. The LF/HF ratio confirmations in Figure 10 decreased as the drivers conscious of presence drowsy. From this study, the results confirmed a total of road accidents might be prevented if the aware is sent directly to a driver who seems to be attainment drowsy during driving.

Table 2. Represented the LF/HF ratio obtained in 10 minutes after 2 hours of driving.

Time (minutes)	Brady-Tachy (drowsiness) (Hz)	Normal (healthy) (Hz)
1	0.1898212	0.455233
2	0.1739241	0.423333
3	0.1523432	0.431313
4	0.1638757	0.411134
5	0.1532332	0.413433
6	0.1644809	0.451242
7	0.1693473	0.441224
8	0.1535363	0.446774
9	0.1734337	0.431234
10	0.1523423	0.452332

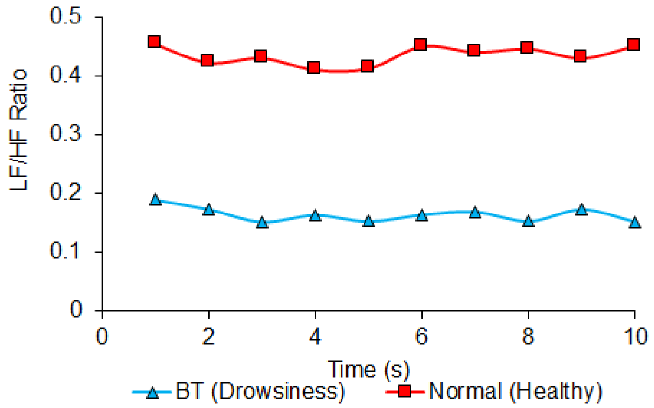


Figure 10. Brady-Tachy (drowsiness) versus normal (healthy) condition.

Heart Rate Variability Analysis

For the physiological signal analysis, the heart rate variability (HRV) signals are determined as the constant value change of the normal interval between heart rate measurement. Normally, the value of HRV signals is definitely obtained and used as a pointer of an autonomic anxious system over the distribution stress and abnormal heart rate correlated factor since the autonomic anxious system is predisposed from the considerate anxious system and parasympathetic anxious system [20]. The HRV signals are frequently intended by considering a time series of beat to beat intermissions from the electrocardiography (ECG) or consequent from edit pulse tendency signal restrained by resources of the PPG waveform. In the particular area system environment in a car, the HRV signals are attained by signal processing as shown in Figure 11. Between the analysis methods to search the indicator that imitates the activity of the autonomic anxious system from the obtained HRV signals, this study practices the explanation of HRV signals in frequency and time domain to display the car driver’s situation precisely.

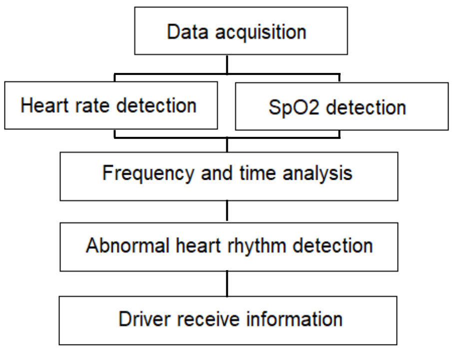


Figure 11. Flowchart of heart rate variability (HRV) analysis implemented on the BT-Heartomotive device for abnormal heart rhythm detection during driving.

Experience Detection using BT-Heartomotive

Firstly, the input indication is distributed into 5-min intervals, and the two driving procedures are confirmed based on the average percentage of BT-Heartomotive measurements over the interval. Detailed information about the operation of the BT-Heartomotive device can be found in our earlier studies [18,19]. Table 3 presented the detail characteristics of the heart rate in an alert and abnormal situation during driving conditions, where a BT-Heartomotive value of 0%~20% indicates alert situations and 20%~40% indicates drowsy situations. This arrangement standard was set to complete our pilot study when subjects informed their sleepiness states. On this measure subjects indicate which level best imitates the psycho-physical state practised in the last 5 min. This is the reason why we composed the data for 5 min intervals.

Table 3. Summary of the two dissimilar driving situations.

Driver situations	Description specifications	BT-Heartomotive
Alert	Driving in the morning [Time: 8:00-12:00]	0%~15%
Abnormal Heart Rate	Driving after lunch when feeling drowsy [Time: 14:00-16:00]	15%~45%

CONCLUSION

In conclusion, the prototype of the BT-Heartomotive device is well developed. This device purposely uses the data and sends an alert to the driver and passengers that they are in precaution, especially in road accidents caused by uncontrollable factors such as medical conditions and drowsiness. They should pull over and take action as early as possible to prevent a motor vehicle accident. This BT-Heartomotive device is simple, easy to use, and automated and still in the early prototype development with positive progress.

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