Green Intelligent Systems and Applications

*Research Article*
**Volume 3(2), 2023, 98–110**
https://doi.org/10.53623/gisa.v3i2.323

# IoT-based Heart Signal Processing System for Driver Drowsiness Detection

**Yunidar Yunidar[1], Melinda Melinda[1]*, Khairani Khairani[1], Muhammad Irhamsyah[1], Nurlida Basir[2]**

[1]Department of Electrical Engineering and Computer, Engineering Faculty, Universitas Syiah Kuala, Banda Aceh, Indonesia
[2]Faculty of Science and Technology, Universiti Sains Islam Malaysia, 71800 Nilai, Negeri Sembilan, Malaysia

*Correspondence: melinda@usk.ac.id

**SUBMITTED: 18 September 2023; REVISED: 3 November 2023; ACCEPTED: 7 November 2023**

**ABSTRACT:** Traffic accidents often result in loss of life and significant economic losses. Indonesia's high number of traffic accidents indicates the need for effective solutions to overcome this problem. Developing a drowsiness detection device is one effort that can be made to reduce accidents caused by drowsy drivers. The data obtained in this study used driver heart rate data. The drowsiness detection tool was developed using the Wemos D1 Pro Esp8266 microcontroller and MAX30102 sensor. Testing was carried out on 25 subjects under two conditions: 'Drowsy' and 'Normal.' The driver's level of drowsiness is determined based on the heart rate measured by the detection device. The Blynk application is used as a visual interface to provide notifications via smartphone if the driver is drowsy. The accuracy of the drowsiness detection tool was compared with the results obtained from the Pulse Oximeter. This research shows that the drowsiness detection tool using the Wemos D1 Pro Esp8266 microcontroller and MAX30102 sensor has an accuracy of around 98% when compared with the pulse oximeter. The Blynk application successfully sends notifications precisely when the driver is drowsy. This study highlights the potential of drowsiness detection devices to improve traffic safety and reduce accidents caused by drowsy drivers.

**KEYWORDS:** Traffic accidents; drowsiness; heartbeat; IoT systems

## 1. Introduction

Traffic accidents are a serious problem that results in negative impacts such as deaths, injuries, and significant economic losses. Globally, around 1 million people die every year due to traffic accidents. Indonesia has the world's fifth-highest traffic accident rate [[1]. The causes of traffic accidents can be grouped into factors related to the driver, vehicle, and environment. One significant factor is fatigue and drowsiness while driving [2]. The United States National Highway Traffic Safety Administration (US NHTSA) identifies four main factors that can cause accidents due to driver actions, one of which is fatigue and drowsiness [3]. Drowsiness-related crash patterns were identified through crash clusters—crashes due to late afternoon driver fatigue, late-night crashes in business and residential areas, and heavy truck crashes on high curves [4]. Studies show that adults need 8 hours of sleep every night to maintain optimal performance. Driving requires a lot of focus, and driving for long periods can cause fatigue, often leading to drowsy drivers. Being drowsy while driving can result in the driver falling asleep unconsciously, which has the potential to lose control of the vehicle and has a high risk of causing a traffic accident [5].

Various studies have been conducted to minimize the risk of drowsiness, including designing a drowsiness detector. Research [6] detects driver drowsiness using a visual-based approach, and driving behavior features do not mention the sample size used in this study, making it difficult to assess the accuracy and generalizability of the study results. Furthermore, research [7] identified driver drowsiness using consumer wearable devices in partially automated driving on real roads. This study shows that partially automated driving has little impact on the relationship between heart rate variability (HRV) and sleepiness, and commercial wearable heart rate monitors have the potential to be a useful tool for assessing driver sleepiness during manual and partially automated driving. However, this study had the drawback of a relatively small number of participants and was only conducted on a 90 km two-lane highway in Sweden. In the domain of drowsiness detection research [8], an Electroencephalography-based (EEG) drowsiness detection system using various machine learning algorithms such as Support Vector Machine with Radial Basis Function (SVM-RBF), K-Nearest Neighbors (KNN), and Random Forest (RF) was developed, but it has drawbacks. This research includes a small sample size because it only involved twelve subjects. The study did not consider real-world driving conditions, which could impact the system's accuracy. Research [9] employs computational methods and software in the biomedical field to detect sleepiness using EEG data. Nevertheless, one of the research's limitations is its relatively low classification accuracy, specifically, a binary classification accuracy of only 43.65%. Additionally, the study involved a limited number of subjects (18), which poses constraints on the generalizability of the findings.

Research [10] designed a deep neural network for drowsiness detection based on electroencephalography (EEG) in various states of consciousness, namely "awake," "sleep," and "drowsy." The shortcomings of this research include non-optimal window lengths and the need for additional classification methods to verify the performance of the proposed neural network. Research [11] proposed a system that uses a combination of biomedical sensors and motion sensors to detect driver drowsiness and alert the driver. Still, this study used a small sample size, which may limit the generalization of the research results. In a distinct approach, research [12] evaluated the effectiveness of driver monitoring systems for detecting drowsiness, but this study did not compare the effectiveness of driver monitoring systems with other drowsiness detection methods. Lastly, Research [13] proposed a model that combines non-intrusive and intrusive approaches to detect driver drowsiness. Behavioral measurements were used as a non-intrusive approach, and sensor-based physiological measurements were used as an intrusive approach. However, this study used intrusive measures, which may only suit some drivers. Because of that, the main contribution of this paper is as follows:

a. This research develops a drowsiness detection tool using a heartbeat that can detect and provide notifications to the user.
b. This drowsiness detection tool is equipped with notification features in the form of alarms and notifications to alert users of drowsiness. It can also monitor the driver from the Blynk app.
c. Utilizing IoT as an output that can provide displays and notifications, namely the driver's condition with a normal or drowsy heart rate obtained from the MAX30102 sensor on

the device.

The application of technology to overcome problems in drivers in the form of tired conditions to regain consciousness so they can rest for a while, so we need a prototype that can detect drowsiness in drivers.

## 2. Materials and Methods

The problem-solving approach in this study is to apply the stages as shown in Figure 1, as follows: preparation of tool design, testing, model evaluation and performance measures: drowsy and non-drowsy heart rate.

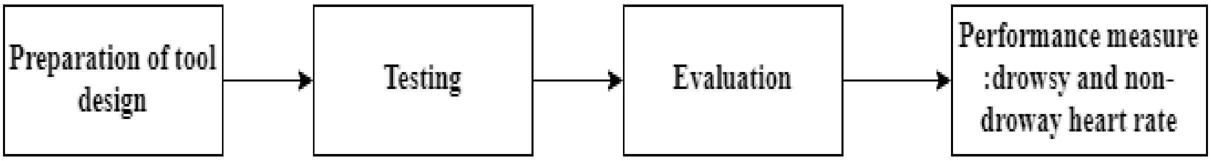



**Figure 1.** Research stages.

### *2.1. Research object.*

The object of the study is heart rate data from drivers of public transportation vehicles such as: HiAce, L300, and so on. The location used is the route from Banda Aceh to Aceh Tamiang, Indonesia.

**Tabel 1.** Equipment used.

| No | Name Of Tool | Specification | Justification |
|---|---|---|---|
| 1. | Laptop | RAM 8 GB, Windows 10 , Ultimate 64 bit, Processor 1.9 GHz | Data Processing |
| 2. | Software Arduino IDE | 1.8.16 | Programming the Program Whole Device |
| 3. | Android | RAM 3 GB, Android 9 | User Device To Provide Notification |
| 4. | Blynk App | 1.3.9 | Data processing to the user |

**Tabel 2.** Material used.

| No | Name Of Tool | Specification | Justification |
|---|---|---|---|
| 1. | OLED I2C | Interface: I2C (3,3V/ 5V logic level) Resolution: 128 x 64 Angle of view: >160 degree. | Display Heart Rate with BPM unit |
| 2. | Module Wemos D1 Pro ESP8266 | Chipset Esp-8266, Flash memory 16 MB, Voltage 3,3 V | Microcontroller / Data Processing |
| 3. | Sensor Heart Rate | MAX30102 | Measuring the heart rate |
| 4. | battery Lippo | 3.7 V, 750mAH | Voltage Source ESP |
| 5. | PCB | 8 x 12 cm | Circuit Boards |
| 6. | Cable Connecting | Male-Female | Design of the device |

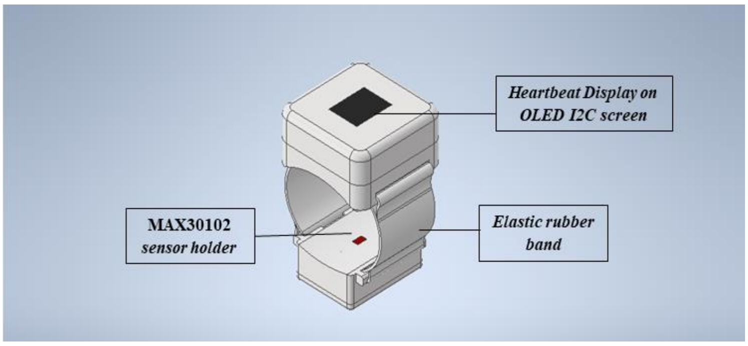
### *2.2. Preliminary preparations*

#### *2.2.1 Hardware design.*

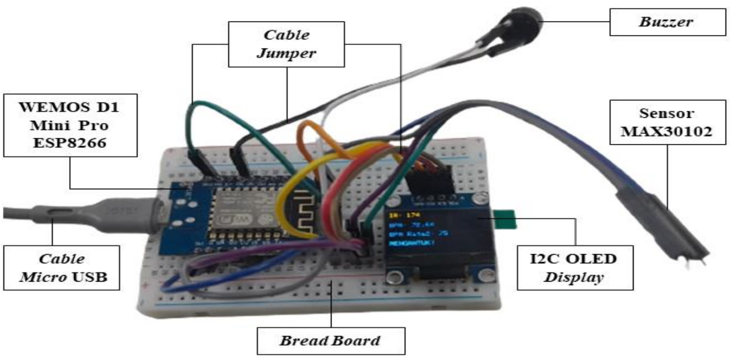
This study covered several locations, including Banda Aceh - Sigli, Banda Aceh - Bireun, Banda Aceh - Lhoksemawe, Banda Aceh - Langsa, and Banda Aceh - Aceh Tamiang. In the process of creating the prototype, various components were utilized, as illustrated in Figure 2. The prototype design of the bracelet-shaped drowsiness detector is depicted in Fig. 2, with design specifications for length x width x height set at 4 cm x 4 cm x 9 cm. The materials used include a MAX30102 sensor, ESP 8266 microcontroller, Buzzer, and OLED I2C. Additionally, data access is facilitated through the Blynk application, which operates on the IoT system.

The Wemos D1 Mini Pro ESP8266 is a chip that provides WiFi connection capabilities and supports the Transmission Control Protocol/Internet Protocol (TCP/IP) stack. Its small size allows the microcontroller to easily connect to a WiFi network and establish a TCP/IP connection using available commands. This chip operates at a speed of 80 MHz, is equipped with 16 MB of external Random Access Memory (RAM), and supports the Institute of Electrical and Electronics Engineers (IEEE) 802.11 b/g/n format, ensuring minimal interference with other users [14]. The ESP 8266 is well-suited for Internet of Things (IoT) projects due to its WiFi and Bluetooth modules [4]. In this research, the ESP8266 is employed to store measurement data from devices such as sensors, which is then continuously sent to users via mobile devices or the internet [15].

The MAX30102 sensor is a module that functions as a tool for monitoring blood oxygen (SpO2) and heart rate per minute (BPM) through the principle of photoplethysmography (PPG) [16]. OLED (Organic Light-Emitting Diode) is a display technology utilizing organic compounds to emit light in response to an electric current. I2C OLEDs consist of a negative cathode, a positive anode, and a layer of organic material emitting light when a voltage is applied [17]. One notable advantage of OLED I2C is its requirement for very low voltage. The most basic OLED I2C structure consists of a cathode, anode, and a light-emitting layer [18].




(a)




(b)

**Figure 2.** Drowsiness detection devices.

This prototype design used a Wemos D1 Mini Pro ESP8266 with an IoT system and a MAX30102 sensor to detect heartbeats placed on the wrist. The heartbeat results were displayed on the OLED I2C display screen. The resulting data was sent via WiFi to Blynk users with the IoT system. If the heart rate decreased by 8 BPM from the normal heart rate [19], a notification alarm sound was triggered and connected to the smartphone.

*2.2.2. Software design.*

At the software utilization stage in this research, Internet of Things (IoT)-based software, namely Arduino Integrated Development Environment (IDE), was installed [20]. Arduino IDE is software used as a programmer for various Arduino devices. Arduino IDE software uses the C or C++ programming language. Arduino IDE could work on Windows, Mac OS X, and Linux. The environment is written in Java and is based on processing and other open-source software [21]. To run the system program, library installation was carried out for the MAX30102 sensor device, OLED I2C I2C device, Buzzer, ESP8266, and the Blynk application [22]. The library could be downloaded from the Arduino Library website. For the ESP8266 Library, it was directly installed in the Arduino IDE software. The programming and algorithm design of each input, in the form of sensors and OLED I2C, produced output in the form of a heart rate display in BPM units or a statement on the notification Blynk [23] (Figure 3).


**Figure 3.** Views on Blynk.

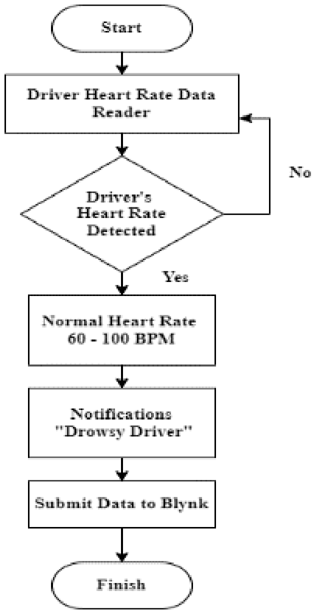



**Figure 4.** Flow diagram of software system.

Using the Blynk application begins by creating a new project on the Blynk application installed on the smartphone. Then, determine the project name, "Heart Rate Monitoring," using the ESP8266 device and connect to Blynk. After completing the project, you received an Auth Token in the email used as an account when you first registered. The Auth Token was used in the Arduino IDE when writing programs. This stage was completed when the hardware program could work and function according to the algorithm that had been designed. The algorithm produced by the software system can be seen in Figure 4.

Based on Figure 4, the software input data from the heart rate sensor. If the driver's heart rate decreased by 8 BPM from the normal heart rate set in the programming algorithm, the user received a drowsy notification. If not, it sent the information automatically to the user's smartphone via the Blynk application. The illustration of an IoT system user detecting sleepiness is shown in Figure 5

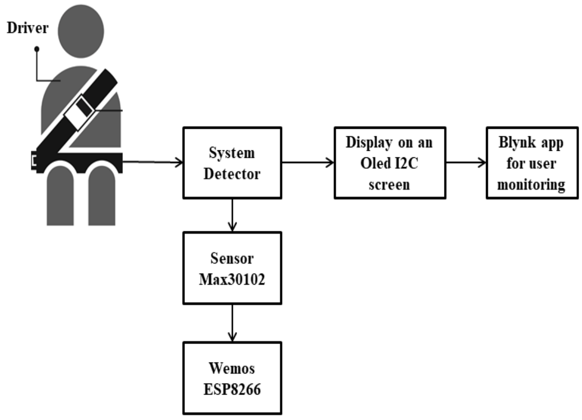



**Figure 5.** IoT system for the driver.

**Table 3.** Participant acquisition data.

| No | Parameters | Description |
|---|---|---|
| 1. | Total Participant | 25 Drivers across Banda Aceh - Aceh Tamiang Region |
| 2. | Age Participants | 28 - 50 Years Old |
| 3. | Total Testing data | Total Data 10 Trips<br>– Banda Aceh – Sigli<br>– Sigli – Banda Aceh<br>– Banda Aceh – Bireun<br>– Bireun – Banda Aceh<br>– Banda Aceh – Lhoksemawe<br>– Lhoksemawe – Banda Aceh<br>– Banda Aceh – Langsa<br>– Langsa - Banda Aceh<br>– Banda Aceh – Aceh Tamiang<br>– Aceh Tamiang - Banda Aceh |
| 4. | Measured data | Driver's Heart Rate |
| 5. | Protocol room | – Travel time day - night<br>– At the time of travel |
| 6. | Configuration Tools | – MAX30102 sensor type<br>– Wearing a bracelet-shaped device on the driver's wrist<br>– The device is connected to the blynk app via wifi to get notifications |
| 7. | Criteria Participants | Each participant must fulfill the following criteria before data collection is carried out:<br>– Physically and mentally healthy<br>– Do not have heart disease<br>– The initial state when checking is not sleepy |
| 8. | SOP Testing | – Testing is carried out during the trip according to the route<br>– Testing was carried out 2 times, namely when going and returning |

*2.3. Working process of the drowsiness detection device.*

At this stage, namely the stage of the tool's working process, where the initial stage until success is to determine the detection of drowsiness in the driver, the steps for operating the tool are as follows:


**Figure 6.** The process of installing the tool on the driver's hand.

Figure 6 shows how the device was attached to the driver's wrist as a bracelet. This tool was equipped with components assembled with a MAX30102 sensor placed under the wrist directly on the skin of the hand close to the pulse, while at the top of the wrist, there was a square-shaped OLED I2C screen display to show heart rate information. Based on Figure 6, activating the tool started with compiling the heartbeat detection project on the Arduino IDE and then transferring it to Wemos as the microcontroller. When the compile process was ready and reached 100%, and the device was connected to the Wi-Fi that had been installed. The process of measuring heart rate using MAX30102 and sending data to the Blynk application, connected to Wemos, was activated until there was a display like Figure 7 below:

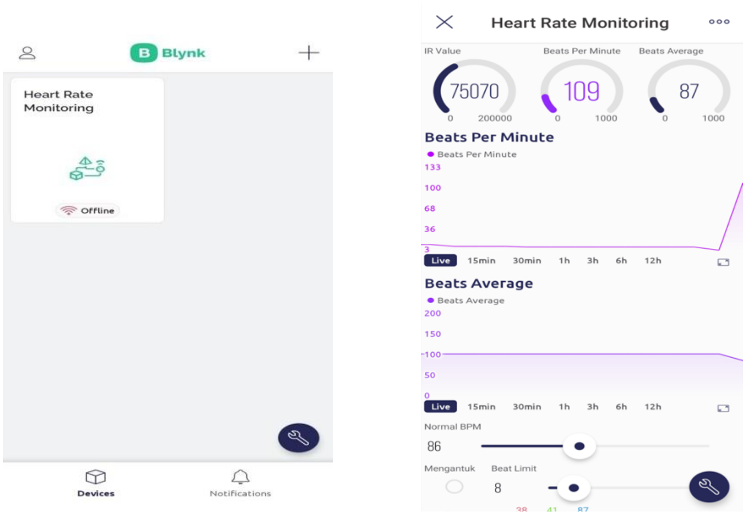
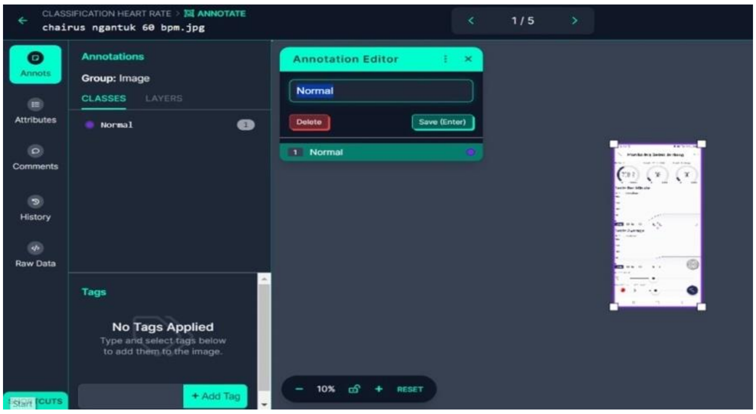



**Figure 7.** Blynk application display.

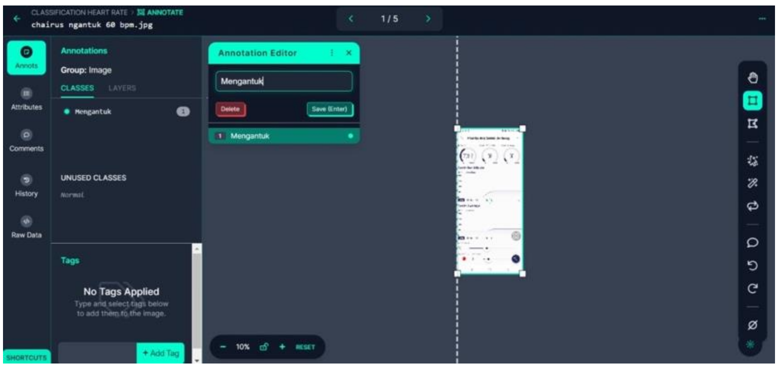
Figure 7 showed the display in the Blynk application, which displayed the IR Value as the infrared light intensity value measured by the MAX30102 sensor on the drowsiness detector. Beats Per Minute is a measurement of heart rate in one minute. In drowsiness detection devices, BPM measured the user's heart rate. BPM could be used to provide information about the user's heart condition and could be the main parameter for detecting sleepiness [24]. Meanwhile, Beats Average was the average heart rate over a certain time as measured by the MAX30102 sensor on the drowsiness detector. The lower the heart rate, the higher the possibility that the user was starting to feel sleepy. This was because the average heart rate was connected to the intensity of infrared light and pulse rate. When the heart rate was lower, it indicated a decrease in the intensity of infrared light and pulse rate, which was associated with wakefulness. Therefore, a lower heart rate suggested that the user was transitioning towards a sleepy state [25]. In the Blynk, the information displayed was that if the normal heart rate decreased by 8 BPM, sleepiness would be detected.

*2.4. Configuring models into datasets in Roboflow.*

The stages of obtaining dataset results involved using RoboFlow by labeling the Blynk application display image. This research initiated a new project called "Classification Heart Rate." It created a new dataset by labeling the results of images from the Blynk app with two classifications: sleepy and normal. The first step involved entering a photo that already had a heartbeat and then labeling it to determine the normal or sleepy classification of the image, as shown in Figure 8. The annotation stage is the process of marking certain objects or areas. Annotation can be done by marking the object's location using a bounding box, marking certain pixels using semantic segmentation, and labeling the object's class using classification.




(a)




(b)

**Figure 8.** Labeling Process (a) “Drowsy” and (b) “Normal”.

## 3. Result and Discussion

*3.1. System design.*

The resulting prototype design has dimensions of length x width x height, namely 4 cm x 4 cm x 9 cm. It consists of Wemos D1 Mini Pro ESP8266, MAX30102 sensor, and OLED I2C. Figure 9 displays the prototype design's results from the research that has been carried out. The prototype design, as shown in Figure 9, is a bracelet-shaped device intended to be worn on the driver's wrist. It includes an I2C OLED to display whether the driver is tired or not. The MAX30102 sensor, placed under the wrist and in contact with the skin, detects the driver's heart rate. The heart rate sensor readings, presented in BPM, are sent to the Blynk application. The ESP8266 microcontroller processes the data generated by the components and transmits it to the Blynk user.


**Figure 9.** Prototype design results in bracelet form.

*3.2. Test results for drowsiness detection devices.*

In this test, the device is placed on the driver's hand and activated using a program connected to the Android system. The system is designed to detect the driver's heartbeat. If the heart rate decreases by 8 BPM from the normal level, the device will identify the driver as drowsy and trigger an alarm sound as a warning. Information regarding heart rate is displayed on the I2C OLED I2C Display screen.

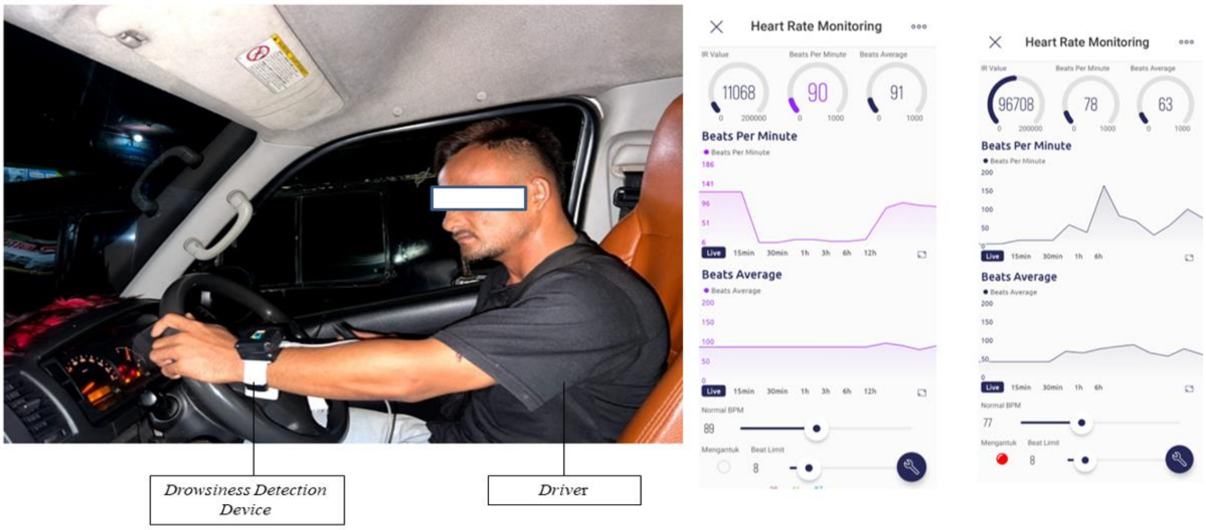



**Figure 10.** Drowsiness detection device on driver's hands.

This driver's heart rate detection tool was designed to measure the driver's heart rate and notify whether the driver was drowsy. Measurements were carried out using non-invasive heart rate sensors such as the Photoplethysmography (PPG) sensor, which was placed on the driver. Heart rate data were sent to the ESP8266 microcontroller for processing and then sent to the

Blynk application via the Internet. The tool provided two notification displays: first, "NORMAL," indicating that the heart rate was within the normal range (60-100 BPM), signifying that the driver was not drowsy; second, "Drowsy," which appeared if the driver's heart rate decreased by 8 BPM from the normal value, indicating the driver was drowsy. Heart rate information was also displayed on the OLED I2C screen installed on the device, making it easier for the driver to see the condition of his heart rate without opening the Blynk application. The Blynk application could be accessed remotely via an internet connection, allowing users to monitor the driver's heart rate in real-time. This tool was expected to help reduce traffic accidents by identifying drowsy drivers early and providing additional awareness to drivers about their health conditions while driving.

a. Testing of drowsiness detection devices for Banda Aceh-Sigli DriversS.

Table 4 shows that when the driver was drowsy, the driver's heart rate decreased by 8 BPM from a normal heart rate. The first subject, with a driving time of 190 minutes, experienced drowsiness during the Banda Aceh – Sigli trip, which was taken during the day. However, in the 4th subject, Razali did not feel sleepy even though his heart rate decreased by 8 BPM because while driving, the 4th subject was chatting with a passenger.

**Table 4.** Test results of drowsiness detection devices for Hiace drivers on the Banda Aceh – Sigli route at (11.00 am – 02.00 pm)

| Name | Starting state | Driving time | Normal Heart rate | Drowsy Heart rate | During the trip | |
|---|---|---|---|---|---|---|
| | | | | | Yes | No |
| Subject 1 | Not drowsy | 190 minutes | 75 BPM | 60 BPM | √ | |
| Subject 2 | Not drowsy | 180 minutes | 77 BPM | 63 BPM | √ | |
| Subject 3 | Not drowsy | 185 minutes | 81 BPM | 58 BPM | √ | |
| Subject 4 | Not drowsy | 165 minutes | 82 BPM | 71 BPM | | √ |
| Subject 5 | Not drowsy | 170 minutes | 82 BPM | 60 BPM | √ | |

b. Testing of drowsiness detection devices for Sigli-Banda Aceh drivers.

Based on Table 5, the departure time can also influence the level of sleepiness because the trip from Banda Aceh to Sigli at 11:00 WIB felt sleepier than the return trip from Sigli to Banda Aceh at 16:00. The length of time driving does not affect whether a person is sleepy or not while driving. The third and fifth drivers did not feel sleepy during the trip because drinking caffeine also affected a person's level of sleepiness. On the way home, individuals appeared tired more quickly than when they left.

**Table 5.** Test results of drowsiness detection devices for Hiace drivers on travel routes Sigli - Banda Aceh at (04.00 pm – 07.00 pm).

| Name | Starting state | Driving time | Normal Heart rate | Drowsy Heart rate | During the trip | |
|---|---|---|---|---|---|---|
| | | | | | Yes | No |
| Subject 1 | Not drowsy | 180 minutes | 75 BPM | 61 BPM | √ | |
| Subject 2 | Not drowsy | 170 minutes | 77 BPM | 68 BPM | | √ |
| Subject 3 | Not drowsy | 165 minutes | 81 BPM | 60 BPM | √ | |
| Subject 4 | Not drowsy | 185 minutes | 82 BPM | 61 BPM | √ | |
| Subject 5 | Not drowsy | 176 minutes | 82 BPM | 67 BPM | | √ |

*3.3. Comparison of test results between objects.*

Figure 11 shows the visual representation of travel data from Banda Aceh to Sigli (away) and from Sigli to Banda Aceh (return). In detail, it depicts the journey from Banda Aceh to Sigli.

The driver's heart rate is within the normal range of 60-100 beats per minute. At this point, the level of drowsiness has begun to be felt, although it has not yet reached a significant level. In the orange graph visualizing the return journey from Sigli to Banda Aceh, a significant increase in sleepiness also occurred. A comparison between the away and return graphs highlights the main difference in the level of drowsiness on the return journey (orange), which is higher than the away journey. This reflects that the journey home tends to trigger feelings of fatigue and sleepiness more quickly than the journey away. This research supports the idea that the return trip often affects drivers more significantly and requires further efforts to maintain safety and performance during long-distance travel.

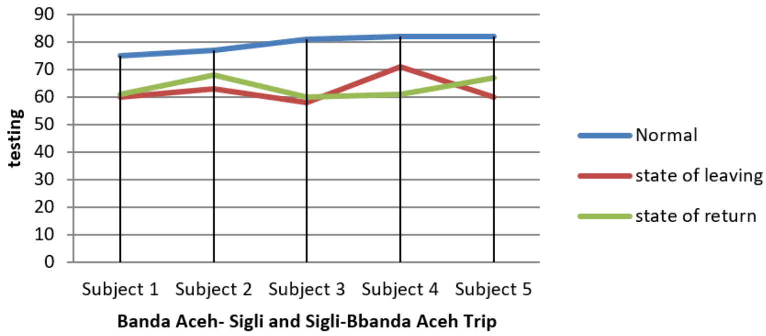



**Figure 11.** Driver heart rate comparison in testing.

### *3.4. Comparison of drowsiness detection results.*

Based on the results of this research, a comparison can be made with previous research that created a prototype in the form of a belt [7]. This research utilized different components, specifically the U-Blox Neo 6M GPS for reading position and the MLX90614 sensor for measuring the temperature of children with Autism Spectrum Disorder (ASD). For the information system in this research, an IoT system is implemented through the Blynk application. This can help users understand body position and temperature better than in previous research [9]. Table 6 compares the performance of several system detector methods used as references in this research. Based on our research, the results show that the method we propose is a development of the previous system, capable of detecting position distress conditions, and is based on an IoT system.

**Table 6.** Performance comparision several method of detector.

| Method | System Detector | | | Ref. |
|---|---|---|---|---|
| | Position | Distress condition | IoT System | |
| PPG and GSR Sensor, SVM Model | √ | √ | √ | [11] |
| DMS signals and vehicle signals with monitoring system DMS | √ | - | √ | [12] |
| Microcontroller , GSR Sensor, Pi Cam 8MP, ACP 3008 | √ | √ | - | [13] |

## 4. Conclusion

The test results demonstrated that the assembled drowsiness detection device functioned well and successfully identified "Drowsy" and "Normal" conditions with an adequate accuracy of 98%. This system allows real-time heart rate measurement, sends incoming data to the Blynk App, and displays notifications that the user can access and monitor. Furthermore, implementing heart rate labeling using Roboflow created a dataset containing information about "drowsy" or "not sleepy" conditions. This dataset can be used for the training and development of driver drowsiness detection systems.

## Competing Interest

The authors declare that there is no any financial or personal conflict of interest with others.

## References


[1] Alkinani, M.H.; Khan, W.Z.; Arshad, Q. (2020). Detecting Human Driver Inattentive and Aggressive Driving Behavior Using Deep Learning: Recent Advances, Requirements and Open Challenges. *IEEE Access*, *8*, 105008–105030. http://doi.org/10.1109/ACCESS.2020.2999829.

[2] Zhang, G.; Yau, K.K.; Zhang, X.; Li, Y. (2016). Traffic accidents involving fatigue driving and their extent of casualties. *Accident Analysis and Prevention*, *87*, 34–42.

[3] Purnamasari, P.D.; Zul Hazmi, A. (2018). Heart Beat Based Drowsiness Detection System for Driver. 2018 International Seminar on Application for Technology of Information and Communication, pp. 585–590. http://doi.org/10.1109/ISEMANTIC.2018.8549786.

[4] Rahman, M.A.; Das, S.; Sun, X. (2023). Understanding the drowsy driving crash patterns from correspondence regression analysis. *Journal of Safety Research*, *84*, 167–181. http://doi.org/10.1016/j.jsr.2022.10.017.

[5] Altameem, A.; Kumar, A.; Poonia, R.C.; Kumar, S.; Saudagar, A.K.J. (2021). Early Identification and Detection of Driver Drowsiness by Hybrid Machine Learning. *IEEE Access*, *9*, 162805–162819. http://doi.org/10.1109/ACCESS.2021.3131601.

[6] Lamaazi, H.; Alqassab, A.; Fadul, R.A.L.I. (2023). Smart Edge-Based Driver Drowsiness Detection in Mobile Crowdsourcing. *IEEE Access*, *11*, 21863–21872. http://doi.org/10.1109/ACCESS.2023.3250834.

[7] Lu, K.; Karlsson, J.; Dahlman, A.S.; Sjoqvist, B.A.; Candefjord, S. (2022). Detecting Driver Sleepiness Using Consumer Wearable Devices in Manual and Partial Automated Real-Road Driving. *IEEE Transactions on Intelligent Transportation Systems*, *23*, 4801–4810. http://doi.org/10.1109/TITS.2021.3127944.

[8] Moura, C.; Lins, I.D.; Ramos, P.M.S.; Maior, C.B.S. (2022). Automatic drowsiness detection for safety-critical operations using ensemble models and EEG signals. *Process Safety and Environmental Protection*, *164*, 566–581. http://doi.org/10.1016/j.psep.2022.06.039.

[9] Sagila Gangadharan, K.; Vinod, A.P. (2022). Computer Methods and Programs in Biomedicine Drowsiness detection using portable wireless EEG. *Computer Methods in Programs and Biomedicine*, *214*, 106535. http://doi.org/10.1016/j.cmpb.2021.106535.

[10] Catarinucci, L.; Colella, R.; Corcione, C.E.; Ingrosso, C.; Greco, A. et al., (2022). Smart IoT system empowered by customized energy-aware wireless sensors integrated in graphene-based tissues to improve workers thermal comfort. *Journal of Cleaner Production*, *360*, 132132. http://doi.org/10.1016/j.jclepro.2022.132132.

[11] Leng, L.B.; Giin, L.B.; Chung, W.Y. (2016). Wearable driver drowsiness detection system based on biomedical and motion sensors. *IEEE Sensors*, 1–4. http://doi.or/10.1109/ICSENS.2015.7370355.

[12] Schwarz, C.; Gaspar, J.; Miller, T.; Yousefian, R. (2019). The detection of drowsiness using a driver monitoring system. *Traffic Injury Prevention*, *20*, S157–S161. http://doi.org/10.1080/15389588.2019.1622005.

[13] Bajaj, J.S.; Kumar, N.; Kaushal, R.K.; Gururaj, H.L.; Flammini, F.; Natarajan, R. (2023). System and Method for Driver Drowsiness Detection Using Behavioral and Sensor-Based Physiological Measures. *Sensors*, *23*, 3. http://doi.org/10.3390/s23031292.

[14] Soares, G.; De Lima, D.; Miranda Neto, A. (2019). A Mobile Application for Driver's Drowsiness Monitoring based on PERCLOS Estimation. *IEEE Latin America Transacation, 17*, 193–202. http://doi.org/10.1109/TLA.2019.8863164.

[15] Parida, D.; Behera, A.; Naik, J.K.; Pattanaik, S.; Nanda, R.S. (2019). Real-time environment monitoring system using ESP8266 and thingspeak on internet of things platform. *International Conference on Intelligent Computing and Control Systems (ICCS)*, 225–229. https://doi.org/10.1109/ICCS45141.2019.9065451.

[16] Ngoc-Thang, B.; Tien Nguyen, T.M.; Truong, T.T.; Nguyen, B.L.H.; Nguyen, T.T. (2022). A dynamic reconfigurable wearable device to acquire high quality PPG signal and robust heart rate estimate based on deep learning algorithm for smart healthcare system. *Biosensors and Bioelectronics: X, 12*, 100223. http://doi.org/10.1016/j.biosx.2022.100223.

[17] Bujnák, M.; Pirník, R.; Nemec, D.; Hruboš, M. (2021). Universal firefighter sensor for dangerous road tunnel environment. *Transportation Research Procedia, 55*, 1019–1025. http://doi.org/10.1016/j.trpro.2021.07.073.

[18] Ganesh, K.V.S.S.; Jeyanth, S.P.S.; Bevi, A.R. (2022). IOT based portable heart rate and SpO2 pulse oximeter. *HardwareX, 11*, e00309. http://doi.org/10.1016/j.ohx.2022.e00309.

[19] Waldeck, M.R.; Lambert, M.I. (2003). Heart Rate During Sleep : Implications For Monitoring Training Status. *Journal of Sports Science and Medicine, 2*, 133–138.

[20] Thouti, S.; Venu, N.; Rinku, D.R.; Arora, A.; Rajeswaran, N. (2022). Investigation on identify the multiple issues in IoT devices using Convolutional Neural Network. *Measurement: Sensors, 24*, 100509. http://doi.org/10.1016/j.measen.2022.100509.

[21] Meje, K.C.; Bokopane, L.; Kusakana, K.; Siti, M. (2021). Real-time power dispatch in a standalone hybrid multisource distributed energy system using an Arduino board. *Energy Reports, 7*, 479–486. http://doi.org/10.1016/j.egyr.2021.08.016.

[22] Kodera, T. (2018). Adaptive antenna system by ESP32-PICO-D4 and its application to web radio system. *HardwareX, 3*, 91–99. http://doi.org/10.1016/j.ohx.2018.03.001.

[23] Balakrishna, K.; Rajesh, N, (2022). Design of remote monitored solar powered grasscutter robot with obstacle avoidance using IoT. *Global Transitions Proceedings, 3*, 109–113. http://doi.org/10.1016/j.gltp.2022.04.023.

[24] Hasdemir, I.; Gökhan, E. (2000). Experimental Analysis of Optical Sensors in Detecting Heart Beat. 2017 Medical Technologies National Congress (TIPTEKNO), pp. 1–4, 2017. https://doi.org/10.1109/TIPTEKNO.2017.8238061.

[25] Jo, S.H.; Kim, J.M.; Kim, D.K. (2019). Heart rate change while drowsy driving. *Journal of Korean Medical Science, 34*, 8–12. http://doi.org/10.3346/jkms.2019.34.e56.