Development of Heart Rate Monitoring System to Estimate Driver’s Mental Workload Level

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Abstract. Driver’s mental workload is affecting the driver’s performance while driving. A high mental workload task proved that the driver’s performance level decrease. The decreasing of driver’s performance lead to driver carelessness that causes a road accident. Thus, the way to estimate and monitor the driver’s mental workload has to be developed. The purpose of this project is to monitor the driver’s mental workload and give a prompt warning to the drivers whether they are safe or not to drive, thus enhancing road safety. This project started by obtaining information about the driver’s mental workload through a driver’s heart rate. For early stage, this project conducted by using an electronic device for education, which is Arduino Kit and heart rate sensor. The heart rate sensor will detect the heart beat through the fingertips as an input. Then the input will be sent to Arduino, and it will monitor the reading of heart beat in beat per minutes (BPM) through a connected screen monitor. An experiment conducted in two conditions which are at rest condition and during Mathematical Arithmetic Task to estimate the driver’s mental workload. By using the developed sensor system, the threshold value of mental workload was collected. The buzzer will produce a sound if the reading heart rate value is exceeding the maximum threshold heart rate reading for the safe driving condition.

1. Introduction
Road safety is one of the crucial things that must be considered by everyone. The carelessness of the driver may lead to an accident. According to the road safety annual report 2017, in 2015 there was a small increase of 0.5% from 2014 in the number of reported fatalities bringing the total to 6706. 20.3% of the total are car occupants [1]. Then, based on provisional data published by the Malaysian Institute of Road Safety Research (MIROS), there were 7 152 reported road deaths in 2016, a 6.7% increase compared to 2015[2]. This shows that the problem of road safety still in critical condition as the year increases mean that the improvement of the safety system developed for vehicles also increases. However, the problem of road safety still cannot be solved as the number of road accident still in high number every year.

After looking at many previous studies about the causes of road accidents, approximately 23% of all crashes and near-crashes were caused by distraction due to the secondary task (task other than driving) [3]. It shows that distracted driving is a vital issue to be concerned. Driver distraction has a relationship to the driver’s mental workload as distraction causing unstable driver’s mental workload [4]. There are risky for the driver to drive in an unstable mental workload due to the driving performance begins to deteriorate and may lead to a road accident [3][4][7]. Realizing the importance of developing a method to estimate and detect the driver’s high mental workload level, this project chooses the heart rate level as the indicator to estimate the mental workload.

There a lot of road accident happened due to human error, which leads by their mental workload. Not many cars have a safety system that focuses on the driver’s driving condition. The main problem is
it is difficult to estimate and monitor the driver’s mental workload to prevent road accident. Currently, the detection of a driver’s mental workload has been a challenging part of the research and become increasingly important in order to develop a precaution warning system for the driver. The studies on estimation of a driver’s mental workload have been conducted using various ways and devices. However, the accuracy of the measurement of the devices is still vague.

There was various way to estimate the mental workload of human. Previously, there was a study about the mental workload that used pupillometry [8]. Pupillometry is the measurement of pupil size and reactivity toward task or work done by someone [9]. Gerhard Marquart and Joost de Winter used the smart Eye DR120 remote eye tracker to record the participant’s pupil diameter, eyelid opening, and gaze direction while sitting behind a desktop computer [8].

In one of the studies conducted, the data were recorded by using human finger photoplethysmogram (PGT). Zeier (1979) measured heart rate in heavy city traffic while subjects drove a car with a manual transmission or a car with an automatic transmission or being a passenger of the car been driven by someone else. Both average heart rate and Heart Rate Variability (HRV) in time domain differed significantly between the manual-transmission condition and the other two conditions. Driving with automatic transmissions or riding as a passenger did not lead to a significant difference in heart rate measures [10]. Meister et al. have designed a model of mental workload and the relationship between the task demand and mental workload level as in Figure 1 [11]. This model divided into three regions, A, B and C. Region A indicated a low level of workload. Increase in workload is not accompanied by variations in performance since the operator has sufficient spare information-processing resources to compensate for a workload increase. Meanwhile, in region B, it consists of a higher level of workload that exceeds the capability of the operator to compensate. Then in region C, degradations in performance will be gradual during the initial stage of overload or total failure will occur at higher levels of load [12].

![Figure 1. Hypothetical workload and performance relationship [11]](image)

2. Material and Methods

2.1 Heart Rate Monitoring Device Component

Arduino software, nodeMCU and Pulse sensor are the main electric components to develop the heart rate monitoring device. After the device is set up, the heart rate data will be display through Blynk applications using a Wi-Fi connection. Table 1 shows the component to build the Heart Rate Monitoring Device and its functions.
Table 1: Heart Rate Monitoring Device Component

| Component        | Name and functions                                      |
|------------------|---------------------------------------------------------|
| Mini Bread Board | - As a platform to build a heart rate monitoring device |
| Jumper Wire      | - As a connecting wire between the equipment            |
| Pulse Sensor     | - To sense the heart rate of the users                  |
| NodeMCU          | - An open source of IoT platform                        |
|                  | - Act as a platform to build a device and as a Wi-Fi port |

2.2 Development of the heart rate monitoring system

Before starting the estimation of a driver’s mental workload, the device to detect the heart rate of the driver has to be developed. In this project, the used of Arduino and heart rate sensor is compulsory to develop the heart rate sensor system to record the data, which is the driver’s heart rate. The following Figure 2 shows how the heart rate sensor warning system was developed summarily.
2.3 Experimental Setup

After developed the device that can detect the heart rate, the experiment on the change of the driver’s heart rate have been conducted. Ten participants aged 20-35 who have a driving license and drive the car almost every day have been recruited for the experiment. The participants needed to sit on the driver seat in a selected car without driving that car. There were two conditions to be performed by the participants. The first condition was at rest, means relax and focus in front of the vehicle. For the second condition, the participants needed to perform a Mathematical Arithmetic Task (MAT) in 2 minutes. MAT task requires the participants to memorize a number presented before as well as solving of calculation. The participants were given a one-digit number. Three seconds will be given to the participants to solve that calculation. The reading of the participant’s heart rates taken during performing the tasks. Figure 3 shows the setting of the devices during the experimental setup. While Figure 4 shows the example of MAT Task to be performed by the participants.
3. Results and Discussion

3.1 Development of heart rate monitoring system

The development of the heart rate sensor system completed. After applying the correct circuit and the correct programming coding installed into the Arduino, this device can function well to detect human heart rate. This device can detect a human heart rate in beat per minute (BPM) and monitor the reading of BPM through LCD that connected with Arduino. If there is no pulse detected, the value on the LCD screen will be more than 200. By using this device, the heart rate data of each participant recorded. Figure 8 shows the setup of the heart rate monitoring system.

The reading shown through the LCD is in the range of normal heart rates according to the United States National Institutes of Health (NIH) which are 60 PBM to 100 BPM for people age ten years old and above [14].

3.2 Result

3.2.1 Heart rate analysis of the driver.

The heart rate data were recorded through fingertips by using the developed system in order to determine the mental workload level. Table 2 and Figure 6 show the reading of heart rate for two tasks. The readings have been taken in 2 minutes for each person in order to get a more accurate value of participant. So basically, the data in these two figures are the average value of heart rate reading in 2 minutes.
Table 2: Heart rate reading

| No | Heart Rate (BPM) No task | MAT task |
|----|-------------------------|---------|
| 1  | 75                      | 87      |
| 2  | 71                      | 82      |
| 3  | 63                      | 76      |
| 4  | 75                      | 88      |
| 5  | 65                      | 73      |
| 6  | 69                      | 78      |
| 7  | 69                      | 80      |
| 8  | 56                      | 72      |
| 9  | 60                      | 72      |
| 10 | 66                      | 76      |
| AVERAGE BPM | 67 | 78 |

Figure 6. Heart rate reading

From Table 1 and Figure 6, the value of heart rate (BPM) for MAT Task is higher than during no task experiment. Averagely, the BPM reading for the mental workload was 67 BPM for no task and 78 for MAT task. So, the threshold value for the high mental workload was set as 78 BPM.

3.2.2 Performance analysis

The performance of the driver indicated by the correct number answer answered by the participants in the MAT task. Table 3 shows the performance analysis of the participants. All participant could answer correctly above 80% as the task in easy level. Based on the table, it can be seen that only 4 out of 10 participants did well, in the task which got correct answer 80% and above. Averagely, the performance of the participant is 78%, which did not meet the success value. This results showed that the participants were in high mental workload during the MAT task.

Table 3: Performance analysis

| Participant | Corrected Answered | Performance (%) |
|-------------|--------------------|-----------------|
| 1           | 35                 | 90              |
| 2           | 22                 | 56              |
| 3           | 33                 | 85              |
| 4           | 29                 | 74              |
| 5           | 29                 | 74              |
| 6           | 33                 | 85              |
| 7           | 30                 | 77              |
| 8           | 29                 | 74              |
| 9           | 31                 | 79              |
| 10          | 32                 | 82              |
| AVERAGE     | 30                 | 78              |
3.2.3 Subjective measurement (Questionnaire)

After completing all the task, all participants were requested to make a judgement about their feeling for the type of task they felt. The questionnaire was developed based on a standard measurement of mental workload which is NASA-TLX. [13]

Table 4 shows the result of the questionnaire. Most of them judged the task mentally demanded, and they were in high mental workload. This condition is not a good condition to drive a car because of the distraction caused by the task. In the real situation of driving, this task indicates the distraction for the driver that prevents the driver from focussing on the road. [3]

Table 4. Subjective Measurements Results (questionnaire)

| Participant | Physical demand | Mental demand | Temporal demand | Performance failure | Effort | Frustration | Level |
|-------------|-----------------|---------------|-----------------|---------------------|--------|-------------|-------|
| No task     | Task            | No task       | Task            | No task             | Task   | No task     | Task  |
| 1           | 2               | 87            | 17              | 18                  | 87     | 2           | 3     |
| 2           | 2               | 87            | 17              | 18                  | 87     | 2           | 3     |
| 3           | 5               | 76            | 12              | 14                  | 83     | 4           | 0     |
| 4           | 5               | 70            | 16              | 17                  | 5      | 50          | 4     |
| 5           | 2               | 73            | 2               | 5                   | 4      | 79          | 3     |
| 6           | 2               | 77            | 7               | 7                   | 2      | 60          | 2     |
| 7           | 2               | 79            | 12              | 18                  | 79     | 5           | 2     |
| 8           | 4               | 74            | 11              | 14                  | 80     | 3           | 18    |
| 9           | 2               | 82            | 7               | 8                   | 3      | 88          | 3     |
| 10          | 2               | 75            | 6               | 6                   | 1      | 85          | 2     |
| AVERAGE     | 5               | 62            |                 |                     | 5      |             | 62    |

4. Conclusions

The study carried out has been successfully met the goals of this project. The result of the installation of the heart rate device was successfully done. The device then used in the experiment. After the experiment, the result of the experiment met the expectation data which is the average value of heart rate, subjective measurement (questionnaire) of the participants for no task experiment is higher than the experiment with MAT task. The performance of the participants for the task also not in best as the average corrected answer answered by the participants is 78% only even though the level of the task is not tough.

For conclusion, from this experiment, the threshold value for the maximum mental workload is 78 BPM. 78 BPM is considered a high mental workload level for the driver and the precaution warning system have to be taken. In this stage, the warning system will be set 78 BPM as the condition that not suitable for driving activity.

For further study, it is recommended to recruit more participants to get a more accurate value, and the task should be levelled up to test the driver’s mental workload level.

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