Evolution in Electrical and Electronic Engineering Vol. 1 No. 1 (2020) 260 - 269

EEEE

Homepage: http://penerbit.uthm.edu.my/proceeding/index.php/eeee
e-ISSN : 2756-8458

IoT Based Forklift Worker Fatigue Monitoring Device

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DOI: https://doi.org/10.30880/eeee.2020.01.01.031
Received 15 Ogos 2020; Accepted 06 September 2020; Available online 30 October 2020

Abstract: Today we are becoming aware that most of the warehouse accidents occur due to fatigue or a drowsy forklift driver. In this study, a fatigue detection system to maintain the safety and health of the workplace was developed by monitoring the heartbeat and hand or finger grip force to detect forklift driver fatigue noninvasively and in real-time through an IoT application (Blynk) using a portable smart band. These alternative methods have been proposed to use with ESP32, Arduino Nano, pulse sensor, and force sensor which attached to the worker's finger. If the driver is fatigued, then the system will give buzz and vibrate the alarm to alert the driver. The changes in the heartbeat rate and grip force were measured experimentally to ensure the accuracy and validity of measuring heartbeat rate and grip force. The experimental results prove that the developed system using pulse and force sensor is able to detect and monitor a person's fatigue level.

Keywords: Forklift Driver, Fatigue detection, Heartbeat, Grip Force, Smart Band, Blynk App, ESP32, Arduino Nano, Pulse Sensor, Force Sensor.

1. Introduction

Each workplace is at risk of health hazards as the day is spent controlling industrial equipment, handling heavy machinery, touching chemicals, or even in an office. Warehouses are no exception, exposed to hard work, heavy lifting, and even hazardous materials. Warehousing and logistics require a wide variety of activities that may lead to multiple risks and challenges. One of the critical issues faced by this industry is how to improve task efficiency and maintain worker safety and health in managing fatigue workers in forklift operation as more than 20,000 employees each year are killed in forklift-related accidents [1].

Fatigue is an inevitable consequence of modern industrial society for a variety of reasons, largely because of high workplace demands, long duty periods, disrupted circadian rhythms, social and societal demands, and insufficient sleep [2], [3]. Fatigue and excessive daytime sleepiness are frequent signs of central or peripheral nervous system disturbances and/or other medical problems, including infections, asthma, gastrointestinal disorders, and metabolic abnormalities [4], [5]. Therefore, a device based real-

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time monitoring system plays a major role in this proposed project. Data from the device will use to prevent accidents due to forklift collision by monitoring fatigue levels, sending alerts to worker and supervisor, and suggesting rest periods.

In manufacturing environments with the routine of movement of forklifts, belts, and other materials handling equipment (MHE) in warehouse operations, incidents involving MHE typically rate among the top safety-related accidents in warehouses every day. This critical problem occurs because of the fatigue faced by the forklift operator. Fatigue may lead to discomfort, decrease muscle activity, and decrease strength. These effects can result in lower efficiency, lower productivity, work-quality deficits, and increased injury occurrence, and human error. All the reasons above support the need to develop a device as a solution for the fatigue forklift driver.

The objectives of this study are to develop a wearable fatigue monitoring device of workers to maintain the safety and health of the workplace, to alert the forklift driver by vibrating the device and notify their fatigue level or health condition to the supervisor using the Internet of Things (IoT) platform, and to analyze the functionality and performance of the developed device.

2. Materials and Methods

2.1 Materials

This section includes the electronic components used in completing the overall functionality of IoT based forklift worker fatigue monitoring device. The selection of the electronic components in this project is classified into the processing module, input module, and output module based on its working principle and capabilities to functions in the system. The electronic components used are listed as follows:

- Input module: Power supply, Pulse sensor, and Force sensor
- Processing module: ESP32 (Main controller) and Arduino Nano
- Output module: Light-emitting diode (LED), Buzzer, Vibrator and Blynk app (IoT)

Figure 1 illustrates the classification of electronic components used based on its functionality in ensuring the flow process of this project.

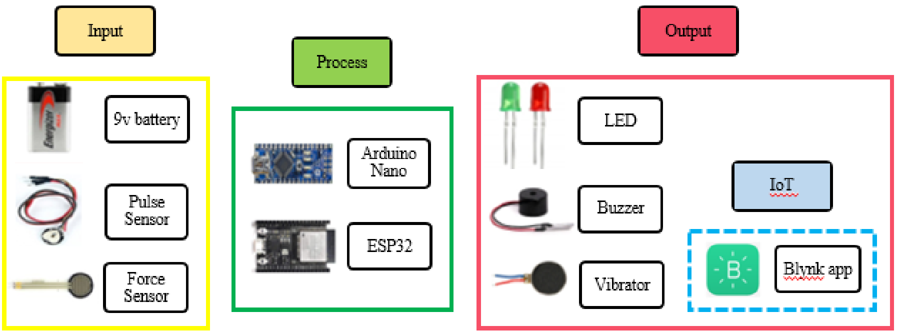


Figure 1: List of hardware and software components used

2.2 Methods

A. Device design

The design strategy is achieved by designing and implementing the input module, process or control panel, and output module. Thus, the main supply provides 9V power used as one of the inputs to operate the sensors, controllers, and output indicators. Pulse sensor provides input to the Arduino Nano which then sends to the main control unit which is ESP32 in order to perform some logical operations to power the LED, buzzer, and vibrator as output used to alert the worker. For the grip force part, input from the force sensor would be transferred directly to the ESP32 to be processed. As an access point, ESP32 is also used for connecting the smartphone by sending the data to an IoT platform which is Blynk application to be monitor by the supervisor on the fatigue level of the forklift driver. Figure 2 illustrates the block diagram of the entire system.

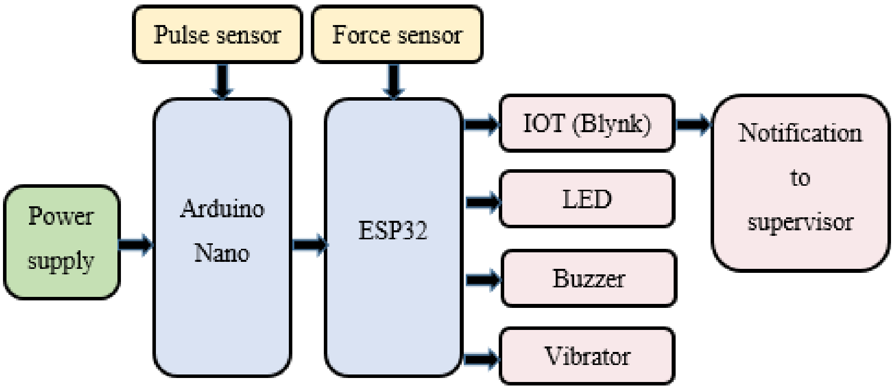


Figure 2: Block diagram of the project

B. Algorithm

The algorithm of the entire system is represented in the flowchart. The flowchart explains in detail the circuit flow and the working principle of the system. First, the force sensor is used to sense and measure the grip force (GF) while heart rate (HR) would be detected by the pulse sensor in order to indicate the fatigue level of the forklift operator. After that, the detected heartbeat transferred to the microcontroller which is Arduino Nano to be processed. Then, the microcontroller will send the data to the ESP32 board. Esp32 is the main controller which controls the handgrip force and heartbeat rate whether its range is bellowed or exceeded normal according to the different modes of operation as presented in Table 1. The LED, buzzer, and vibrator will be activated based on the current rate of heartbeat and grip measurement in order to alert the worker. Then, the data will be sent to the Blynk application to notify the supervisor on the fatigue level of forklift drivers to be monitor on their smartphone. For the condition where the heart rate value lies in the normal range (70-100 beats per minutes (bpm)), the pulse sensor will keep monitoring the heart rate constantly.

Table 1: Modes of operation

Condition			Output		
HR (bpm)	GF (%)	LED (Green/yellow/red/blue)	Buzzer	Vibrator	Notification
< 45	1-100	Blue	-	-	✓
45-66	0	Red	✓	✓	✓
45-66	1-100	Yellow	✓	-	✓
67-69	1-100	Yellow	✓	-	✓
70-100	1-100	Green	-	-	-
> 100	1-100	Blue	-	-	✓

This device was developed along with a switch used as an input and also as false alarm to the system. The false alarm switch can be pushed at any time by the driver, which turns off the alarm. This is done via interrupt and therefore the switch is not shown in the flowchart of Figure 3 that describes the entire system.

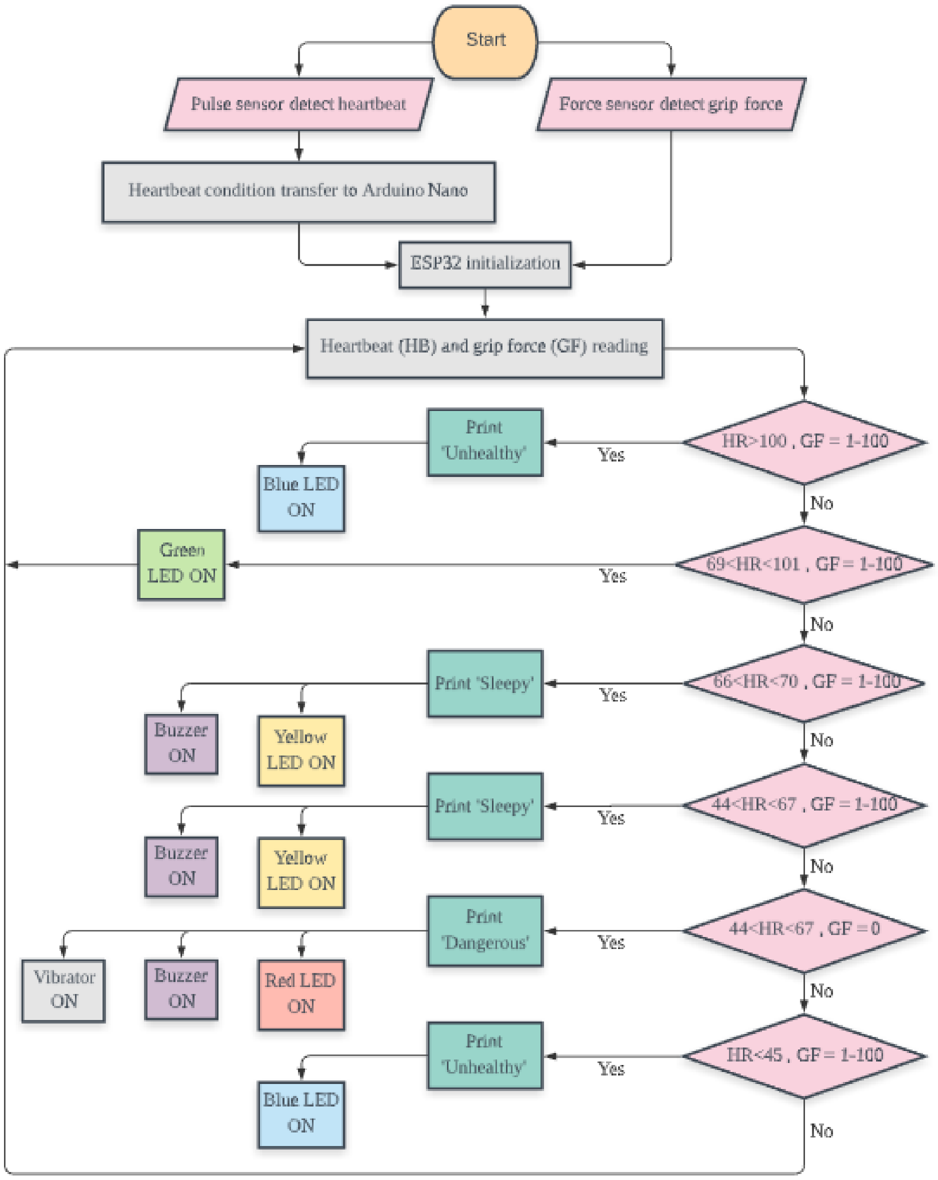


Figure 3: Overall system flowchart

Besides, the algorithm of the supervisor monitoring features of the IoT based forklift worker fatigue monitoring device is illustrated in the process diagram as shown in Figure 4. The features provide the supervisor to self-monitor the fatigue level of their forklift driver.

The start of this fatigue monitoring system can be divided into two-part since there are two sensors used for these features. These features allow the supervisor to self-monitor the fatigue level of their forklift driver easily. The process flow of these two sensors is similar, therefore it can be explained in the same flowchart. For heartbeat monitoring, the process begins at the heartbeat sensor. The worker will wear the smart wrist band with the heartbeat sensor on their finger. As the sensor records the user's heartbeat it will then transferred to the controller to be processed. Besides, the reading value of both sensors will be sent to the Blynk application in order to notify the supervisor's mobile phone on the fatigue level of their worker.

In the hand steering-wheel grip force part, it can easily be measured by placing the finger on the force sensor connected to the smart wrist band. Basically, the flow process of this feature is similar to the heartbeat monitoring features. The data obtained from the force sensor will then be processed and sent to the Blynk application for the supervisor's monitoring purpose.

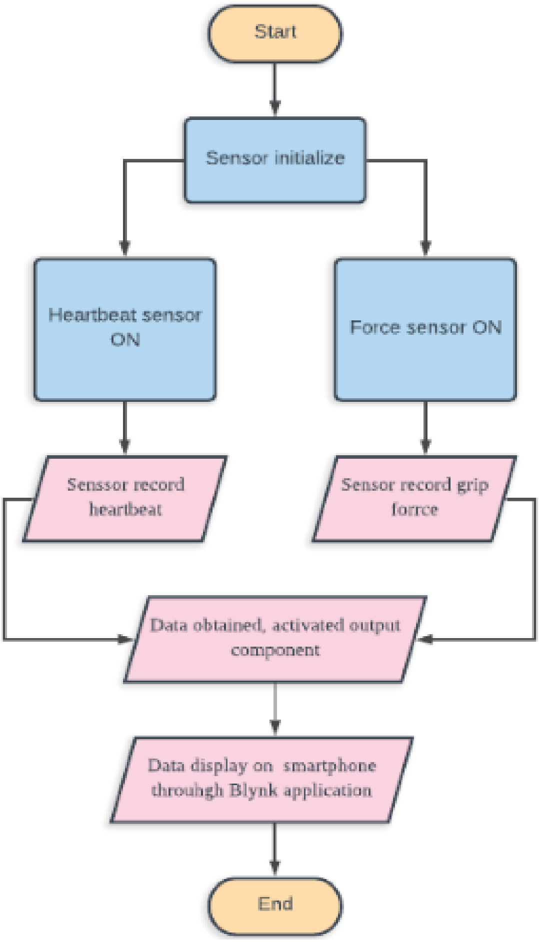


Figure 4: Fatigue monitoring process

C. Experimental data collection

The feasibility of using the current sensors which are pulse sensors to collect data on a forklift driver's heartbeat rate and force sensor to collect data on a forklift driver's gripping force should be tested and analyzed. This method was evaluated using two separate experiments intended to achieve the correct result for this system. The procedure was conducted at different times and days.

i. Experiment 1

- Experiment: Heartbeat rate accuracy and pulse difference in three states: not sleepy, drowsy and sleeping
- Participant: 18 (9 female adults and 9 male adults)
- Apparatus: XERON Automatic Blood Pressure Monitor
- Purpose:
  - To determine the accuracy of the developed device
  - To prove that a difference in a person's awareness state can affect a person's heart rate, and how much heart rate varies in not sleepy, sleepiness, and sleeping.
- Procedure:
  - The heartbeat reading obtained from the developed device was compared to the pulse rate reading generated from the medical device
  - Heartbeat readings for each state or condition have been recorded manually and analysed from 10 a.m. to 3 p.m.

ii. Experiment 2

- Experiment: Grip force and subjective sleepiness
- Participant: 18 (9 female adults and 9 male adults)
- Apparatus:
  - Gaming chair with a steering wheel and screen
  - Forklift simulator
- Purpose:
  - To identify the validity of detecting driver fatigue using the grip force technique
  - To increase metric accuracy and consistency of grip force
- Procedure:
  - The changes in the grip force were measured while the participants performed a driving task in a room for an hour after having their lunch
  - Subjective sleepiness level was measured on a 7-point scale (1 point: not at all sleepy-7 points: very sleepy)

3. Results and Discussion

This section would discuss the project's results and analysis which included the final design of the project that has been done and tested. Figure 5 shows the final design of the developed device from the top of view. The circuit connection of the system which consists of a pulse sensor, force sensor, Arduino Nano, ESP32, LED, buzzer, and vibrator could be seen from the top view of the device.

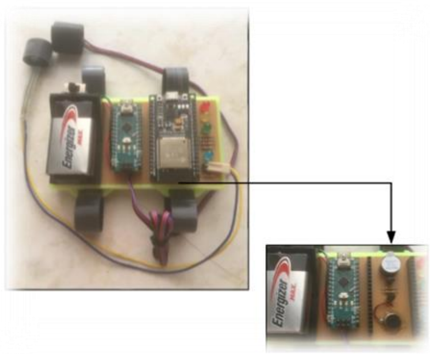


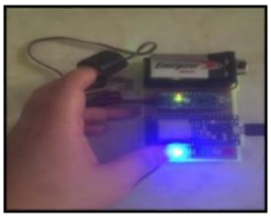
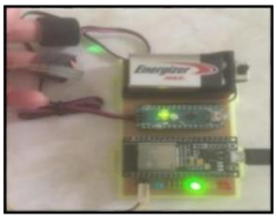
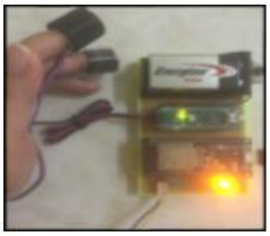
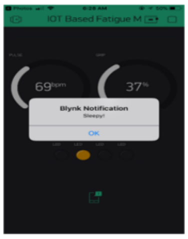
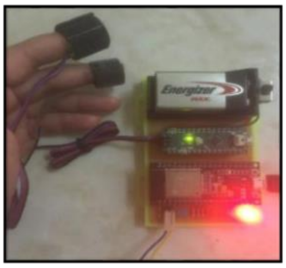
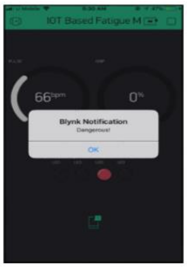
Figure 5: The top view of the developed device

The sensors record the values of fatigue monitoring and device control the heartbeat rate and grip force measurement. The recorded values are displayed on the supervisor’s smartphone through the Blynk application. Figure 6 shows the Blynk displays updated values of heartbeat rate and grip force along with the LED indications to notify the supervisor on their smartphone.

Figure 6: Blynk output display

Table 2 shows the main findings that has been classified into cases, hardware result, software result, and description of the result.

Table 2: Hardware and software result

Cases	Hardware result	Software result	Result description
Case 1			Blue LED is on, the buzzer and vibrator are not triggered but there will be a pop-up notification (unhealthy state) to alert the supervisor
Case 2			Green LED is on, the buzzer and vibrator are not triggered and there is no pop-up notification alert on this situation
Case 3			Yellow LED is on, only the buzzer is triggered the forklift driver and there will be a pop-up notification (sleepy state) to alert the supervisor
Case 4			Red LED is on, the buzzer and vibrator is triggered the forklift driver and there will be a pop-up notification (dangerous state) to alert the supervisor

To make this system achieve the first and second objectives of this project, some of the cases should be tested in the system. Four possibilities have been designed and the results should meet the objectives of this project. The possibilities are listed below:

- Case 1: The detected heartbeat exceeds 100bpm or drops below 45bpm with gripping force respectively. As a result, the warning system is not triggered in this situation but there will be a notification to alert the supervisor.
- Case 2: The detected heartbeat lies in the range of 70-100bpm with gripping force. As a result, the warning system is not triggered and there is no notification alert on this situation.
- Case 3: The detected lies in the range of 67-69bpm or 45-66bpm with gripping force respectively. As a result, the buzzer will trigger the forklift driver and there will be a notification to alert the supervisor.
- Case 4: The heartbeat lies in the range of 45-66bpm with no gripping force. As a result, the buzzer and vibrator will trigger the forklift driver and there will be a notification to alert the supervisor.

Based on the third objective of this project, the functionality and performance of the developed device were successfully analysed using two different types of experiments, which were designed to produce the best measurement of this system.

3.1 Heartbeat rate accuracy

This experiment was performed to compare the developed device to a medical instrument, digital sphygmomanometer XERON Automatic Blood Pressure Monitor which capable of measuring heart rate. The experiment results are used to determine the accuracy of the current device by comparing it with a trusted tool or machine to measure heart rate. The higher the accuracy of this system the better the results of the system already generated. Based on the experiment results in Figure 7, it is observed that the built device has good accuracy as the difference in the average bpm between the developed systems with the XERON Automatic Blood Pressure Monitor tool is just 3.61%. This means that the heartbeat sensor's calculation is correct, even there is still some data that is quite different from the digital sphygmomanometer.

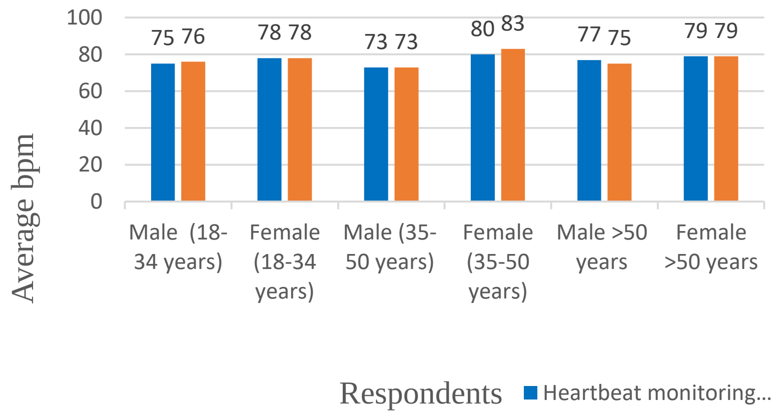


Figure 7: BPM accuracy among respondents using a benchmark device

Besides that, the study also calculated heartbeat differences in three conditions of respondents: not sleepy, drowsy, and sleeping. Figure 8 indicates that each respondent's bpm will be decreased according to their conditions. Decrease calculations are derived by comparing the average heart rate as fresh to the average heart rate as sleep, and then dividing it by the average heart rate when not sleepy, and how many drops in heart rate can be due to sleepy and sleep conditions could be identified.

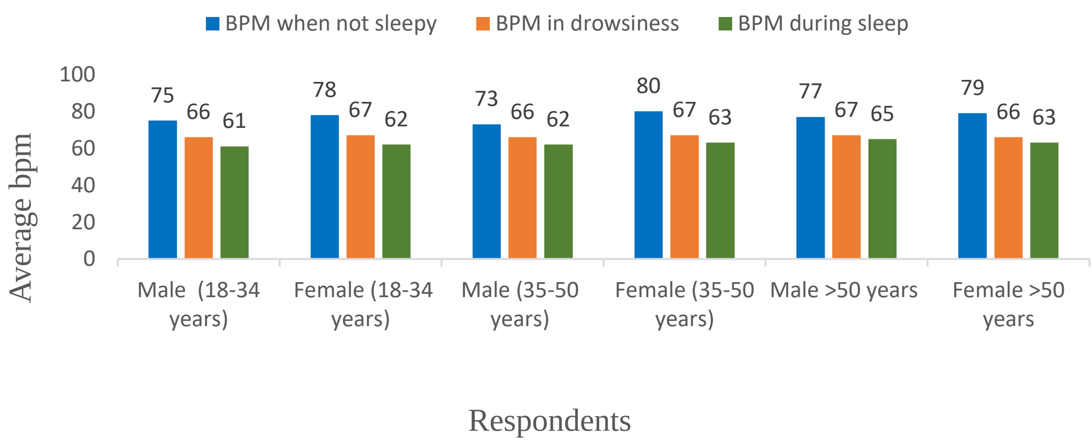


Figure 8: Comparison of heartbeat in three different condition

From the test result, 7 to 13 % decreased from fresh to sleepy, and 11 to 17 % decreased from fresh to falling asleep. This means that once a person's body is calm, their pulse rate will also naturally decrease. The reduction that happens is also quite similar to the reference where the human heartbeat decreases by about eight beats as it reaches the relaxed phase [6]. More specifically, a person's heart rate will decrease from 7 to 10 beats when not in a sleepy state. When a person in the sleep phase, the heart rate should drop from 11 to 16 rhythm beats from the not sleepy phase. This suggests that the heart rate will decrease as individuals enter a relaxing process and also decrease after a prolonged period of sleep.

3.2 Grip force and subjective sleepiness

In this experiment, the average value of grip force (%) of the last 30 s in each 10 min intervals and the participant's subjective sleepiness while driving was being tested and analysed. The results presented in Figure 9 indicates that the grip force decreased over time during the one-hour driving and it decreased significantly after 50 min. In contrast, the degree of subjective drowsiness increased over time and increased significantly after 20 min. Therefore, as participants' degree of sleepiness increased over time, grip strength decreased. In conclusion, this analysis observed that there would be a reduction in grip force over time, suggesting that grip strength measurement could be a new method for detecting driver fatigue.

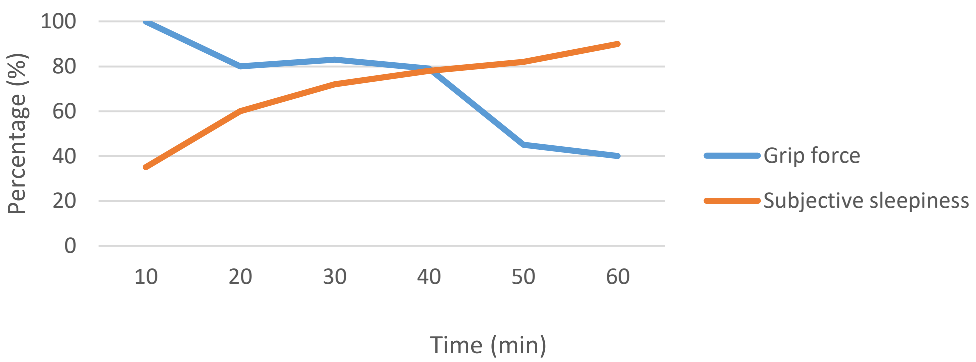


Figure 9: Grip force and subjective sleepiness over time

4. Conclusion

In this study, the analysis and design of forklift driver fatigue detection, alert, and monitoring system was presented. The proposed system was used to avoid various warehouse accidents caused by fatigue or drowsy driving of the forklift driver. This study involves a system that is used to avoid accidents by continuously measures the heart rate and body temperature of the forklift driver and provides monitoring and tracking through an android and IOS based interface with the help of a Smart Band. If the driver is fatigued, then the system will give buzz and vibrate the alarm to alert the driver. The data would be sent to the Blynk application to be notified and monitor by the supervisor using the smartphone. From the experiments, it was proven that the developed system using pulse and force sensor is able to detect a person's fatigue level but it still needs further improvement. Algorithms enhancement to measure heart rate and grip force are required for future implementation as it needs to sense or detect only drowsiness signs so the device does not get any unwanted driver signals. Of course, this system could make further improvements to the design of the device. The design improvement is essential in order to make the device more compact, robust, and multifunction. The developed system could be improved by using other physiological methods including EEGs and other strategies, such as face recognition, to improve sensitivity to fatigue detection. Besides, it is also necessary to measure other objective measures along with the heart rate and grip force in future studies. Thus, by making this project successful, the numbers of warehouse accidents could be reduced when this project is implemented to detect the fatigue or drowsiness of the forklift driver.

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