EEG-BASED DROWSINESS ALERT SYSTEM WITH IOT INTEGRATION FOR SAFE DRIVING

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This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronics Engineering Technology (Industrial Electronics) with Honours

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DEDICATION

I would like to dedicate this project research, especially to my supervisor which is Ts. Khairul Azha bin A Aziz. This thesis will be dedicated to him because I want to thank him for all the sacrifices that he made for me while I have been studying at this university. Secondly, this dedication is given to both my parents and family who always being for me through thicks and thins during accomplishing this thesis. Next, I would like to express my gratitude toward fellow classmates for being helpful while completing the study research.

ABSTRACT

Driver drowsiness and fatigue are major factors in road accidents because they reduce focus, slow response times, and delay decision-making. In severe circumstances, drivers may suffer microsleeps, small moments of unconsciousness that can result in serious accidents if they occur while driving. To solve these problems, this research proposes an EEG-based drowsiness detection system that includes IoT integration for real-time monitoring and alert. Electroencephalogram (EEG) readings, which assess neural activity are used as physiological indicators to identify early signs of drowsiness. The system collects brainwave data using the MindLink brain sensor, a wireless EEG headband. The data is delivered to an ESP32 microcontroller over Bluetooth and evaluated to detect signs of tiredness. Real-time data is transmitted to the IoT platform ThingSpeak for storage, display and remote monitoring. This allows refined functionality like data analysis and application integration. The detection technique is based on assessing the power spectrum concentration of EEG signals, with particular focus on theta wave activity. The system detects drowsiness by observing an ongoing pattern of theta waves, as well as a drop in concentration and an increase in meditation. When the system detects drowsiness, it sends a multi-modal alert that consists an auditory alarm, a visual warning on an LCD display, and visual indicators to assure the driver's safety. This initiative aims to prevent drowsy driving accidents and increase road safety through the implementation of EEG technology and internet of things (IoT) connections.

ABSTRAK

Mengantuk dan keletihan pemandu adalah faktor utama dalam kemalangan jalan raya kerana ia mengurangkan tumpuan, masa tindak balas yang perlahan dan melambatkan membuat keputusan. Dalam keadaan yang teruk, pemandu mungkin mengalami microsleeps, detik-detik kecil tidak sedarkan diri yang boleh mengakibatkan kemalangan serius jika ia berlaku semasa memandu. Untuk menyelesaikan masalah ini, penyelidikan ini mencadangkan sistem pengesanan mengantuk berasaskan EEG yang merangkumi penyepaduan IoT untuk pemantauan dan amaran masa nyata. Bacaan Electroencephalogram (EEG), yang menilai aktiviti saraf digunakan sebagai penunjuk fisiologi untuk mengenal pasti tanda-tanda awal mengantuk. Sistem ini mengumpul data gelombang otak menggunakan penderia otak MindLink, ikat kepala EEG tanpa wayar. Data dihantar ke mikropengawal ESP32 melalui Bluetooth dan dinilai untuk mengesan tanda-tanda keletihan. Data masa nyata dihantar ke platform IoT ThingSpeak untuk penyimpanan, paparan dan pemantauan jauh. Ini membolehkan fungsi yang diperhalusi seperti analisis data dan penyepaduan aplikasi. Teknik pengesanan adalah berdasarkan penilaian kepekatan spektrum kuasa isyarat EEG, dengan tumpuan khusus pada aktiviti gelombang theta. Sistem ini mengesan rasa mengantuk dengan memerhatikan corak gelombang theta yang berterusan, serta penurunan kepekatan dan peningkatan dalam meditasi. Apabila sistem mengesan rasa mengantuk, ia menghantar amaran pelbagai mod yang terdiri daripada penggera pendengaran, amaran visual pada paparan LCD dan penunjuk visual untuk memastikan keselamatan pemandu. Inisiatif ini bertujuan untuk mengelakkan kemalangan memandu mengantuk dan meningkatkan keselamatan jalan raya melalui pelaksanaan teknologi EEG dan sambungan internet of things (IoT).

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LIST OF SYMBOLS

1. µV: Microvolts
2. Hz: Hertz

LIST OF ABBREVIATIONS

3. EEG: Electroencephalogram
4. IoT: Internet of Things
5. LED: Light Emitting Diode
6. LCD: Liquid Crystal Display
7. HC-05: Bluetooth Module
8. ESP32: Microcontroller used in this project
9. BCI: Brain-Computer Interface
10. ECG: Electrocardiogram
11. PPG: Photoplethysmogram
12. HRV: Heart Rate Variability
13. EoG: Electrooculogram
14. EMG: Electromyogram
15. IMU: Inertial Measurement Unit
16. CNN: Convolutional Neural Network
17. PERCLOS: Percentage of Eye Closure
18. TL-VGG16/19: Transfer Learning with Visual Geometry Group

CHAPTER 1

INTRODUCTION

1.1 Background

Driver fatigue is one of the main factors contributing to fatalities in vehicle crashes. The sense of unusual tiredness or fatigue is called drowsiness. The long travel to the destination causes the driver to get sleepy. As a result, the driver was distracted and unable to maintain control over the speed of the car. With today's advanced technology, one of the greatest ways of determining a driver's level of drowsiness is by physiological testing. An improved and dependable way to identify drowsiness is with an Electroencephalogram(EEG). It is vital to have a real-time system that continuously tracks a driver's level of drowsiness The sensor's data allows for the creation of a system that can recognize the early indicators of fatigue. By alerting the user, this can stop any accident from occurring.

Malaysia recorded an astounding 598,635 traffic accidents in year 2023. A significant increase over the previous year and nearly back to pre-pandemic levels. 12,417 of these occurrences were fatal, leading to several fatalities and serious injuries. With 173,129 incidents, Selangor had the most accidents, followed by Johor (87,370) and Kuala Lumpur (72,701). These figures highlight the urgent need for practical steps to improve traffic safety and lower accident rates [1] .

1.2 Problem Statement

Globally, drowsy driving is a significant factor in traffic accidents. Numerous research and publications on highway safety indicate that being tired or drowsy could affect a driver's ability to react quickly, which can result in serious accidents and fatalities. There are disadvantages to using conventional techniques to identify driver fatigue, such as steering behavior analysis and visual observation using in-car cameras. These techniques frequently have poor precision and reliability, which renders them ineffective in avoiding accidents involving drowsy drivers. Recent developments in EEG technology, on the other hand, offer an alternative by tracking the driver's brain activity directly to identify tiredness accurate.

An accurate and timely approach to identify tiredness is desperately needed in order to reduce accidents and improve safety in high-risk situations. The accuracy, intrusiveness and sustainability of current options for ongoing monitoring are restricted. Additionally, there are technological and user-related difficulties in integrating such a system into current workflows and IoT ecosystems. Furthermore, a lot of current solutions disregard driver compliance and comfort. Particularly wearable technology can be invasive and uncomfortable, which discourages constant use. Drivers are less likely to wear the gadgets regularly if they are uncomfortable or distracting, which further reduces the efficiency of the system.

1.3 Project Objective

The main purpose of this project is to create an effective IoT-based EEG-based drowsiness alert system that can monitor and alert of driver fatigue in real-time. By using brainwave analysis to precisely identify signs of drowsiness and providing immediate alerts to avoid accidents caused on by driver drowsiness, the technology aims to improve road safety.

a) To develop a smart system that able to detect driver’s drowsiness level by using EEG sensor.

b) To develop alerting system to warns the driver to stay focus in driving.

c) To integrate IoT applications in the system for remote monitoring.

1.4 Scope of Project

The scope of this project are as follows:

a) Utilizing the use of Mindlink brain sensor with ESP 32 integration to monitor brainwave activity.

b) Analyze theta waves from the brain wave to assess the driver’s alertness level to detect early signs of drowsiness.
c) Display and stores data gained using Thingspeak for
d) Provides warnings to warn drivers to prevent drowsiness related incidents from occuring.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review section of this study examines previous reseach and studies related to EEG-based drowsiness detection alert systems with IoT integration for safe driving. It explore various approaches and techniques employed in monitoring the performance of suitable equipments. The review focuses on the use of sensor, data analytics and machine learning algorithms to detect patterns in EEG study. By analyzing existing literature, this study aims to identify gaps and contribute to the existing knowledge by proposing a novel system for the EEG-based drowsiness detection.

2.2 Background Literature Review

2.2.1 Electroencephalography(EEG)

An electroencephalogram(EEG) is a test that assesses human brain activity. Healthcare providers request EEGs to diagnose brain-related illnesses. An EEG exam measures the naturally occurring electrical activity in the human brain. During an EEG, a technician applies small metal discs (electrodes) to the scalp. The electrodes connect to a machine that detects the electrical impulses that brain cells (neurons) use to interact with one another. Monitoring such communication reveals how well the different parts of the brain function [2].

EEG test can also be used to identify other conditions that affect brain function such as Alzheimer's disease,certain psychoses and narcolepsy are possible examples. An EEG test can also be used to measure the total electrical activity of the brain. For example,it could be used to assess trauma,drug intoxication or the amount of brain damage in a coma patient.Depending on the location of the injury,an EEG is one of many tests used to determine brain death in critically ill patients.During surgery, an EEG may be used to monitor blood flow in the blood arteries of the brain or neck [3].

However,eventhough EEG has been utilised for many years.It is considered a safe procedure.The exam produces no discomfort towards human as subject.The electrodes works on brain activity recording.The procedure do not cause any sensations of harmness towards health.There is no chance of receiving any electric shock by the test procedure.In rare situations,an EEG can trigger seizures in people with seizure disorders. This is due to the flashing lights or deep breathing that may occur during the test [4].

2.2.2 Brainwave

Brain is a complex organ that regulates the nervous system.It processes sensory information, regulates body functions and supports cognition, emotions, memory and movement.The brain is made up of around 86 billion neurons, which are specialised cells that convey information using electrical and chemical impulses. Glial cells nourish and protect neurons.

One frequently investigated parameter is the electrical activity of the brain.An electroencephalogram(EEG) is recorded over time using electrodes on a person's head and related electronics.) to show the electrical activity of the brain at different electrode sites. Generally, EEG signals brainwaves,which also known as electrical activity or neural discharge patterns have been investigated to understand the correlation between mental,emotional and cognitive states [5].

Brainwaves are electrical impulses in the brain that can be detected with an electroencephalogram (EEG). These brainwaves are essential for understanding a variety of brain activities and moods, including alertness, sleep, and different levels of awareness. Table and figure below shows the type of brainwave chart based on the frequency and function based from human’s state or condition [6].

2.2.3 Brain Computer Interface

Brain-computer interfaces (BC) allow users to communicate and control without relying on peripheral nerves and muscles. Back in 1995,there were just six active BCI research organisations. Currently, there are more than 20 research studied on BCI. The new communication and control technology relies on brain electrical activity, either it is captured from the scalp as electroencephalography (EEG) or from within the brain as single-unit activity [7].

Because BCIs differ widely in their inputs, translation algorithms, outputs, and other properties, comparing them can be challenging. Although different systems may have varied uses, a standard performance metric can serve as a general benchmark for BCI development. A standard measurement of communication networks is bit rate or the volume of information.Which is the communicated data per unit of time. The bit rate depends on both speed and precision. BCI now send information at a maximum rate of 5-25 bits per minute. Improved signal processing, translation algorithms and user training are necessary to provide faster and more accurate results. Improved outcomes require interdisciplinary collaboration among neuroscientists,engineers,computer programmers,psychologists and rehabilitation professionals,as well as the use of objective methodologies to evaluate alternative approaches. Effective use of BCI technology requires developing acceptable applications, identifying relevant user groups and tailoring to individual needs and preferences [8].

2.3 Related Study

2.3.1 Drowsiness Detection

Psychological approaches, such as the monitoring of ocular condition are utilized in a focused protocol for the application of drowsiness detection to identify tiredness in drivers. The duration of the eye closure is proportional to the driver's level of weariness. Furthermore, a number of research have concentrated on identifying eye blinking, a characteristic that is used to determine driver's level of drowsiness by measuring the frequency and depth of eye closure [9].

To evaluate driver tiredness, Baccour et al. proposed an offline adaptive system based on eye blinking detection. The study employed a Savitzky-Golay filter and an algorithm to track and calculate the closure of a driver's eyelids using information from a distant camera. The Mercedes-Benz driving simulator served as the source of their dataset. The driving experiment period (124±53 minutes) was recorded from 24 participants. The Karolinska Sleepiness Scale (KSS) is used to determine the degree of tiredness in drivers. An attached camera on the dashboard of the car recorded the blinking behavior. The infrared illumination of the camera measures the eye blinking at a frequency of 50 hertz. The results highlight how the algorithm can adapt to individual variations in skin tone and eye shape. The entire evaluation shows that the drowsiness detection system capacity is high [10].

In other psychological approach,a real-time sleepiness detection system based on eye blinking detection utilizing a web camera was proposed by Rahman et al.. After using the Viola-Jones technique to identify the facial region in video frames, the authors employed a cascade classifier to identify the eyes and a Harris corner detector to identify the corner points of the eyes. The 16 webcam that were captured at various light levels and camera resolutions make up the testing dataset. The outcome shows that, in ideal conditions, the rate of detection accuracy is 94% [11].

An eye gaze tracking system was proposed by Mavely et al. to identify driver drowsiness in real time. The study developed a system that supports night vision by utilizing an LED infrared light source, a web camera, and a Raspberry Pi 2. A system that tracks the driver's face and measures the number of times the driver's eyes blink was put into place. When a driver closes their eyes for more than two seconds, an alert sound and a vibration in the steering wheel indicate that the driver is drowsy. As stated in the research study, the final result indicates the detection accuracy is fair [12].

Another approach that has been used in recent study efforts is yawning. A tendency to yawn when driving occurs when one is drowsy. To enhance the blood's intake for oxygen, the mouth is opened. By analyzing open mouth, lip corner placement and mouth shape, this study were able to diagnose driver drowsiness through the use of the yawning mechanism. Lastly, another function that identifies patterns in head movement is the detection of head movement. Utilizing cutting-edge machine learning methods, researchers monitored the head movement to identify driver drowsiness [13].

In other study in the physiological-based methods, this study employs a variety of physiologic signals, such as electroencephalogram (EEG), in addition to electrocardiogram (ECG), photoplethysmogram (PPG), Heart Rate Variability (HRV), electrooculogram (EoG), and electromyogram (EMG) signals to diagnose driver drowsiness [14].

An online sleepiness detection system based on features from driver eyes pictures was proposed by Hussein & Abou El-Seoud. Based on compiling a feature list, the study research created a system with four support vector machines (SVM) classification models. 113 face photos of 113 individuals were gathered from the system camera sensor. The outcome demonstrates that the fourth model, which combines four characteristics—texture features, wavelet coefficients, circularity, and black ratio set at 91.3% possesses the highest accuracy [15].

A real-time driver sleepiness detection system utilizing convolutional neural networks (CNN) was proposed by Hashemi et al. They used three neural networks: a transfer learning network (TL-VGG16), a fully designed neural network (FD-NN), and a transfer learning network (TL-VGG19). The ZJU dataset, which the scientists used, was gathered from 4 distinct participants and contained 4,157 webcam-captured photos which is 2100 open and 2057 close shots. The finding show that under various circumstances, the (FD-NN) network's accuracy is 98.15% [16].

2.3.2 EEG Technology in Drowsiness Detection

K. R. K.Goyal et. al. (2017) investigated and compared various facial recognition and tracking methods according to their spatial and temporal properties. It was found that Haar cascades were the most successful algorithm for face detection out of all those that were tested. The research also focused at the distinctions between the face identification algorithms in Matlab and OpenCV, as well as the advantages and disadvantages of each of them. The researchers discovered during experimenting with various algorithms, techniques like camshafts and Haar cascades perform better than motion detection. They discovered that the motion detection algorithm and the camshaft algorithm execute quicker. According to the study's findings, applying Haar cascades can improve face emotion identification accuracy [17].

Several aspects are included in the system proposed in the study for alerting and recognising sleepy drivers in vital infrastructures. It employs real-time image processing to identify driver tiredness, analyses the driver's face and eyes to determine whether their eyes are open or closed. The system also warns the driver with lighting and sounds. In addition, the alarm's repetition is intended to be modest and not to distract the driver's attention. The technology detects and alerts drivers of their drowsiness with the goal of increasing road safety [18].

A model for averting accidents was suggested and applied into practice during the study by MS. Suhail Razeeth et. al. (2021). Because CNN algorithms typically classify data with high accuracy, it will be easier to identify drowsiness and warn drivers in advance if they start nodding away. The study's new approach uses a combination of machine learning approaches to identify impairment and regulate the vehicle's direction, speed, and distance travelled. In addition, the sensors employed in this investigation are more advanced and efficient compared from other studies [19].

Research study by Roopalakshmi R. et. al. (2019) proposes an eye blink count-based method for identifying driver drowsiness that determines the degree of drowsiness. Car driver have to wear eye movement monitors all the time and they have to use a vibrating device to let them know when they start to feel sleepy. The system emits out a vibrating signal that awakens the user when it detects that they have been closed their eyes for a long time. The technique's experimental results showed that it could identify drowsiness with a high degree of precision [20].

A temporal and situational algorithm that utilises the use of the accelerator pedal placements, vehicle speeds and steering angles proposed by McDonald, A. D. et. al. . (2018) A Bayesian Network is trained with these values to identify whether a driver exhibits signs of drowsiness. In comparison with PERCLOS methods, which predict drowsiness based on patterns and movements of the eyelids, the algorithm was found to have reduced rates of inaccurate predictions. The study's main conclusion was that situational context is essential for accurate prediction. Understanding if the person is at risk of lane departures due to drowsiness requires a knowledge of the data it collected over a preceding 10-second period [21].

Another approach is based on studies regarding prediction using EEG measurements, brain waves and driver pulse.Kartsch et al. utilised EEG with Inertial Measurements Units (IMU) sensors to detect 5 levels of tiredness with around 95% accuracy because EEG alone is insufficient to detect all phases of drowsiness. The researchers combined behavioural data from the IMU with EEG data to identify drowsiness. The power requirements for these gadgets were another weakness in the EEG system. This method has also made it possible to deploy a parallel ultra-low power (PULP) platform on a microcontroller, increasing the battery life to over 46 hours and enabling the creation of low-maintenance and easy wearable gadgets [22].

Another technique is utilising the use of computer vision capability. New developments in Deep Learning provided computer vision additional capabilities for categorization and detection. Imaging data has had a significant impact in this area. Computer vision experts have tried to take use of the fact that drivers' facial features change dramatically when they grow tired and use this to create methods for sleepiness detection. A method to measure the angle of eyelid curvature and determine whether or not the eyes are closed was put forth by Tayab Khan et al. They used this technology to attain 95% accuracy, but its drawback is that it performs badly at night and requires sufficient light to function [23].

2.3.3 IoT Integration in Drowsiness Detection

This research study recognize faces using deep learning, OpenCV and Python Adrian Rosebrock's tutorial blog demonstrates how to perform facial recognition using OpenCV, Python and advanced learning. Within the deep learning system, a model is commonly trained to generate a classification or label for a single input image. On the other hand, deep metric knowledge operates differently. Unlike trying to construct a single tag, we are creating a real-valued feature vector. The dlib developer, Davis King, trained the network using a dataset consisting of approximately 3 million pictures. Compared to other modern techniques, the network achieves 99.38% accuracy on the Labeled Faces in the Wild (LFW) dataset [24].

An IoT-based solution was proposed by Priyanka Basavaraj Murdeshwar et al. in response to the problem statement. The recommended method makes use of the HAAR algorithm to produce output images that can be recognized as faces and CHT to track eyes from the output photos. The EAR (Eye Aspect Ratio) is used to view the eye condition. The system was tested on a Raspberry Pi 3 Model B with 1GB RAM and a Logitech HD Webcam C270, following the instructions. The intended average rate of 95% was achieved by the system [25].

Chen et al. implemented smart glasses to identify sleepiness. In this section, sensors and a Raspberry Pi module are used. An Internet of Things device that is connected to alert the driver to activity accomplishes so via the help of a camera and controller unit. Speech recognition algorithms are also used to enhance system process notifications. The use of an eye blinking state recognition and prediction system for driver fatigue [26].

A model for detecting tiredness has been developed using OpenCV and the Raspberry Pi 3. A warning will appear if drowsiness is identified. Determining the level of fatigue is the main goal of the attempt. The Linux-based single board computer is used for the construction and advancement of the driver fatigue detection system. If a driver feels sleepy while driving vertically, the system will alert them. Python with OpenCV is an open-source alternative that enables anyone to contribute to the tutorials, documentation and libraries. The use of automatic object detection is limited to certain areas. Managing a car's acceleration can alter how other cars in the vicinity respond to drowsy drivers [27].

Using Internet of Things technology, Anil Kumar Biswal et al. created an alarm system to continuously monitor driver fatigue and collisions. The Raspberry Pi was used as a single-board computer to detect drivers' weariness and concentrate on behavioral metrics. Extremity collisions were detected using the FSR and crash sensors. The driver receives quick mail and a voice message alert if they appear sleepy. The Google map link has been used to send warning or alert messages to the surrounding hospitals situated in the prone zone, even though the alarm systems function as intended in the event of a collision. This research project has produced results with an accuracy rate of 97% [26].

2.3.4 Eye blink rate related with drowsiness.

It has been shown that a person's eyes play a significant role in assessing how responsive he is to his environment. A person tends to become less attentive when he is tired either from work or from not getting enough sleep. If the same individual is operating a vehicle in this scenario, someone may be more likely to be involved in an accident.

In this study, eight volunteers were selected to qualitatively examine variations in blink time when they were fatigued and when they were not in order to illustrate the relationship between tiredness and blink frequency. Participants completed an eye-blink test during 10:00 am compared during 10:00 pm. To determine if participants were sleepy, researchers measured their blink frequency . Light intesnity and the distance between participants towards the device were maintained constant to guarantee the validity of the survey and empirical testing [28].

The hypothesis from the study shows that the tired or fatigue someone is, the more eye blinking rate will be. The results from the study is shown as table below:

	1	2	4	5	6	7	8
10:00am	20	21	19	20	18	22	21
10:00pm	25	26	30	25	26	24	26

Table 2.1: Eye blinking rate

People typically blink 10–15 times per minute, ranging between 100 and 200 milliseconds on average. But when drowsiness sets in, the blink rate frequently rises to 20–30 blinks per minute, with slower eyelid reopening and longer durations exceeding 400 milliseconds. These patterns are strong signs of drowsiness especially when combined with partial blinks or incomplete closures. These measurements are tracked by sensors or cameras in advanced detection systems, especially in automotive applications and are then fed into machine learning models for increased accuracy. This study highlights how crucial it is to incorporate blink analysis into safety systems in order to reduce fatigue-related dangers [29].

2.3.5 Alarm sound and indicator.

The frequency of the sound matters when creating sound warning signs since it ensures their efficacy, especially when warning people with varying hearing capacities. According to studies, awake individuals such as those with hearing impairments torespond better to lower-frequency sounds, such as those around 450 Hz. This is because low-frequency noises are more ideal for settings like houses, industries, and transportation systems since they can pass through barriers like walls and are less likely to be muffled by background noise than higher frequencies.

Compared to high-pitched frequencies, which may create a sense of urgency without necessarily creating annoyance, slow-pitched frequencies (lower in Hz) also have a tendency to be more detectable and non-jarring. since of this feature, they are perfect for low-intensity or long-duration warnings since they are noticeable without being overpowering to the listener [30].

Since it can immediately draw attention, high-pitched frequencies typically in the 2,000–4,000 Hz range are frequently utilized in warning systems. These frequencies stand out because of their sharpness and penetrating effect, making them especially useful in settings with background noise. High-pitched noises are perfect for emergency signals like fire alarms or car crash warnings since they can be alarming and are frequently connected to danger or urgency.

High-pitched alarms can be especially helpful during brief notifications or unexpected emergencies where immediate action is required. For instance, smoke detectors, which typically emit a high-pitched 3100 Hz tone, are designed to warn people of fires. Because of their high frequency, they can be used even when a person is drowsy [31].

2.3.6 Theta Wave Power Spectrum

The voltages of theta waves, which normally have a frequency between 4 and 8 Hz, are typically between 20 and 100 microvolts (μV). These numbers indicate the magnitude of the electrical impulses in the brain linked to these slower waves, which are frequently observed during significant relaxation, light sleep or meditation. Theta waves tend to be lower in voltage during more relaxed states, such meditation, yet can display larger amplitudes during deeper sleep stages. Age, the area of the brain being examined, and individual brain activity can all affect the exact value [32].

In other study,deep relaxation, light sleep and drowsiness are all linked to theta waves, a type of brain wave that usually has an amplitude of about 50 microvolts (μV) and a frequency range of 4 to 7 Hz. Depending on the level of sleep or relaxation, the voltage can vary from 20 to 100 μV; however, in normal situations, some reports indicate amplitudes closer to 50 μV.Theta waves are slower in frequency than other brain waves, but they can still produce a significant amount of neuronal activity. This is frequently observed when the brain is in less active or passive states, including light sleep or deep relaxation [33].

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2.4 Comparison between related research studies

1	Driver fatigue detection systems: A review	Eye blinking method	Interpersonal depends on individu	Not ideal for real-time driver drowsiness detection
2	Camera-Based Eye Blink Detection Algorithm for Assessing Driver Drowsiness	Eye blinking behaviour (EOG)	High reliability	Drowsiness level can only be validated using high video rating
3	Real time drowsiness detection using eye blink monitoring	Behavioral method to measure drowsiness level	High accuracy, detection rate 94%	Limitation during night driving
4	Eye gaze tracking based driver monitoring system	Evaluate driver's eye blinking frequency	Fair result	Complex hardware
5	Head movement-based driver drowsiness detection: A review of state-of-art techniques	Yawning measurement	Most precise technique	Invasive, disturb driver, not easy to acquire.
6	A smart system for driver's fatigue detection remote notification and semi-automatic parking of vehicles to prevent road accidents	Power spectrum analysis in MATLAB determines dominant frequency components in signals.	Fair result	Relies on EEG signals which may have limitations in accuracy.
7	An efficient system to identify user attentiveness based on fatigue detection	Image processing techniques used to monitor eyes and mouth behavior.	High accuracy (more than 90%) achieved in experiments	Slow system processing.
8	Towards Safer Roads: A Deep Learning-Based Multimodal Fatigue Monitoring System	Deep neural network designed for eye and mouth state classification	High accuracy , 98.15%	Limited discussion on generalizability or real-world implementation challenges.

9	Face detection and tracking: Using OpenCV	Haar cascades provide better accuracy in facial expression detection.	Haar cascades provide better accuracy in facial expression detection.	Time and space consuming process for subtraction and error calculation.
10	Drivers' Drowsiness Detection and Warning Systems	Real-time image processing	High accuracy	Different drivers have unique behaviors and expressions when drowsy, making it challenging to create a one-size-fits-all model.
11	Accident Mitigation System with Drowsiness Detection: A Machine Learning and Iot with Hybrid Approach	Head nodding evaluation with CNN algorithm	High accuracy	Combining data from multiple sources can be challenging. Inconsistencies and synchronization issues between different data streams can affect the system's overall accuracy.
12	Driver Drowsiness Detection System Based on Visual Features	Eye-blink count-based method	High degree precision	Makes driver feels slightly uncomfortable by wearing eye monitor all the time.
13	A contextual and temporal algorithm for driver drowsiness detection	Vehicle physical sensing method	High rate compared to PERCLOS	Managing and processing this large volume of data can be computationally intensive.
14	Development of Drowsiness Detection System Based on Respiration Changes Using Heart Rate Monitoring	EEG- Based measurements	High accuracy rate 95%	High power to supply the system.
15	Smart Real-Time Video Surveillance Platform for Drowsiness Detection Based on Eyelid Closure	Computer vision capability method	Attain high accuracy at 95% rate	Need sufficient lighting and not suitable during night
16	Face detection based on deep convolutional neural networks exploiting incremental facial part learning	Face recognizition using camera	Average 95% result accuracy	High cost hardware

17	Driver Drowsiness Detection using Machine Learning Approach	Eye-blinking recognition	Fair result	Irrelevant or redundant features can reduce model performance.
18	IoT-Based Smart Alert System for Drowsy Driver Detection	Face recognition method	Average rate 95%	External factors like lighting conditions, weather changes, and road vibrations can affect sensor readings, leading to false positives or false negatives.
19	A drowsiness detection system using computer vision and IoT	Face detection and feature extraction from a video stream using OpenCV and Dlib’s pre-trained facial landmark detector	High accuracy	Ensuring low latency processing within the vehicle's hardware constraints is challenging.
20	IoT-based intelligent warning system to detect drowsy drivers	A camera monitors the driver’ eye blinking, eye closure, face detection and head posture	97% accuracy	Regular calibration is required to maintain sensor accuracy. Any deviation can lead to incorrect drowsiness detection.

Table 2.1: Literature Review Comparison

2.5 Summary

Drowsiness detection systems play a critical role in improving road safety by tracking drivers' attention and delivering alerts in an efficient way. Numerous approaches have been devised, all one possessing unique advantages and disadvantages. Every technique has its pros and cons. High precision is provided by EEG-based equipment, with an expense of user comfort and cost. While non-intrusive, computer vision-based solutions are considerate of privacy issues and the surrounding environment. IoT-integrated systems are scalable and capable of operating in real time, but they also require solid safety and consistent network connectivity. Hybrid systems, which offer high accuracy and robustness while have greater complexity and cost, integrate the best features from multiple technologies.

Due to its immediate assessment of brain activity, high sensitivity and specificity and resistance to external factors, EEG-based drowsiness detection devices offer unmatched reliability. Although cost and user comfort are important factors to take into account, these problems are being addressed by developments in technology and design. All things considered, EEG is a strong and reliable way of ensuring driver safety by precisely and quickly detecting drowsiness.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The methodology section of this study outlines the approach and techniques employed to achieve the research objectives. It provides a detailed description of the steps and procedures followerd in implementing the proposed EEG-Based Drowsiness Alert System with IoT Integration for Safe Driving. The section begins by explaining the hardware integration, including the use of ESP 32 as the central processing unit and the connection of EEG sensor to collect real-time data. Next,the software development is discussed, highlighting the utilization of HC-05 Bluetooth Module to receive the data of EEG signals transmitted from the brain sensor.

3.2 Project Overview

The workflow of this project shows the flow process for the system. The first step on completing this project is the research study based on the related past study with EEG-based drowsiness detection system. During this process, comparison between past studies is analyze to make a comparison between each of its proposed methods or techniques used in each study. By comparing each methods, numerous approaches or key point of each study can be used as the comparing parts key out critera sush as the methods accuracy and weakness of each proposed methods. Next,is to determine the system design which consists of hardware and software setup. The use of suitable components is vital for preliminary result to consider its functionality in the real system.

3.3 General Methodology

The general methodology for this project involves several key steps. Firstly, a literature review is conducted to gain relevant information from journals and articles from past research study. To ensure reliable detection of driver drowsiness and timely alerts, a methodical approach is being used in the development of an EEG-based drowsiness alert system with IoT application integration. The approach, which includes system design, hardware configuration, signal processing, Internet of Things integration and real-time alarm systems is outlined in this methodology. The device employs EEG sensors to track brainwave activity with the main aim of improving road safety by averting sleep-related collisions. The methods and tools utilised to create a trustworthy and efficient drowsiness detection system are described in depth in the following sections.

3.4 Flowchart

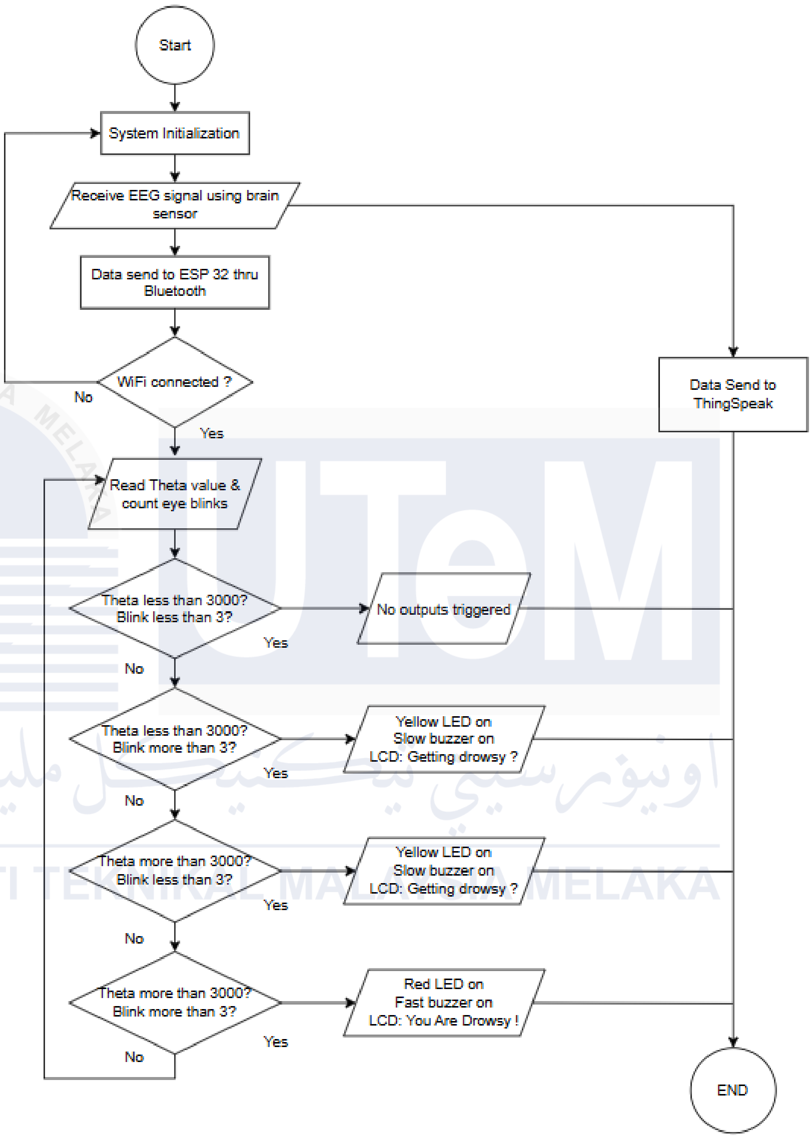

Figure 3.1: Flowchart

Figure illustrates the flowchart to achieve the objectives. The flowchart delineates the organize sequence of the project, commencing with a comprehensive literature review to amasss pertinent information. It subsequently advances to crafting circuit connections, wherein the HC-05 Bluetooth Module is seamlessly integrated with the Mindlink brainwave sensor with ESP 32 using basic C programming. The sensor adeptly gather EEG signal data, prompting a validation step to ensure the precision of data acquisition. Then it will go for WiFi connectivity test to continue the process. If WiFi connection is successfully connected to ESP 32, the process will continue for theta value check and eye blinks count.

The corresponding output with the parameters of theta value and blinks rate will be displayed in the system. Outputs used in the system is three LEDs, 2 buzzers with different frequency and a single LCD I2C display. Plus, the collected data gained from the brain sensor will be transmitted to ThingSpeak cloud for remote monitoring.

3.5 Block Diagram

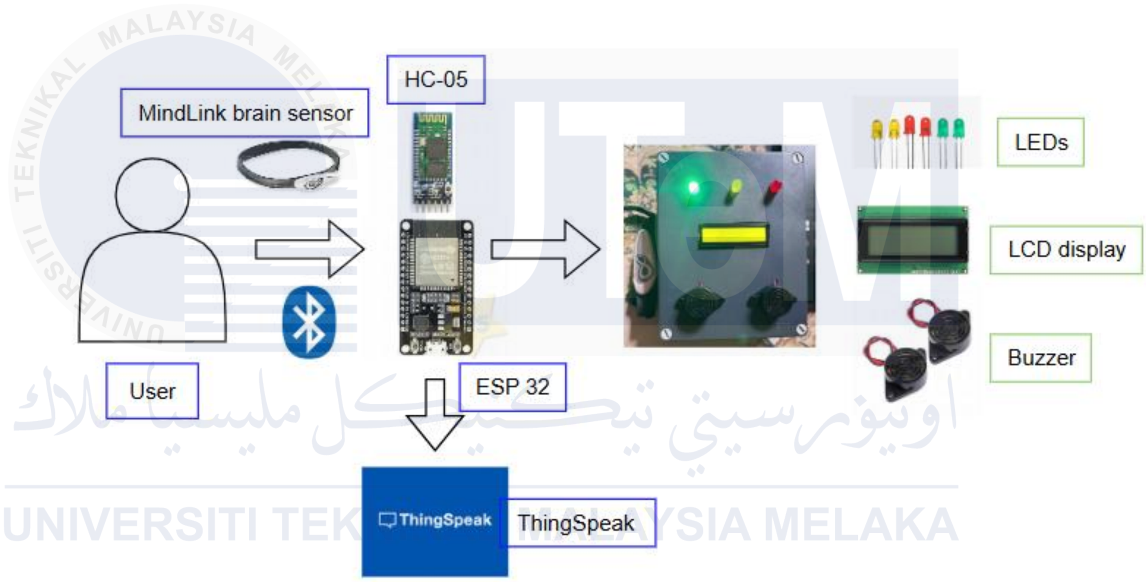

Figure 3.2: Block Diagram

By referring to figure above the EEG signal will be delieverd from user brain activity that is read by Mindlink brain sensor. The brainwave will be extracted to ESP 32 microcontroller via the used of HC-05 Bluetooth module.By going through processes , it will then display and deliver the corresponding output which is the LEDs,LCD display and buzzer to sign any warnings. In the same time, the brainwave read in the process will be send to Thingspeak created channel.

3.6 Experimental setup

Configuring this system requires a combination of hardware and software. The hardware and software setup is shown as below :

3.6.1 Hardware setup

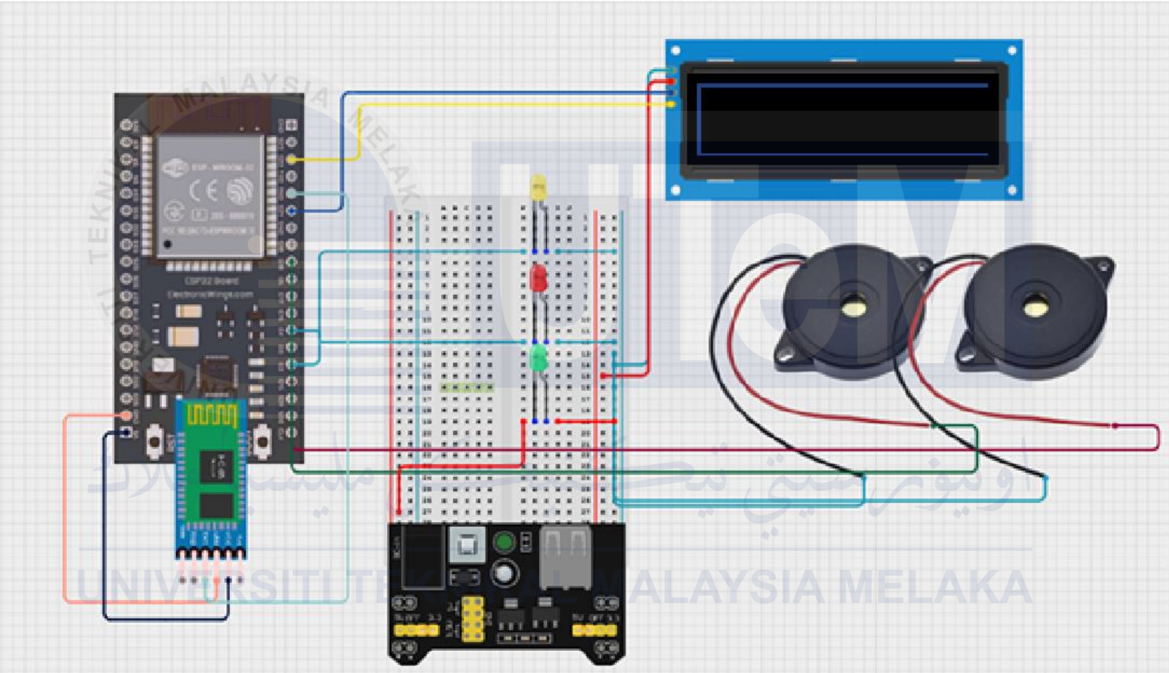

Figure 3.3: Wiring diagram

This wiring diagram shows an ESP32 microcontroller connected to an HC-05 Bluetooth module, LEDs, two buzzers, an LCD display and a power module via a breadboard. The HC-05 supports wireless communication, while the LEDs display system states and the buzzers sound warnings. The LCD displays messages or alerts and provides visual feedback. The module powers all components and connects them to the ESP32 GPIO pins, which control how they operate. This setup appears to be intended for an alert system, such as drowsiness detection for safe driving.

3.7 Software setup

3.7.1 Arduino IDE

Figure 3.4: Arduino IDE Compiler

The Arduino IDE enables the integrattion that require libraries, write logic for processing EEG signals and control components such as LEDs, buzzers and an LCD display for this EEG-based drowsiness alert system for safe driving. Using the IDE, uploaded programming code can be done to the ESP32 to detect drowsiness, send alerts via buzzers, display warnings on the LCD and even transmit data wirelessly via the HC-05 module. Its simplicity makes it ideal for prototyping and adjusting these safety-critical applications.

3.7.2 ThingSpeak Internet of Things(IoT)

Figure 3.5: ThingSpeak

MathWorks created the Internet of Things (IoT) platform ThingSpeak. For gathering, storing, displaying, and evaluating data from linked devices or sensors, it offers an architecture based on the cloud. The purpose of ThingSpeak is to enable Internet of Things applications and make it easier to combine data from multiple sources. Because of the platform's MATLAB integration, users may analyze and conduct complex statistics on the gathered IoT data. ThingSpeak allows for the direct development and processing of MATLAB code for a variety of tasks, including machine learning, statistical analysis, and calculations. ThingSpeak will functions to display and store data gained from processed brainwave signal.

3.8 Equipment

Components used for EEG-based drowsiness detection system is based on schematic diagram in Figure 3.5.

3.8.1 ESP32-WROOM-32

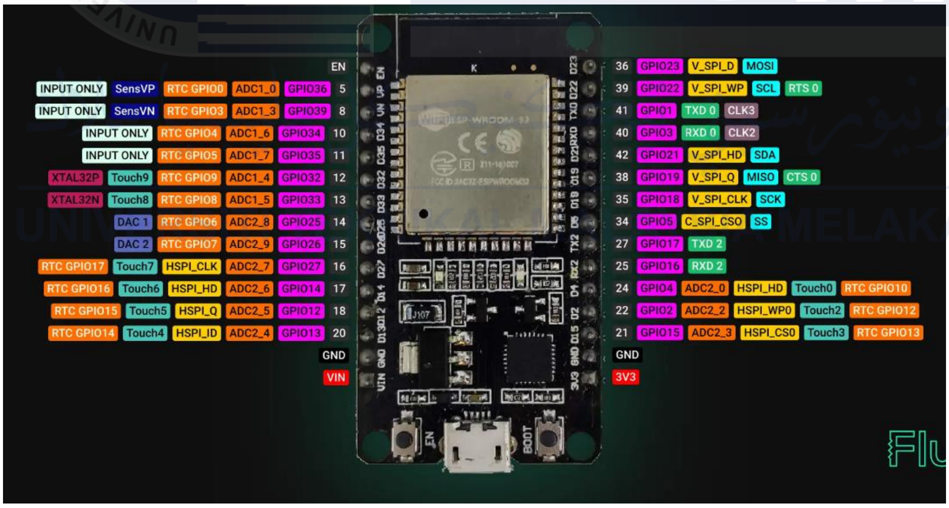

Figure 3.6: ESP 32-WROOM-32

In the EEG-based drowsiness alarm detection system with IoT integration, the ESP32-WROOM32 serves as the main control unit, processing EEG signals to identify drowsiness and initiating real-time responses. It receives brainwave data from EEG sensors, analyzes it to determine awareness levels and adjusts visual and audio signs to warn the driver accordingly. Its Wi-Fi and Bluetooth features allow for smooth IoT integration, including real-time data transmission to cloud platforms or mobile applications for remote monitoring and notifications. With its low power consumption and excellent processing capabilities, the ESP32 provides dependable and responsive performance, making it a key component of this safety-focused system.

3.8.2 Breadboard Power Supply Module

Figure 3.7: MB102 Breadboard module

Any breadboard-related project that requires 5V, 3.3V, or both power requirements can benefit from the addition of the MB102 Breadboard power supply module, which is a simple to operate and very useful device. The breadboard power supply module provides a consistent and reliable power source for the system's multiple parts during development and testing. It provides regulated voltage to important hardware such as the ESP32 microcontroller, EEG sensors, LEDs, and buzzers, ensuring consistent operating and avoiding voltage fluctuations that could affect signal processing or system performance. The module reduces prototype by smoothly integrating with the breadboard, allowing for convenient powering of the circuit during the project's design and troubleshooting phases.

3.8.3 LCD 16x2 IC

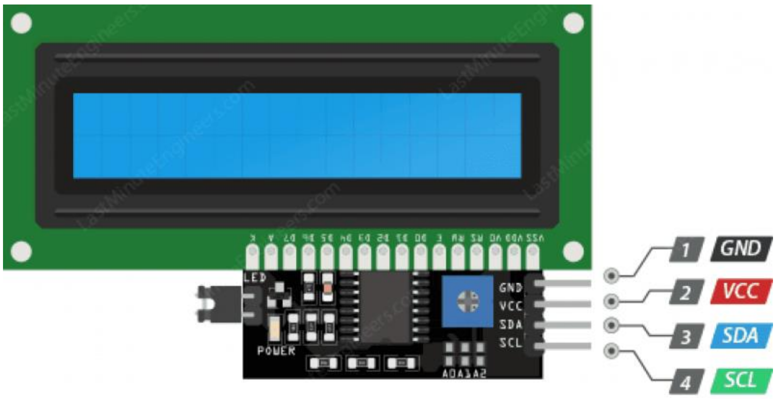

Figure 3.8: LCD display with I2C module

A high-quality 2-line, 16-character LCD module with an I2C communications port, backlight and onboard contrast control adjustment. No more complex and complicated LCD driver circuit connections for new users. The use of LCD I2C component in this project is to display warning messages to inform the drivers about their current status or condition either they are in normal condition, nearly drowsy condition or being drowsy and sleepy in the meantime.

3.8.4 HC-05 Bluetooth Module

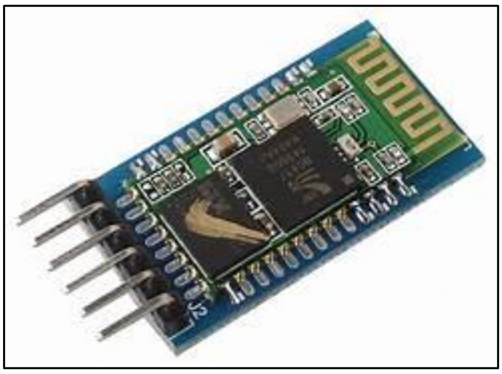

Figure 3.9: HC-05 Bluetooth module

The HC-05 Bluetooth module is a common and affordable approach to allow devices to communicate wirelessly. The HC-05 module enables real-time monitoring and alarms in a drowsiness detection system by enabling the ESP 32 to wirelessly communicate data to an external device.

An EEG-based drowsiness detection system can function more effectively due to the HC-05 Bluetooth module, which enables wireless data transmission and real-time monitoring. It is the perfect fit for this application because of its versatility, dependable performance, and ease of integration. Utilizing the HC-05's capabilities, brainwave signal from Mindlink brain sensor can be transmitted to ESP 32 microcontroller.

3.8.5 Mindlink brain sensor

Figure 3.10 : Mindlink brain sensor

A modern development in neurotechnology, the MindLink Brainwave Sensor is intended to track and analyze brain activity in real time. It provides a non-invasive way to record electroencephalogram (EEG) data, which can be used to provide important insights into mental health and cognitive states. The MindLink Brainwave Sensor is a crucial component of drowsiness detection systems and other applications because it can identify variations in brainwave patterns linked to alertness levels. By using this brain sensor, the brainwave signal can be collected and be transmitted to the ESP 32 for further integration by the HC-05 Bluetooth module.

3.8.6 Light Emitting Diode

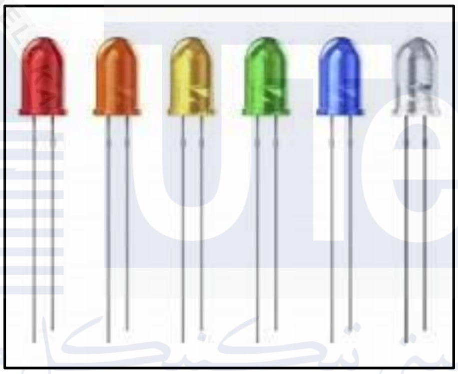

Figure 3.11: Light Emitting Diode (LED)

LEDs are a cheap and efficient component used in electronic systems to provide visual feedback. When drowsiness is detected in a driver, a drowsiness detection system can employ LEDs to visually alert the driver. Their instantaneous visual impact, minimal energy consumption and ease of usage make them the perfect option for this application.

The used LEDs colours in the system is red,yellow and green. The green LED is used to indicate system is operation either it is in operating mode. Meanwhile, yellow color LED is used to indicate the driver is pre-drowsy condition. Lastly, red colour LED willl be triggered when the system detected that the driver is getting very sleepy or getting drowsy.

3.8.7 Buzzer

Figure 3.12: Buzzer

Buzzers are an easy-to-use and efficient way to add audible feedback to electronic systems. When indicators of drowsiness are detected, a buzzer in a drowsiness detection system might sound an alert to the driver. It is essential that the driver pay attention to this immediate audio warning in order avoid accidents.

An efficient sound indicator to warn the driver is provided by a drowsiness detection system that uses a buzzer. Buzzers improve the system's overall safety and efficiency by enhancing its capacity to deliver rapid and straightforward feedback when linked with the Arduino Uno and other parts like LEDs and Bluetooth modules. The device makes sure the driver gets timely warnings to prevent sleepy driving accidents by combining both visual and audio alarms. By setting the buzzer to give output in low frequency (1kHz-3kHz), it can give noticable warning for driving to gain their focus back during driving. High pitch alarms frequency which is 3kHz and above will provides extremely loud and annoying sounds to wake up drowsy or sleepy drivers to immediately wake up to focus on their driving.

3.9 Mindlink Sensor Manual

The sensor itself, charger cable, EEG headband and Bluetooth Module(HC-05) comes in the package. The sensor is a very sensitive items, a very careful procedure is needed when operating with the device. Due to its sensitivty, any activtiy such as to charge the device must be taken carefully. To connect and integrate the sensor with the Bluetooth module, wiring connection is displayed as table below :

ESP 32 pinouts	HC-05 Bluetooth Module
5V	VCC
GND	GND
RX	TX

Table 3.1: ESP 32 to Bluetooth Module Connection

Once connection as table above has been constructed, C programming language will be run and the program will be uploaded to the Arduino by using compiler. By clicking the power on button of the sensor, a single blue LED will start to blink and beeping sound can be heared as the sensor and the HC-05 module is connected successfully.

3.10 Sensor Placement

Figure 3.13: Correct sensor placement

The single nodes functions as the sensor while the other two functions as grounding elements. It is important to make sure that all nodes touches user forehead to be able to operate in good condition.

By using the headband straps, carefully place it on the forehead. Make sure that all nodes touch the forehead skin. Additionally, user can clean their face to make sure all nodes clearly touch the skin.The example of correct and good way to wear the EEG headband is as figure below :

3.11 Summary

The Mindlink Brainwave Sensor and ESP 32 microcontroller drowsiness detection integration requires an organized process that includes sensor setup, algorithm implementation, and practical testing. This process ensures the development of a reliable and effective system that can improve safety by identifying and warning users of possible drowsiness in crucial situations.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

The analysis of brainwave data obtained under three different mental states which is drowsiness, concentration during gaming and relaxation. All data taken is presented in this section. The duration of each test condition approximately 15 minutes, which gave sufficient time to examine changes in brain activity. In addition to measures for meditation and attention levels, the analysis focuses on Delta Wave, Theta Wave, and Low Alpha Wave. These metrics provide significant data on mental states like drowsiness, concentration, relaxation and cognitive activity. It seeks to illustrate the variances in neural activity and their consequences for mental states by comparing the brainwave amplitudes and attention-meditation scores under specific circumstances.

1. Condition 1: Feeling sleepy.
2. Condition 2:Focused.
3. Condition 3:Relaxed.

4.2 Hardware Result

In the context of an EEG-based drowsiness alarm detection system for safe driving, visual and auditory indications play a key role in ensuring driver safety and reducing drowsy driving incidents. The use of LEDs and buzzers in various colors and frequencies provide the driver with rapid and noticeable feedback, indicating their state of concentration and the need for immediate action.

Figure 4.1:Prototype of the system

Output	Function
Red LED	When the system detects drowsiness, it delivers a crucial alert to notify the driver of a potential risk. This would signal the need for immediate action, such as pulling over or taking a break.
Yellow LED	Indicate a moderate level of drowsiness, acting as a signal to the driver to be aware of their concentration levels and take preventive steps, such as a short rest.
Slow frequency buzzer	Providing a subtle alert to the driver to remain alert without being excessively distracting.
Fast frequency buzzer	Immediately call the driver's attention and take appropriate action before the situation turns unsafe.

Table 4.1: Project outputs and functions

4.3 Brainwave Pattern Analysis

The collected brainwave signals taken during 3 conditions within 15 minutes during process is shown as below :

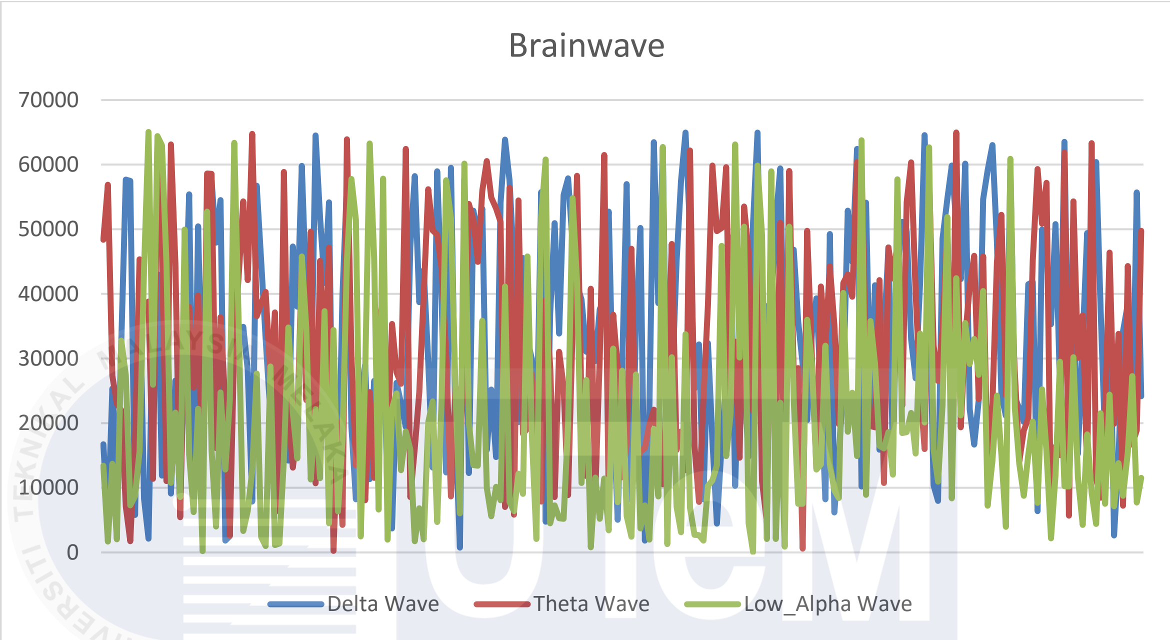

Figure 4.2: Relaxed Brainwave Signal

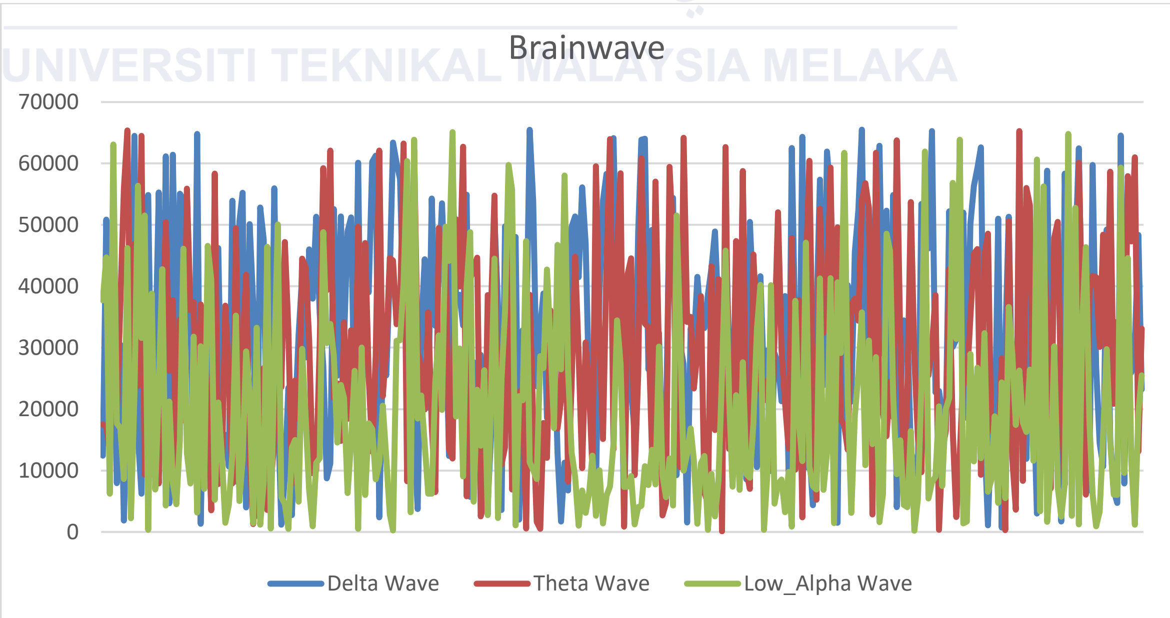

Figure 4.3: Focused Brainwave Signal

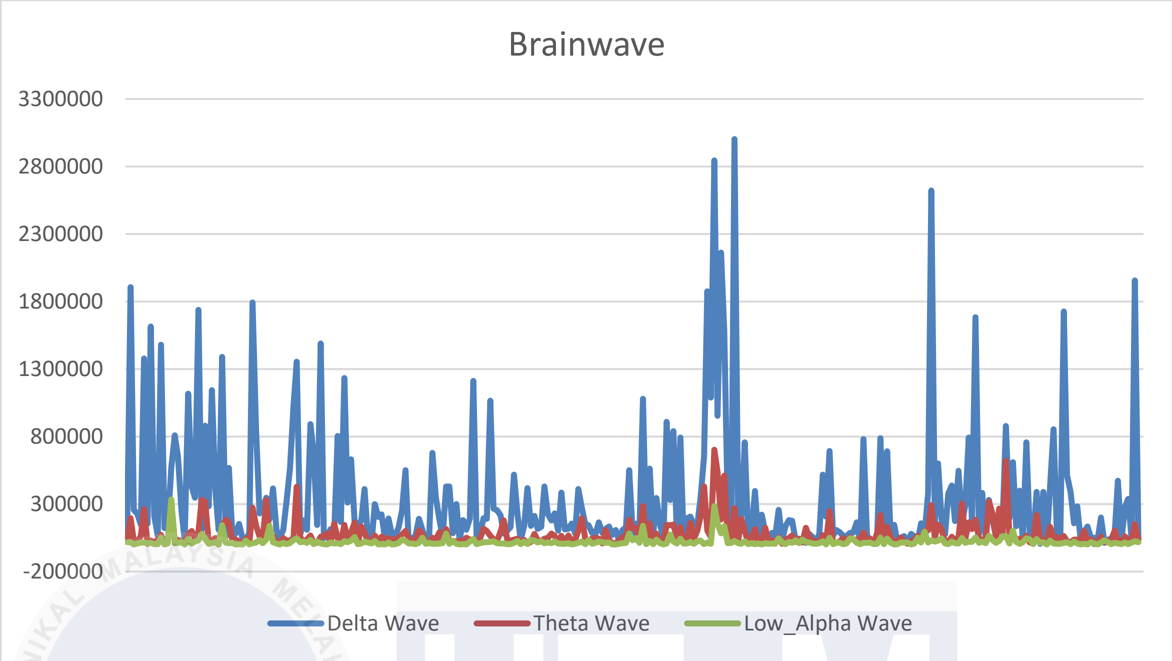

Figure 4.4 : Sleepy Brainwave Signal

The test aims to identify levels of alertness and fatigue for vehicle drivers. In this project, an analysis was conducted on a subject who was instructed to perform specific activities, such as being focused, relaxed and sleepy. The purpose of these activities was to analyze activity trends in three types of brain waves which is delta, theta and alpha waves. Additionally, focus and meditation were taken into consideration in this analysis.

4.4 Delta Wave Analysis

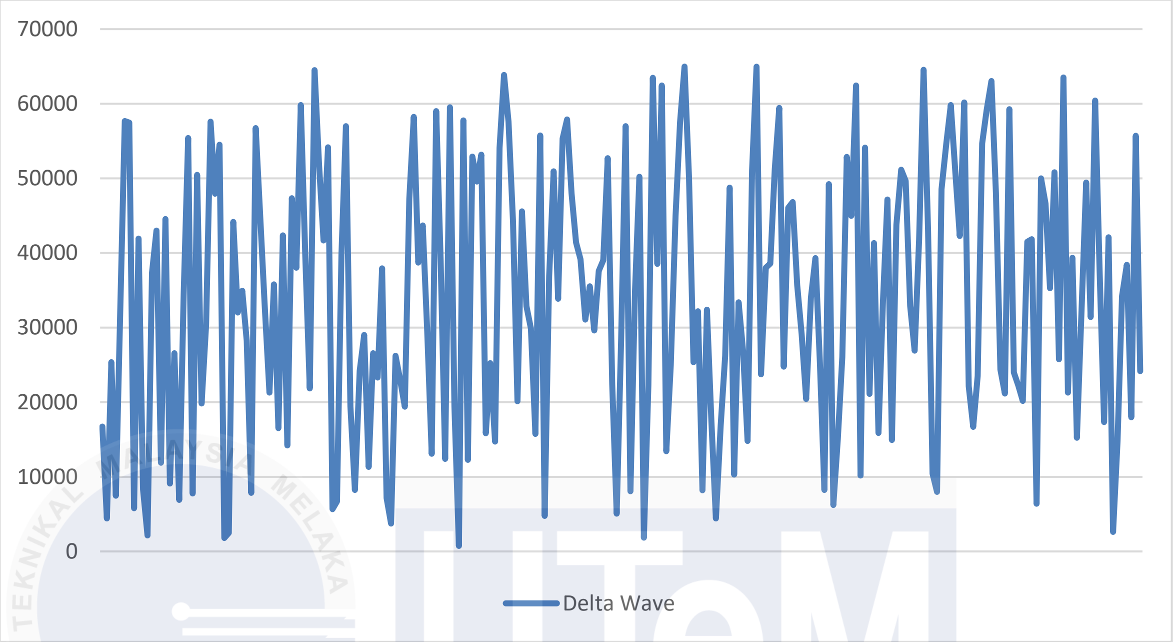

Figure 4.5: Delta Wave Relaxed Condition

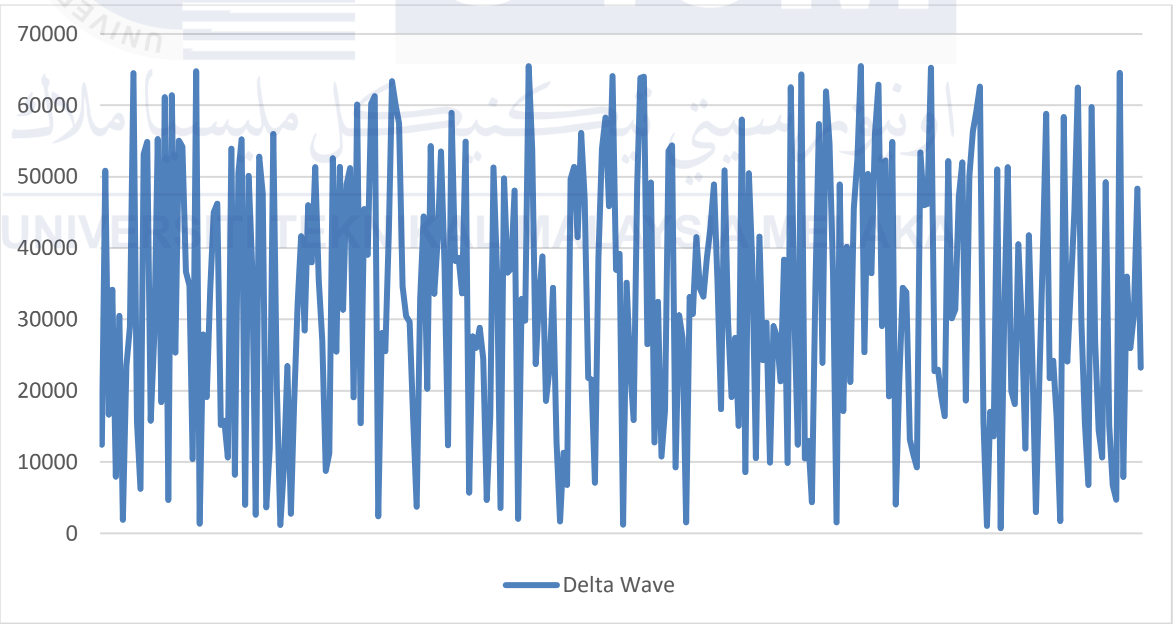

Figure 4.6: Delta Wave Focused Condition

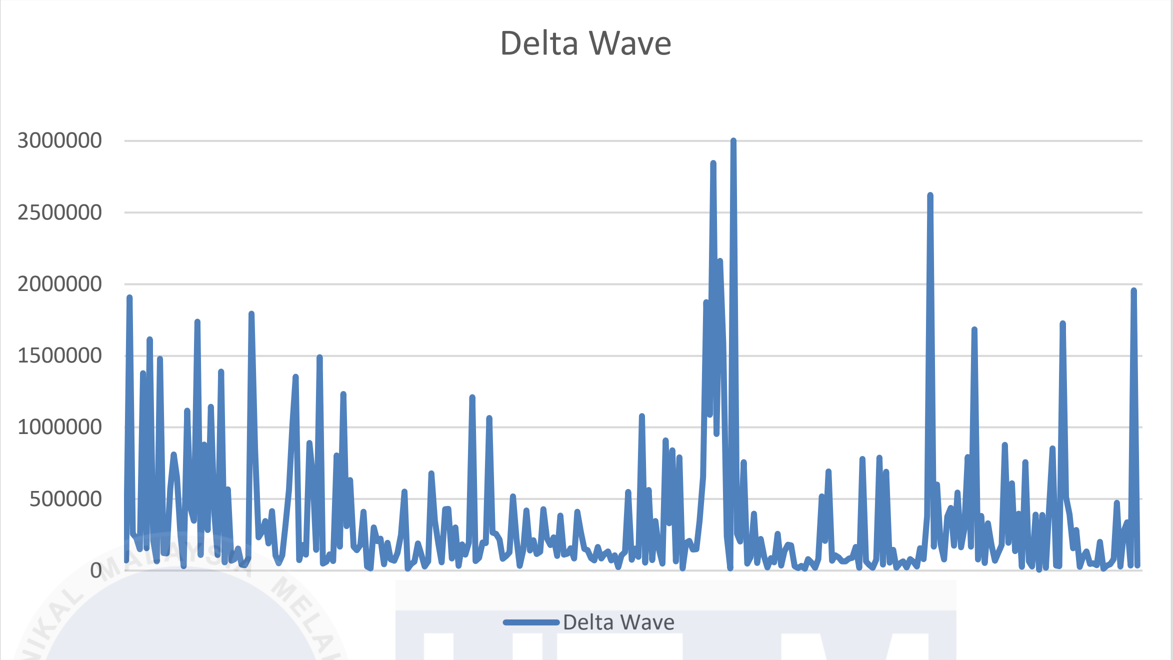

Figure 4.7: Delta Wave Sleepy Condition

Delta waves are present during deep sleep and they can be identified by their slowest and highest amplitude. Peak performers usually minimize Delta wave activity when trying for intense focus and optimal performance. Individuals with attention disorder often report a spike in Delta activity when attempting to stay focused, which differs from the typical pattern. The data shows that delta waves are slower during in sleepy condition and more active during relaxation and getting focused.

4.5 Low Alpha Wave Analysis

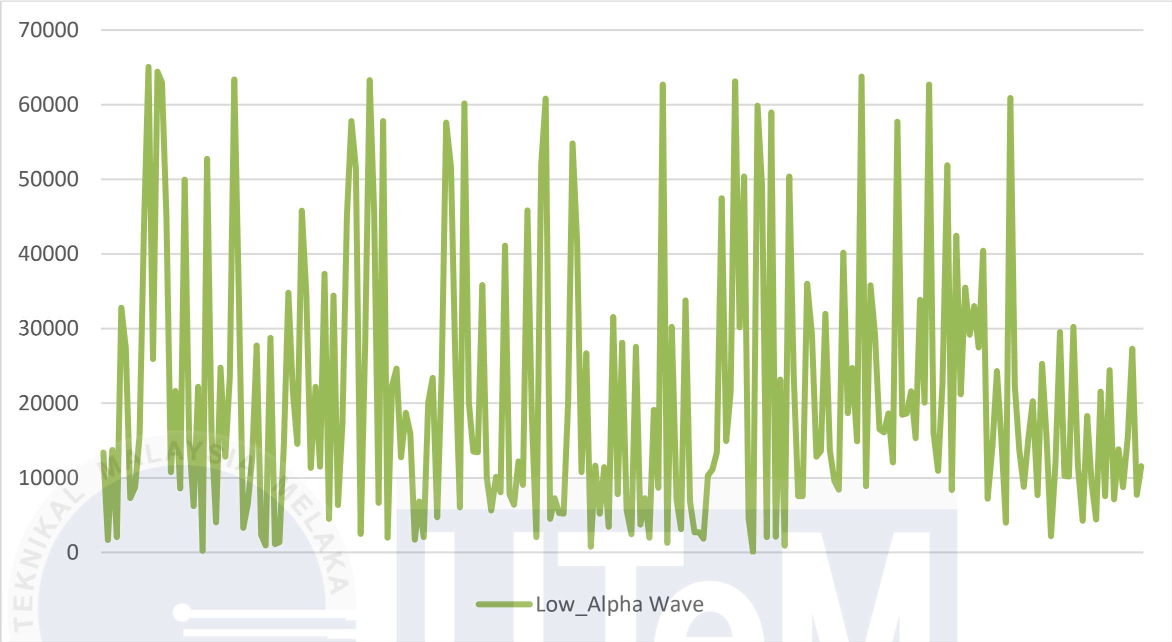

Figure 4.8: Low Alpha Wave Relaxed Condition

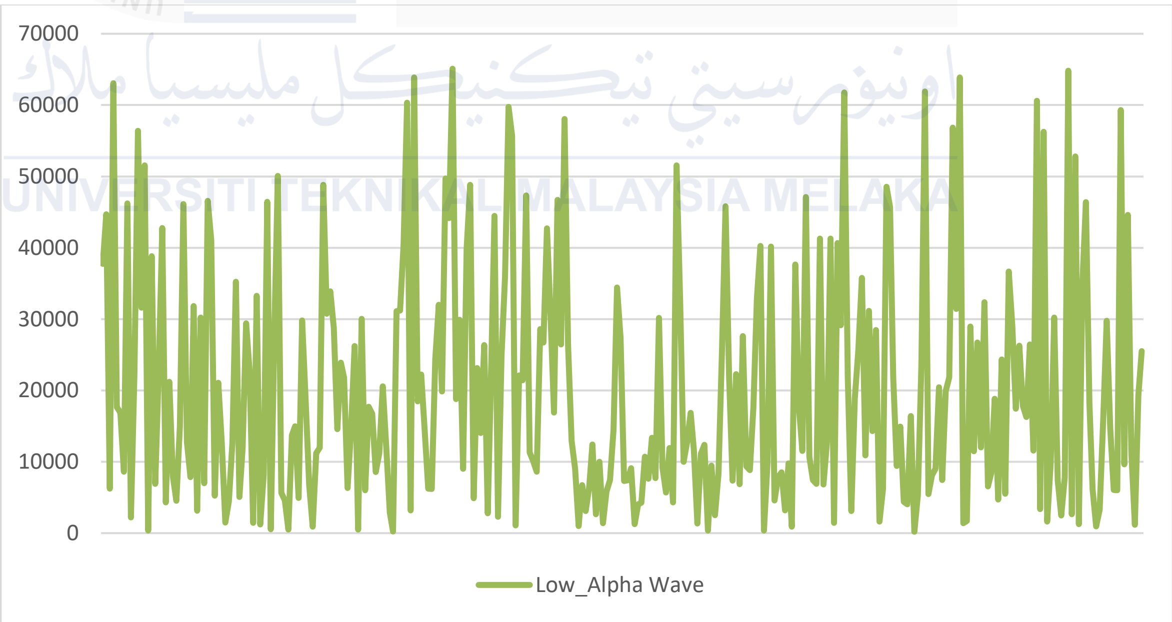

Figure 4.9: Low Alpha Wave Focused Condition

Figure 4.10: Low Alpha Wave Sleepy Condition

Alpha waves occur when people are in a condition of relaxation and calmness, such as during meditation or a quiet stroll across nature. They create peace of mind and are claimed to enhance creativity and focus. Subjective states of sensation include being at peace and calm. Being consciously aware without drowsiness The graph analysis indicates that alpha levels are lowest when subject is being sleepy.

4.6 Theta Wave Analysis

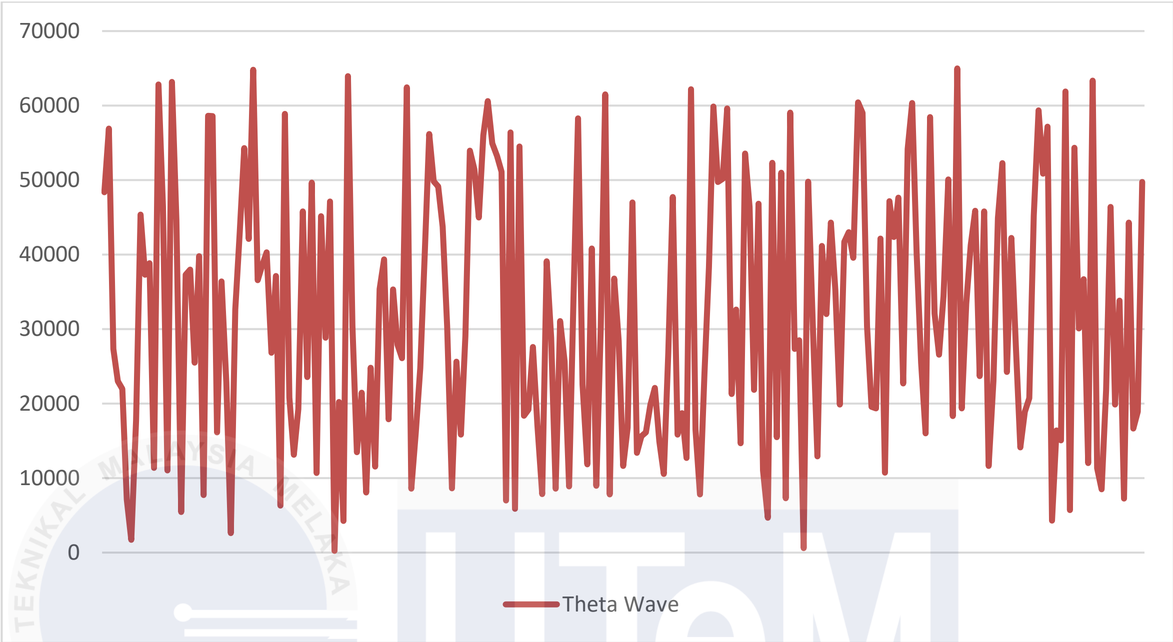

Figure 4.11: Theta Wave Relaxed Condition

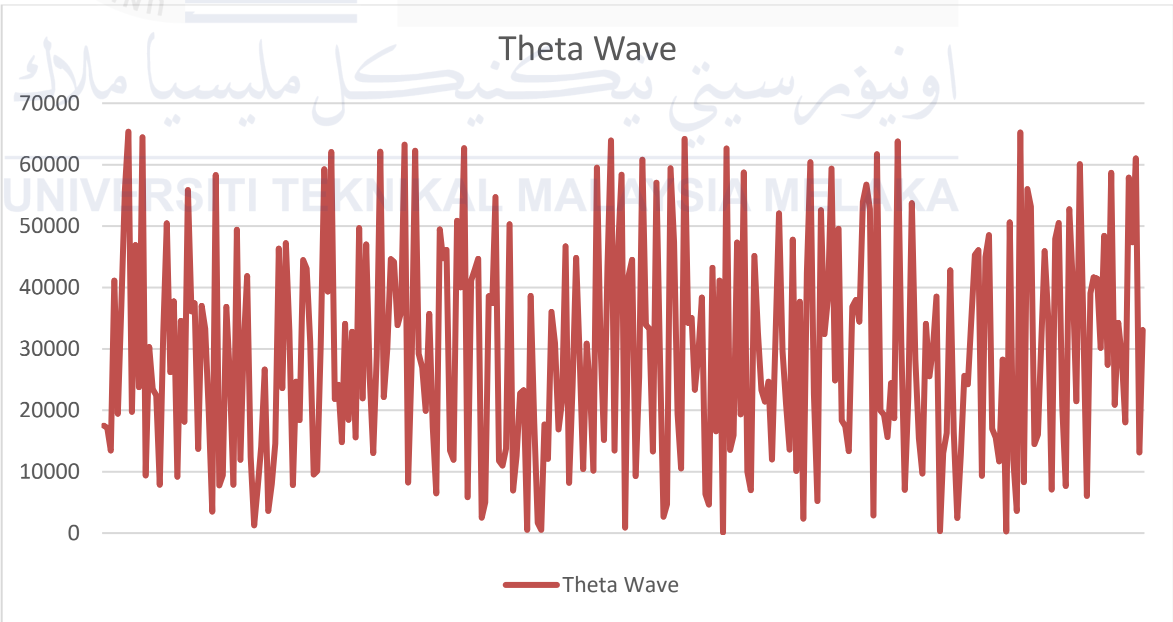

Figure 4.12: Theta Wave Focused Condition

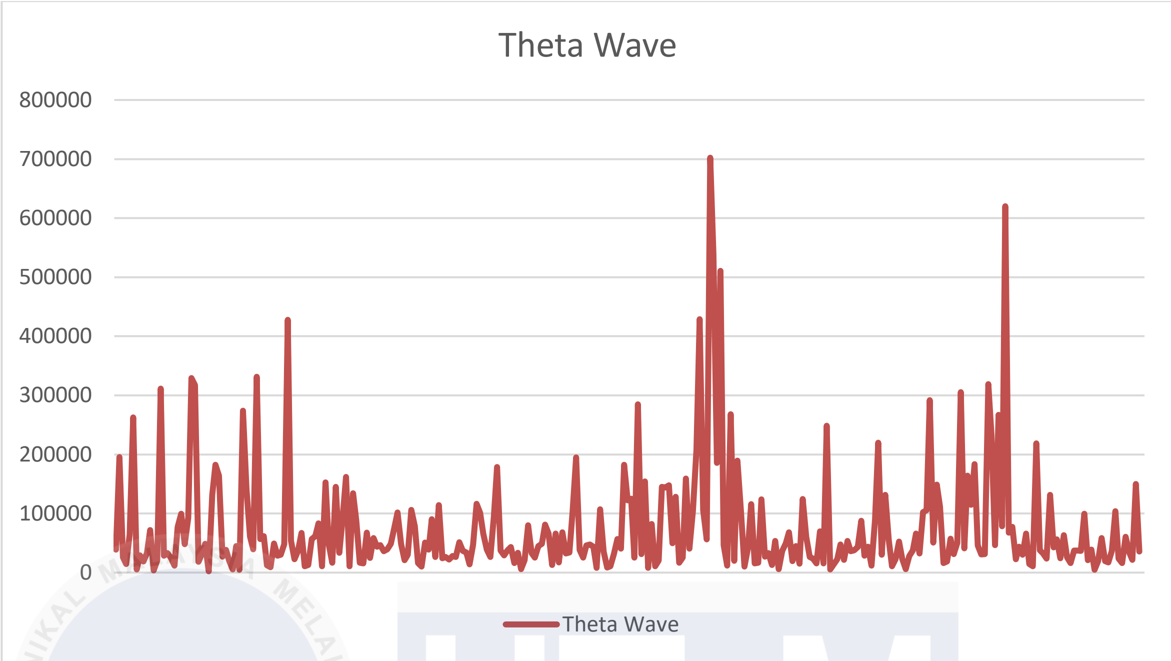

Figure 4.13: Theta Wave Sleepy Condition

Theta activity is classified as a type of "slow" brain activity. Theta waves are more noticeable during inside attention, meditation, prayer, and religious practice. This condition represents the transitional phase between waking and sleeping that is associated with the unconscious mind. Subjective sensations include creativity, intuition, remembering, fantasies, visual perception, dreaminess, changing thoughts and drowsiness. The results of average value of each waves during 15 minutes in each condition is shown in Table below :

Condition	Average Value (uV)		
	Delta	**Theta**	**Low Alpha**
Focused	32373.20	29435.20	20009.10
Relaxed	34039.23	3223.26	22029.094
Sleepy	344122.37	76179.15	21523.27

Table 4.2: Average Value

4.7 ThingSpeak Analysis

Thingspeak is an Internet of Things platform that collects and analyzes data in real time. The graph below shows an examination of theta wave spectrum difference as a person is getting sleepy and being focused. It takes 20 minutes to experiment on a person. The time it takes for data to reach Thingspeak is not in sync with what is presented in the serial monitor. Free ThingSpeak user accounts have a 15-second rate limit, while premium commercial accounts have a 1-second rate limit.

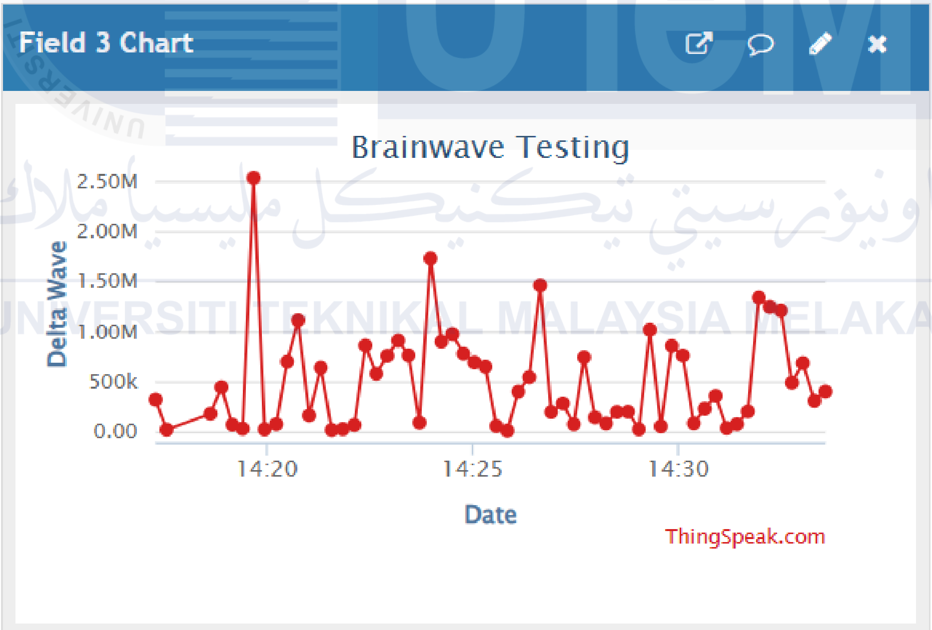

Figure 4.14: Delta Wave Focused

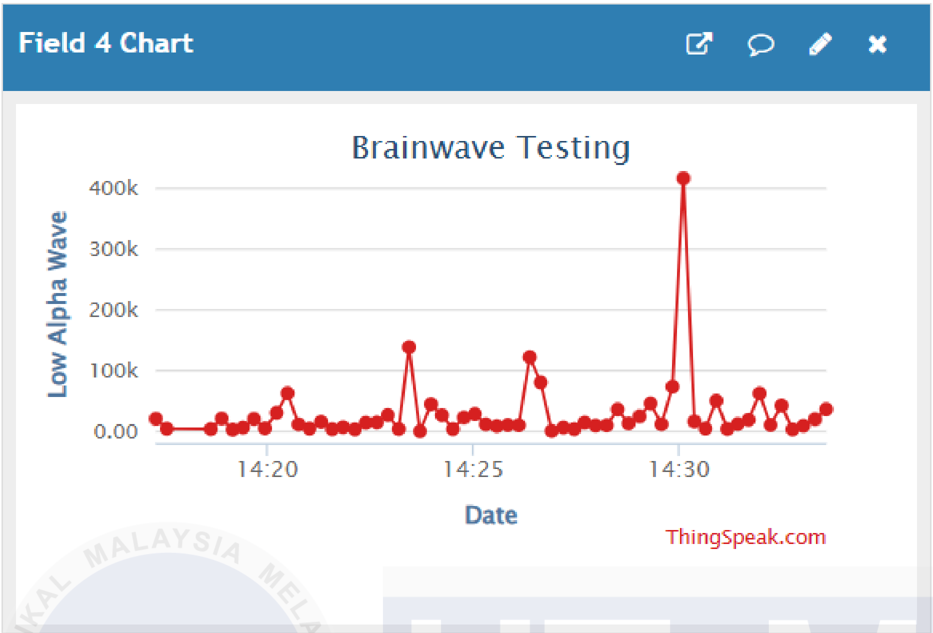

Figure 4.15: Low Alpha Wave Focused

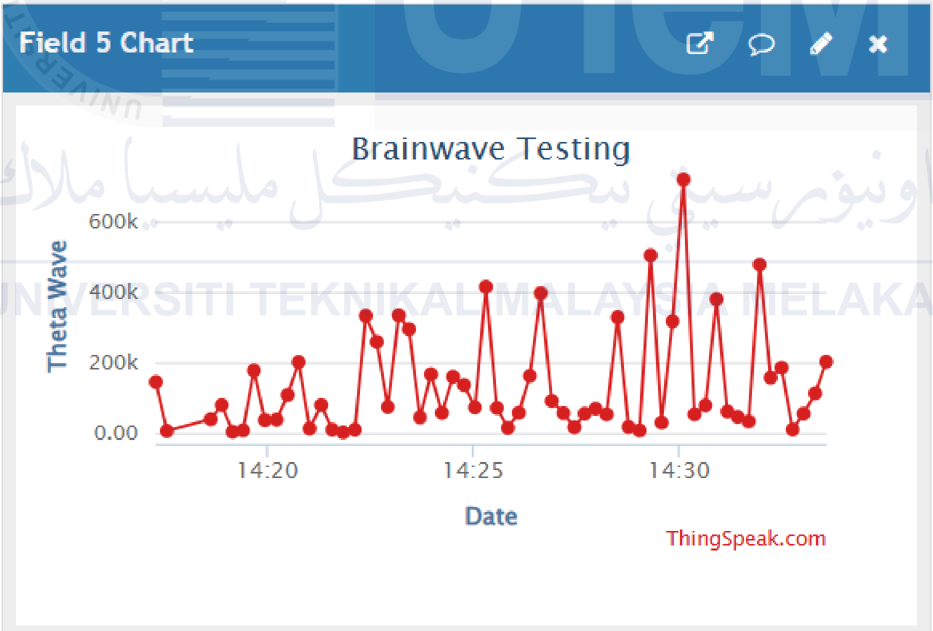

Figure 4.16: Theta Wave Focused

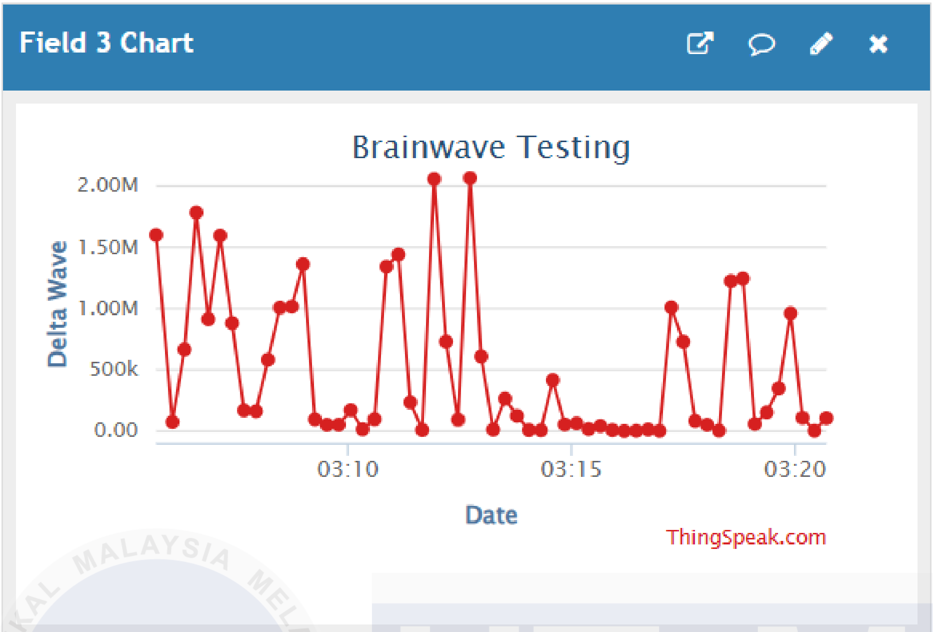

Figure 4.17: Delta Wave Sleepy

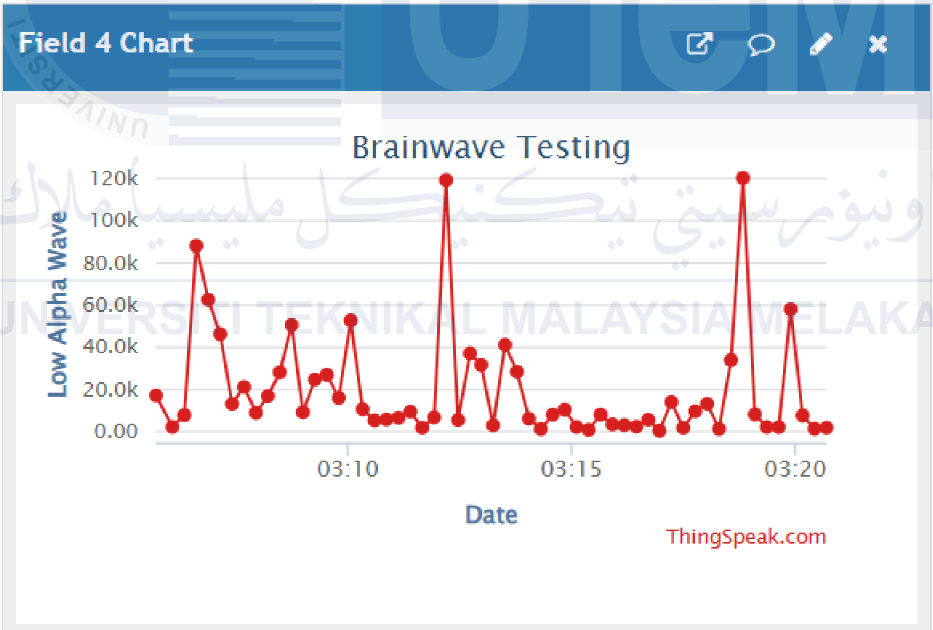

Figure 4.18: Low Alpha Wave Sleepy

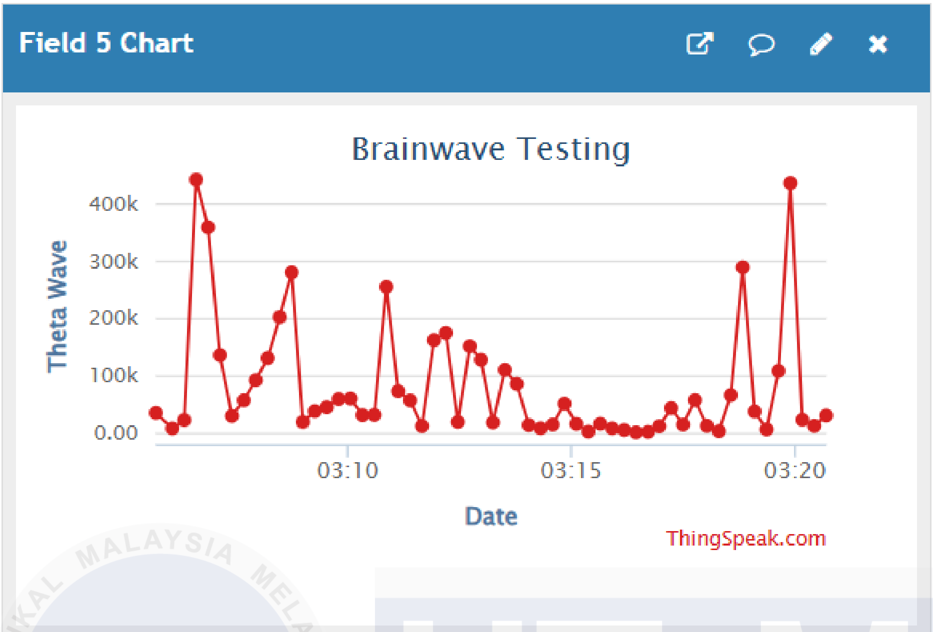

Figure 4.19: Theta Wave Sleepy

4.8 Summary

The development of a drowsiness detection system using the MindLink Brainwave Sensor and ESP 32 represents a significant advancement in improving safety and performance across a variety of applications, especially in situations where cognitive state monitoring is important, such as driving and operations.

To sum up, the MindLink Brainwave Sensor and ESP 32 integration in a drowsiness detection system marks a significant breakthrough in the application of neurotechnology to improve performance and safety in demanding situations. The system's capacity to reduce hazards related to compromised cognitive states is highlighted by its practical uses in many industries and its efficacy in identifying drowsiness. Future developments and improvements in technology are expected to enhance the performance of sleepiness detection systems and ultimately lead to safer and more effective operational procedures worldwide.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, the research achieves its goals by analyzing EEG signals for early detection of driver drowsiness, developing an alarm system based on theta, attention, and meditation levels, and transmitting brainwave data to cloud storage. The findings suggest that real-time monitoring and detection of driver drowsiness can improve road safety.

The examination of EEG signals, particularly theta waves, provides vital information about the early signs of driver drowsiness. In this experiment, theta values greater than 30000 are used to detect drowsy drivers. Thingspeak, an IoT platform, is used to store and analyze brainwave data in real time while transmitting it to the cloud. However, a synchronization issue between Thingspeak and the serial monitor has been observed, which is due to rate limitations.

5.2 Future Works

For future improvements , accuracy EEG-based drowsiness detections could be enhanced as follows:

i) Discover about signal processing techniques beyond basic filtering. Wavelet analysis and machine learning methods can help detect drowsiness more accurately.

ii) Implement real-time data analysis capabilities to allow for fast responses to changes in driver attention. This could include improving algorithms or using edge computing to process data on-board.

iii) Integrate machine learning algorithms to do predictive analysis using previous data. This improves the system's ability to adapt and offer individualized alerts to drivers.

iv) Improve the user interface to facilitate setting and monitoring. Creating a user-friendly dashboard or mobile app improves system accessibility.

v) Conduct validation studies with diverse drivers to guarantee system effectiveness across demographics, driving conditions, and cultural differences.

vi) Design a system to collect and analyze user input. This can assist identify spots for improvement and address user-specific issues or preferences.

vii) Incorporating these suggestions will improve the project's real-time drowsiness detection system, resulting in more secure roadways.

5.3 Potential for Commercialization

The project has commercial potential for developing a real-time system to monitor driver awareness and identify drowsiness. Potential commercialization strategies include integrating the system with existing automotive safety features.Develop standalone vehicle devices and collaborate with car manufacturers or automotive safety companies. Integrating technology into fleet management solutions can reduce accidents and improve road safety for companies with large fleets.

Wearable technology, such as smart headbands or caps for drivers, may appeal to individuals and organizations concerned with personal safety and well-being. Exploring collaborations with logistics and transportation firms to integrate the Integrating a system into their operations can ensure the safety of drivers on long-distance journeys. Collaborating with insurance companies to integrate the system as a safety feature may result in lower rates on insurance for those who implement it.Collaborating with projects related to smart cities to integrate technology into infrastructure promotes a holistic approach to road safety.

Providing the technology as a service to research institutions or companies interested in studying and improving driver behavior and safety can be an effective commercialization strategy. Creating customized solutions for specialized vehicles, such as public transportation or emergency services, where driver alertness is crucial, is another market opportunity.

Partnering with wellness and health care companies to promote the technology as a tool for general wellness and stress management can lead to new commercialization opportunities. Exploring global growth opportunities, taking into account differences in road safety regulations and cultural acceptance, can help the project reach a broader target market.

To ensure successful commercialization, it is critical to conduct thorough market research, identify target industries, form strategic alliances, and comply with all safety and privacy regulations. Continuous improvement and updates based on user feedback and technological advancements will be essential for long-term accomplishments.

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