

Enhancing Two-Wheeler Rider Safety with Helmet-Based Head Movement Monitoring and IoT Integration Using Safe Angle Formula

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Abstract Two wheeler safety is crucial due to riders' vulnerability, yet existing mechanisms often overlook unintentional head movements that compromise control and awareness. Current Internet of Things based safety systems focus on collision detection, braking assistance, and rider posture monitoring, but often neglect the risks posed by unintended head movements, which can lead to loss of control and harmful accidents. To address this gap, we proposed a helmet mounted system that calculates a safe head movement angle using a specialized safe angle formula based on motorcycle speed. Our system employs integrated gyroscopic sensors and Global Positioning System data to continuously monitor head orientation and speed, providing real time alerts. The bike sensor records speed and Z axis angles to determine bike tilt, while the helmet sensor captures the riders' head angle. This data is transmitted to a microcontroller in the bike unit, which calculates the angle difference and sets a speed based safe threshold. If head movement surpasses this calculated threshold, the system triggers audible, tactile and visual alarms. By ensuring that riders maintain a safe head position while riding, this system minimizes distractions that could lead to collisions, particularly at high speeds. The proposed solution enhances two wheeler safety by preventing accidents caused by sudden or excessive head movements, integrating seamlessly with existing motorcycle safety mechanisms. Real world testing and validation of our system demonstrate its effectiveness in reducing the likelihood of accidents caused by unintentional head movements. This innovation highlights the importance of maintaining safe head orientation and suggests integration into broader safety strategies, advanced rider training, and protective measures. The introduction of the safe angle formula positions this system as a potential benchmark for future motorcycle safety technologies.

Keywords Two Wheeler Safety; Smart Helmet System; Rider Head Movement Detection; IoT Based Accident Prevention; Real Time Rider Alerts; Helmet Safety System; Head Movement Monitoring; Rider Awareness.

AMS 2010 subject classifications 97P40, 97P60, 97R40

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1. Introduction

Sometimes, bike riders lose attention while riding, which causes accidents. Many injuries in road accidents can be avoided if these unintentional behaviors are detected and the rider is warned on time. A rider's chances of avoiding rear side collisions significantly improve if they receive additional warning time. Studies suggest that the likelihood of crash avoidance can increase with just an extra 1 second of warning [1]. Riding a bike at high speed is one of the causes of accidents. Nowadays, GPS positioning technology allows us to measure the speed of a vehicle without touching any hardware in the vehicle [2]. A complete 3 axis accelerometer can measure the tilt of a vehicle, microcontroller records the measurements and makes use of them to detect crashes [3]. A gyroscope and an accelerometer can track the rider's head movement and orientation. Together, this gyroscope accelerometer, and GPS collect information about vehicle speed and riders' head direction. A microcontroller can use this information and analyze it to make a decision related to the bike accident.

We have seen a significant number of works using helmets to prevent bike accidents. Stopping the start of the bike through alcohol detection if intoxicated or not starting the vehicle if the helmet is not worn, these works deserve praise undoubtedly [4]. But the cause of accidents is not only drinking alcohol or coming too close to the car. Nor is the rider not wearing a helmet the cause of the accident. A helmet can save riders' lives in case of an accident. But it cannot prevent accidents. Another major cause of accidents can be a lack of concentration while riding a bike. But if he had been told how far he could look left or right compared to his speed, and if he had been given a warning if he unintentionally looked too far, this accident would have been much easier to prevent. Warnings for a bike rider can be of many types, and warning messages can be given through a display on his bike's instrument panel. Alternatively, the rider can be alerted by tactile feedback through vibration motor, LED and beep alarm sounding in different patterns [5].

First, we need to detect the direction of the rider's head by how many degrees his head has turned right or left from the starting position. Also, we need to detect the bike's direction. For this, we have used the MPU 6050 accelerometer gyroscope sensor. It can detect position change in roll, pitch, and yaw angles [6]. Due to inattention, the bike rider usually looks left or right while the bike is in motion. Again, it may need to observe left and right while riding the bike. So, we will take only the Z axis according to our needs, which will tell us how many degrees the position has changed from the initial to the right or left for the bike and rider's head. On the other hand, we will use GPS to know the speed of the bike. GPS usually connects to satellites to determine the current location. The speed of a vehicle can be calculated by calculating how many meters the position changes in the interval of time [7]. As an alarm device, we have taken a BUZZER alarm module [8], LED, and organic light emitting diode display. So that the rider can get the necessary warning signal. There are many single board microcontrollers available in the market for making digital devices. However, for machine-to-machine communication, we need a microcontroller where 2 boards can communicate with each other without the Internet. Node Microcontroller Unit can communicate from one board to another board through Wi Fi connectivity [9]. Considering the requirements, we found Node MCU to be a good choice. Node MCU will calculate speed from GPS data and safe head movement angle calculation by collecting Z axis value from MPU 6050 locating in bike and helmet. The sensor will calculate the head direction every millisecond. If the head moves beyond the safe head movement angle, an warning device will immediately alert the bike rider.

Nowadays, on many modern bikes, the speedometer's warning lights and alarm sounds are seen to warn when driving at high speed. In many cases, the rider also forgets to switch the indicator lamp. When the bike takes a right or left turn, the rider's body tilts slightly toward the turn. With the help of an accelerometer, Yang et al. have shown the technology of detecting which direction the body is tilting and turning on the automatic indicator light [10]. Technology such as not starting the bike without wearing a helmet only helps the rider to reduce the damage after an accident. However, it is important to take steps to avoid accidents. Although researchers have proposed various solutions to prevent bike accidents, they have not given much insight into how to prevent accidents caused by unnecessary head movements of bike riders at high speeds. Most existing research on motorcycle safety has focused primarily on reactive measures. Such as detecting accidents after they occur, preventing riding in unsafe conditions, preventing ignition when intoxicated or not wearing a helmet, preventing fires, and automating emergency alerts

through IoT based systems. While these methods undoubtedly increase post accident safety, they offer limited effectiveness in preventing accidents that occur due to rider inattention or distraction while riding. We give a clear idea of how to prevent such accidents and how to warn the rider about potential accidents before they happen. The primary contribution of this work lies in the development of a speed sensitive smart helmet system that continuously monitors the rider's head movement and issues real time alerts when unsafe head orientations are detected. Unlike existing systems, our approach dynamically determines a safe head movement angle based on the motorcycle's speed, enhancing rider safety by addressing distraction related risks. Through extensive evaluation, including both controlled testing and on road trials involving volunteers and authors, the proposed system demonstrates its potential to prevent accidents by maintaining the rider's situational awareness. This research contributes to the growing field of two wheeler safety innovations, particularly focusing on head movement monitoring as a novel safety parameter. Here is a summary of what we have mentioned about our contribution to this paper:

- We developed a helmet mounted system that generates warning signals when the riders' head is misaligned with the bike, addressing a critical gap in motorcycle safety by focusing on unintentional head movements.
- The system enhances real time safety by calculating head movement angles using a specialized safe angle formula based on motorcycle speed, providing timely alerts.
- Our system integrates gyroscopic sensors and GPS data to continuously track head orientation and bike speed. A microcontroller analyzes the angle difference between the rider's head and the bike, activating alerts to ensure timely rider awareness.
- Real world testing confirms the systems' effectiveness in reducing accident risks associated with unsafe head movements, offering practical applications for rider safety training and broader traffic safety initiatives.
- This innovation positions the safe angle formula as a pioneering approach in motorcycle safety, setting a benchmark for future advancements in protective technologies.

The rest of our paper is organized into different sections. In Section 2, we discuss related work. In section 3, we discuss the materials and methods in detail. The methods used to determine the safe angle and the algorithm used in our system are explained in detail. In the next section, we discuss the results of testing our system. In the conclusion, we talk about the challenges we faced and the limitations we overcame while working.

2. Literature Reviews

Researchers have made various contributions to accident prevention with IoT. Some of their contributions are highlighted in this section. Table 1 provides a summary of relevant works in the field of bike accident prevention and rider safety technologies.

2.1. IoT in Accident Prevention with Crash Detection for Emergency Help

Nowadays, IoT technology is widely used in accident prevention in various industries. A case study by Yeo et al. showed the effectiveness of IoT technology according to the frequency of accidents, the severity of accidents, and the cost of implementing IoT technologies [25, 28]. The results of their case study proved that IoT technologies can reduce the number and severity of accidents. Detecting bike accidents and sending locations to relatives, hospitals, or police is much appreciated. In recent times, we have seen such features in almost every work related to smart helmets or bike accident prevention systems. A study in 2023 by Ramu et al. showed how a micro electro mechanical system sensor can detect a possible crash, and at the same time, a GPS can get the crash location's latitude and longitude and send an emergency message with the accident location to a registered phone number [14]. Also, there is no need to call for help in minor accidents or if the sensors send wrong messages due to technical problems.

2.2. Drunk Driving Prevention

Drunk driving is one of the leading causes of bike accidents. Researchers have focused more on accident detection and helmet wearing, as well as the inability to start a bike while intoxicated. A study of 2023 by Chandra et al.

Table 1. Reviews of Existing Literature Study

Works	Technologies Used	Implementation	Addressing Challenges
Pradeep et al. [11]	Artificial Intelligence, Computer Vision, IoT	Self-locking system to ensure the rider wears the helmet	Helmet usage
Khule et al. [12]	IoT sensors, GPS, Short Message Service, Microcontroller	Smart system for bike accident prevention	Drunk driving, Helmet usage, Accident detection, Accident location
Chandra et al. [13]	IoT sensors, Microcontroller, GPS, GSM, SMS	Smart Helmet for accident prevention	Drunk driving, Helmet usage, Accident detection, Accident location, Quick medical assistance
Ramu et al. [14]	IoT sensors, Radio Frequency transmitter, Microcontroller, GPS, GSM, SMS	Smart Helmet for accident prevention	Drunk driving, Drowsy Driving, Helmet usage, Accident detection, Accident location, Quick medical assistance
Riya et al. [15]	IoT sensors, GPS, GSM, SMS, Solar power	Solar powered smart helmet for accident prevention	Over speeding, Accident location, Accident detection, Quick medical assistance
Tiwari et al. [16]	IoT sensors, GPS, GSM, SMS, Microcontroller	Smart helmet for reducing accidents and the risk of death	Over speeding, Drunk driving, Helmet usage, Accident detection, Accident location, Quick medical assistance
Srinu et al. [17]	Object detection, Deep Learning	System for detect non-helmet riders and Triple riders	Helmet usage, Overload driving
Karuna et al. [18]	IoT sensors, GPS, Fire-base, Microcontroller	System for detect accident and emergency rescue	Accident detection, Accident location, Quick medical assistance
Kumar et al. [19]	IoT sensors, GSM, SMS, Microcontroller	System for detecting accident and emergency rescue request	Accident detection, Accident location, Quick medical assistance
Bhowmick et al. [20]	IoT sensors, GSM, GPS, Microcontroller, Cloud	Intelligent Accident Proof Helmet	Over speeding, Drunk driving, Helmet usage, Accident detection, Accident location, Quick medical assistance
Selvam et al. [21]	IoT sensors, AI, Big data, Microcontroller	Smart Communication System for accident prevention system	Accident detection, accident prevention, Alert authorities
Santhakumar et al. [22]	IoT sensors, Microcontroller, GSM, GPS	Smart Helmet system for accident prevention and detection	Drunk driving, Helmet usage, Accident detection, Accident location
Yustiana et al. [23]	IoT sensors, Microcontroller, GPS, GSM, SMS	Smart helmet to prevent bike theft	Bike theft, Helmet usage
Shalini et al. [24]	IoT Sensors, RF, GPS	Smart Safety Ignition and Accident Alert System	Helmet usage, Drunk Driving, Accident location, Rescue request
Yeo et al. [25]	IoT Sensors, Data Collection, Statistical methods	IoT Safety Quantification	Accident Prevention
Rahman et al. [26]	IoT Sensors, Firebase, GPS, RF	Smart Safety Ignition and Accident Alert System	Overload driving, Absence of Helmet, Drunk Driving, Accident location, Rescue request
Mannaet al. [27]	IoT sensors, GPS, Microcontroller	Smart helmet for accident avoidance	Drunk driving

showed if the alcohol detector Micro Quality sensor can be placed on the helmet, it can detect whether the rider is intoxicated by detecting the presence of alcoholic substances in the rider’s breath while wearing the helmet [13]. If alcohol is detected, the helmet module transmits a stop signal to the motorcycle’s control unit, thereby disabling engine ignition. if the rider is not drunk, then the start signal will go, and then the bike will start. They showed that the sensor in the helmet would detect drunkenness and not start the bike. However, there is no idea whether the sensor will work properly or not due to the flow of air while riding the bike. It will be easier to prevent accidents if there are additional measures to detect their behavior while driving under the influence of alcohol and take precautionary measures accordingly. While such sensor based systems focus on preventing the start of the bike, recent developments in AI based detection systems have shown promise in enhancing real time traffic safety monitoring and rule enforcement. A study by Rajyalakshmi et al. [29] employed the YOLO v8 and FusionNet models to detect unauthorized parking and identify vehicles through license plate recognition with high accuracy, enabling automated enforcement actions.

2.3. Ensure Wearing Helmet and Speed Adjusting Helmet

Almost every study on bike accidents and helmets has ensured that riders have to wear helmets. Pradeep et al. showed AI algorithms and computer vision technology can confirm that a rider is wearing a helmet [11]. They used a camera on the bike's instrument panel. The camera takes video and detects whether the rider is wearing a helmet or not. Bhowmick et al. worked to ensure helmet wearing. They showed an Infrared sensor can ensure the rider is wearing a helmet[20]. They showed that an IR sensor inside the helmet will detect whether the rider is wearing a helmet or not. Since the IR sensor can detect an object at a certain distance in front, if it can be placed inside the helmet, it can detect the human head while wearing the helmet. Due to this, the system will understand that the rider is wearing a helmet. Then, if the signal is sent to the device on the bike, then the bike will start. They have done a good job, but it would have been nice to have a way to start the bike while wearing the helmet if the IR sensor stopped working due to a technical fault inside the helmet. If the IR sensor stops working, the rider may be confused that the bike won't start even with the helmet on. Since IR rays are invisible to the open eye, It would be nice to have a way to know in advance whether the sensor is giving accurate readings or if the reading needs to be tuned. Another work done by Chandra et al. to ensure helmet wear is to place a touch sensor inside the helmet to detect whether the helmet is worn or not. While wearing a helmet, it detects the touch of the rider's head to tell if the rider is wearing a helmet [13]. On the other hand, if an automatic system detects the possibility of an accident in advance and adjusts the speed of the bike, it can contribute significantly to the prevention of accidents. To prevent accidents, Tripathi et al. showed an idea of such a system that can adjust the speed of the bike. They showed that if there is an object or any other vehicle near the bike, the IR sensor will detect it and adjust the speed of the bike [30]. The IR sensor can detect an object in a certain alignment at a certain distance. This system cannot detect other vehicles on the road if they are not in alignment. At the same time, the system would have been more effective if they had explained exactly how the speed of the bike would be reduced and how much speed would be reduced for how far the object would be.

2.4. Drowsiness Detection Helmet and Ensure Have Driving License

Many bike riders feel drowsy due to fatigue, which can surely lead to accidents. A study in 2023 by Ramu et al. showed a drowsiness detection system in bike helmets using an eye blink sensor. Then the Eye Blink Monitoring System warns the rider to be careful. Another study by Essahraoui et al. showed that their system detects drowsiness by analyzing the ratio of eye closing video and notifying the rider through an alarm[31]. The system used advanced AI models for better accuracy. It would have been better if this system had specified where the camera should be placed while riding the bike. In most cases, people are sleepier at night, so the system would have been more effective if there was an alternative system to detect the eye blinking ratio at night. Furthermore, a valid driver's license is a prerequisite for driving vehicles. A driver without a driving license can cause an accident anytime he drives a vehicle. Accidents can be prevented by ensuring that the driver has a driving license at the time of starting the bike.

2.5. Automatic Overload Protection with Bike Collision Avoidance System

It is often observed that more than two riders travel on a single motorcycle, posing a safety hazard and increasing the likelihood of accidents. For overload protection, riding an overloaded bike is likely to cause accidents due to loss of balance. Srinu et al. demonstrated that the system measures vehicle load using a load sensor and permits engine ignition only when the measured weight is within the allowable limit; exceeding the threshold automatically disables ignition[17]. A recent study by Brady et al. examines the driver dilemma[32] and showed roadside enforcement stopping powers. Similarly, Rahman et al. reported that when the combined rider and passenger weight is 180 kg or less, the system authorizes engine ignition, whereas exceeding this limit triggers an ignition lock[26]. If three riders are on the bike at the same time and their total weight is 180 kg, then explaining what measures will be taken will prevent overload. On the other hand, it is dangerous to drive two vehicles too close together. A close collision at high speed can lead to serious accidents. A study by Shalini et al. showed an ultrasonic sensor mounted on the back of the helmet is capable of keeping a safe distance from 2 vehicles [24]. They measured the distance of the vehicle behind using ultrasonic sensors. If the sensor detects that the vehicle is too close to the rider,

the rider will be alerted by an alarm. A single ultrasonic sensor operates at a fixed distance and fixed alignment. In their study, they measured the distance to vehicles behind them. However, it would have been a better system considering the danger of getting too close to all the neighbor vehicles. At the same time, it is a challenge to keep the sensor alignment correct in different riding positions.

In summary, most existing studies in the field of two wheeler safety systems have repeatedly focused on drunk driving prevention, helmet usage enforcement, crash detection, and emergency response through IoT based systems. While these approaches contribute significantly to post accident safety and rider protection, they do not directly prevent accidents arising from rider distraction or unintentional head movements at high speeds. The literature lacks a dedicated focus on monitoring the rider's head orientation in real time and correlating it with speed to preemptively warn against unsafe movements. This research gap motivated our work. No prior system specifically addressed the risk posed by unintended rider head movements which can lead to crashes. Our study aims to fill this gap by proposing a helmet mounted monitoring system that determines a speed sensitive safe head angle and provides real time alerts to prevent potential accidents before they occur. So, we have discussed this solution in the remaining part.

3. Methodology

Our study aims to prevent motorcycle accidents and provide early warnings through an innovative helmet mounted system supported by electronic hardware and algorithms. The working flow of this system is illustrated in Fig. 1. The proposed system requires the hardware components shown in Fig. 2. A detailed workflow model followed for system implementation is shown in Fig. 3. After implementing the system, the process of generating warning messages based on speed is illustrated in Fig. 4. The system comprises two main sensors: one mounted on the bike and another on the helmet. The bike unit uses a GPS module to measure real time speed and an MPU6050 sensor to track the Z axis angle, indicating the degree of bike tilt from its initial position. This data is transmitted to a microcontroller in the bike unit (Fig. 5). Simultaneously, the helmet unit, equipped with an MPU6050 sensor, records the riders' head angle, representing the degree of head movement from the initial position. This data is sent to the bike unit's microcontroller via Wireless Fidelity for machine to machine communication (Fig. 6). The microcontroller calculates the difference between the bike and helmet angles and determines the safe movement threshold based on the bike's speed. The safe angle, which decreases as speed increases, defines the maximum allowable deviation between the head and bike alignment. If the angle difference exceeds this threshold, the system triggers audible, tactile feedback through vibration motor and visual alarms to alert the rider. The system's flowchart in Fig. 3 outlines the step by step operation, starting from device initialization, sensor calibration, and data collection. During device startup, the MPU6050 sensor automatically calibrates its initial position to 0 degrees. For our setup, a maximum bike speed of 110 km/h is set, but this can be adjusted based on the bike model and rider preference. The safe angle is calculated using the formula $S = 55 \times (1 - (Z/\text{max speed}))$, and the angle difference $D = |X - Y|$. If the angle difference surpasses the safe angle, an alert is activated. The process repeats until the rider corrects their head alignment or the bike is turned off. In case of a false warning or technical issue, the system includes a calibration button for realignment.

Algorithm 1 details the systems' procedure, beginning with activation, sensor calibration, and continuous monitoring until the bikes' ignition is switched off. This approach ensures timely alerts, maintains rider safety and prevents potential accidents.

3.1. Required Hardware

Our microcontroller based portable system for monitoring head movement in motorcycles required various hardware components to construct separate units for the bike and helmet. Fig. 2 shows different types of hardware components used in the system. Their name and types are given in the table 2. The primary component was the NodeMCU microcontroller (Fig. 2A), chosen for its built in Wi-Fi capability, enabling machine to machine communication between the bike unit (host) and the helmet unit (client) [33]. To capture head and bike angles, we employed the MPU6050 sensor (Fig. 2B), which is equipped with a 3 axis accelerometer and gyroscope [34]. This

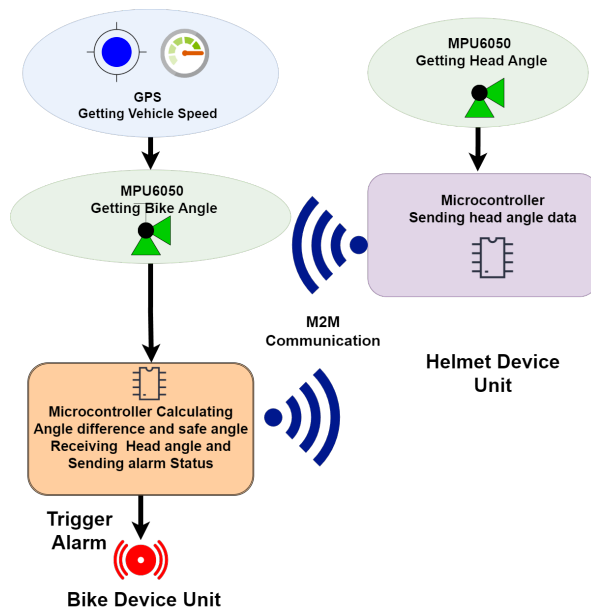


Figure 1. Overview of the Proposed Model

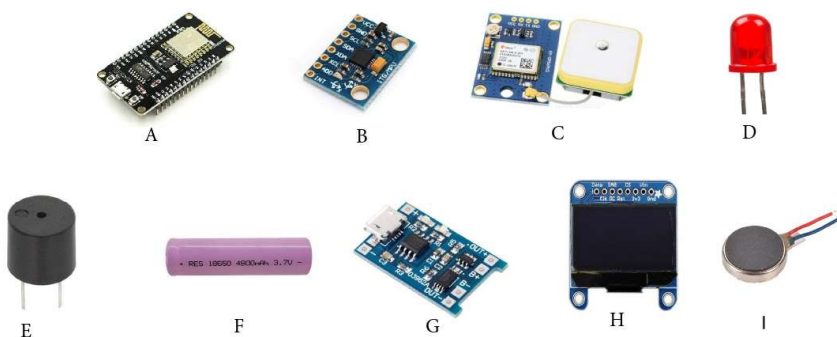


Figure 2. Hardware Components

Table 2. List of Components and Figure Numbers

Type	Name	Figure Number
Microcontroller	NodeMCU ESP8266	2A
Sensor	MPU6050	2E
Speed Detector	GPS Module	2B
Warning Device	LED, Buzzer, OLED Display	2C,D,F
Power source	Lithium Ion Battery	2G
Charger	TP4056	2H
Vibration Motor	Vibration Motor	2I

allows it to provide Z axis data for assessing the orientation of bike and helmet. The Neo 6M GPS module (Fig. 2C) was integrated for speed measurement through location tracking, ensuring device portability without wired connections [35]. To alert the rider, we included an LED Fig. 2D for visual cues, a buzzer Fig. 2E for audible

Algorithm 1 Proposed Algorithm for Rider Head Movement Monitoring

Require: Head Angle, Bike Angle, Bike Speed

Ensure: Warning Status A

```

1: Calibrate sensor. Set  $HeadAngle \leftarrow 0$  and  $BikeAngle \leftarrow 0$ 
2: while True do
3:   Get  $HeadAngle, BikeAngle, BikeSpeed$ 
4:    $AngleDifference \leftarrow |HeadAngle - BikeAngle|$ 
5:    $SafeAngle \leftarrow 55 \times (1 - \frac{BikeSpeed}{BikeMaxSpeed})$ 
6:   if  $AngleDifference \leq SafeAngle$  then
7:      $WarningStatus \leftarrow 0$ 
8:   else
9:      $WarningStatus \leftarrow 1$ 
10:  end if
11:  if Calibration Button is Pressed then
12:    Go to Calibration Step
13:  end if
14: end while
    
```

signals and a vibration motor 2I for tactile warning signal . Both units were powered by 18650 lithium ion batteries (Fig. 2F) capable of supplying 3.6 volts on average [36], with charging supported by TP4056 modules (Fig. 2G), which include over current protection and charge indicators [37]. An Adafruit 168*64 OLED display (Fig. 2H) was used to present essential data such as the safe head angle and warnings to the rider.

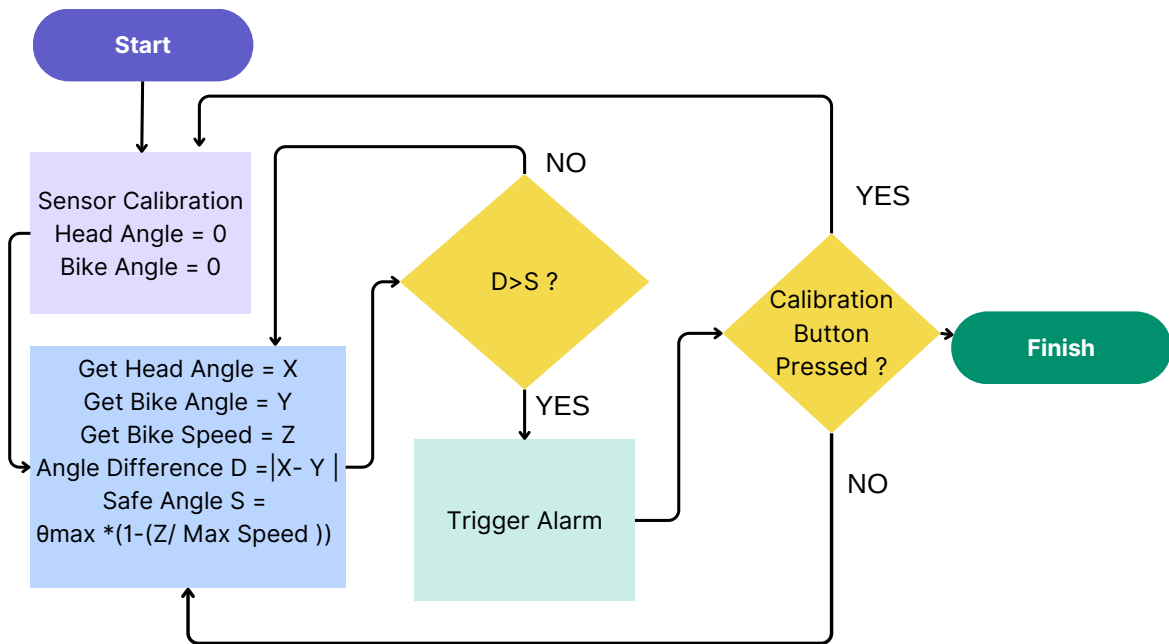


Figure 3. Workflow Model of the Proposed System

In this section, we discuss some key aspects regarding the presented system, such as speed detection procedure, detection of rider's head angle & bike angle, angle difference, and then the safe approach of angle.

3.2. Speed Detection

To predict an accident, it is necessary to first calculate the speed of the vehicle. In the case of motorcycles, the higher their speed, the higher the risk of accidents. If something unexpected happens suddenly while riding at high speeds, there is not much time to respond to that situation. The bike unit device Fig. 5 has a Neo 6M GPS module. This GPS module plays a key role in bike speed detection in the proposed system. The receiver of this GPS module receives its location from different satellites [38]. The GPS module also receives time information from the satellite. At every small unit time interval, it calculates the distance between the coordinates it receives [7]. It can determine the speed with the help of a from a certain distance at a certain time interval, which can then be used for any purpose. We have taken a maximum speed input of 110km/h for our system and if the speed has exceeded 110km/h we have converted it and taken the speed data as 110km/h. The system will put it in a variable and use it in the next calculation.

3.3. Detects Riders' Head Angle

MPU6050 can measure the angle in these 3 axes: X, Y, and Z. It can work in roll, pitch, and yaw mode [7]. To calculate the yaw angle, the sensor calculates the Z axis angle. It determines by the Z-axis angle how many degrees it turns to the right or left from the initial position. This sensor on the helmet unit device in Fig. Fig. 6 collects this data and sends it to the NodeMCU. The NodeMCU sends this angle data to another device located on the bike.

3.4. Detects Bike Angle

Like the helmet unit device shown in Fig. 6, the MPU6050 sensor collects the bike's Z axis angle. NodeMCU then uses this angle in the next step calculation.

3.5. Angle Difference

In this stage, the difference between the 2 angles collected by the MPU6050 sensor in the helmet and bike unit is calculated. As soon as the MPU6050 sensor starts, it assumes its initial position to be 0 for the x, y, and Z axis. Every time the device starts, it assumes all angles are zero. And considers it a reference to the initial position for subsequent movement angle calculations. When it is turned in one direction from the initial position, it increases the value of the degree in the positive direction and when it is turned in the opposite direction, it increases the value of the degree in the negative direction. When the bike rider takes a turn to the right or left of the bike, the orientation of the bike, as well as the orientation of his head, will go in that direction. So, when the bike takes a turn on one side, both the sensors on the bike and on the helmet positively increase the value of the degree. Similarly, when the bike takes a turn in the opposite direction, both sensors will increase the value of the degree negatively. However, NodeMCU will find the difference between those two angles and take the absolute value.

3.6. Safe Angle

This safe angle delineates the maximum range within which individuals can safely turn their heads or make observations while riding a bike without compromising their safety. Usually, people's situational awareness decreases as the speed of the bike increases. People don't have much time to react when confronted with any unexpected event. So, while riding a bike at high speed, unnecessary head movement can cause accidents. That's why it is necessary to determine how much a rider can move his head to the left or right is safe at a certain speed of the bike. If the speed increases, the safe angle will surely decrease. And if the speed slows down, there will be an increase in the safe angle. Finally, there is a linear relationship between safe angle and bike speed, and whereas bike speed increases, safe angle decreases at a constant rate. Before determining a safe angle, it is necessary to know how many degrees the head can turn. However, this can vary from person to person. It also depends on the age, flexibility, and spinal condition of the human body. [39] Stephens et al. showed human being can rotate their

heads from 60 to 80 degrees on each side. That is, from a neutral position, a person can move his head 60 to 80 degrees to look right or left, which is a total of 120 to 160 degrees. Another study by Kitazaki et al. showed that a field of view in vertical mode is 110 degrees [40]. So, on average, we're assuming a total of 110 degrees for ordinary people. That is, from the straight position, the head can turn 55 degrees to the right and 55 degrees to the left while riding a bike.

Liu et al. shows a linear correlation between motion speed and neural activity in the middle temporal visual area [42]. They presented that neuronal firing rates in the middle temporal visual area vary systematically and approximately linearly with the perceived speed of moving stimuli. Based on this, as speed increases, the visual system allocates proportionally more processing to motion cues and less to peripheral spatial awareness effectively narrowing the functional field of view. Using a similar concept where the safe angle is inversely proportional to speed. As speed increases, the safe angle decreases. The relationship between safe head movement angle and bike speed can be described by the following equation:

$$\theta_{\text{safe}} = \theta_{\text{max}} \times \left(1 - \left(\frac{v}{v_{\text{max}}} \right) \right) \tag{1}$$

Where:

- θ_{safe} : Safe head movement angle.
- θ_{max} : Maximum allowable head movement angle on each side (assumed to be 55 degrees for this study).
- v : Current speed of the bike.
- v_{max} : Maximum speed of the bike (assumed to be 110 km/h for this study).

This equation indicates that for every unit increase in bike speed, the safe angle will decrease proportionally. When the bike speed is at its maximum value of 110 km/h, the safe angle will be at its minimum value of 0, and when the bike speed is at its minimum value of 0 km/h, the safe angle will be at its maximum value of 55 degrees.

Case 1: Safe Angle when Bike Speed is 20 km/h

$$\theta_{\text{safe}} = 55 \times \left(1 - \frac{20}{110} \right) = 55 \times 0.818 = 45 \text{ degrees} \tag{2}$$

Case 2: Safe Angle when Bike Speed is 10 km/h

$$\theta_{\text{safe}} = 55 \times \left(1 - \frac{10}{110} \right) = 55 \times 0.909 = 49.99 \text{ degrees} \tag{3}$$

Case 3: Safe Angle when Bike Speed is 1.5 km/h

$$\theta_{\text{safe}} = 55 \times \left(1 - \frac{1.5}{110} \right) = 55 \times 0.986 = 54.23 \text{ degrees} \tag{4}$$

This equation 1 indicates that for every unit increase in bike speed, the safe angle will decrease. When the bike speed is at its maximum value of 110, the safe angle will be at its minimum value of 0, and when the bike speed is at its minimum value of 0, the safe angle will be at its maximum value of 55. Finally, equation 1 will give us the value of safe angle, given a value of bike speed. The proposed relationship equation 1 is intended as a first order heuristic capturing the empirically observed narrowing of effective visual scanning angle with increasing speed.

The evidence by Liu et al. showed that neural activity in the middle temporal visual area, the cortical locus of motion processing varies approximately linearly with perceived motion speed [42]. Thus, as vehicle speed increases, the perceptual field effectively contracts due to neurovisual and attentional constraints.

3.7. Trigger Warning

The system calculates the safe angle according to the speed and checks whether the head direction is at a safe angle or not. That is, the difference in the angle of the orientation of the head with the bike is checked to see whether it

is within the safe angle. If it is within the safe angle, no warning is triggered, but if the angle difference is greater than the safe angle, the system triggers an warning through alarm and vibration. The buzzer on the bike unit device in Fig. 5 then continues to ring and vibration motor in the helmet unit vibrate until the head is within a safe angle. At the same time, the red LED starts blinking to warn the rider. This process is done by the microcontroller or NodeMCU. To better understand when the warning will trigger, we can consider the red zone and green zone in the following Fig. 4.

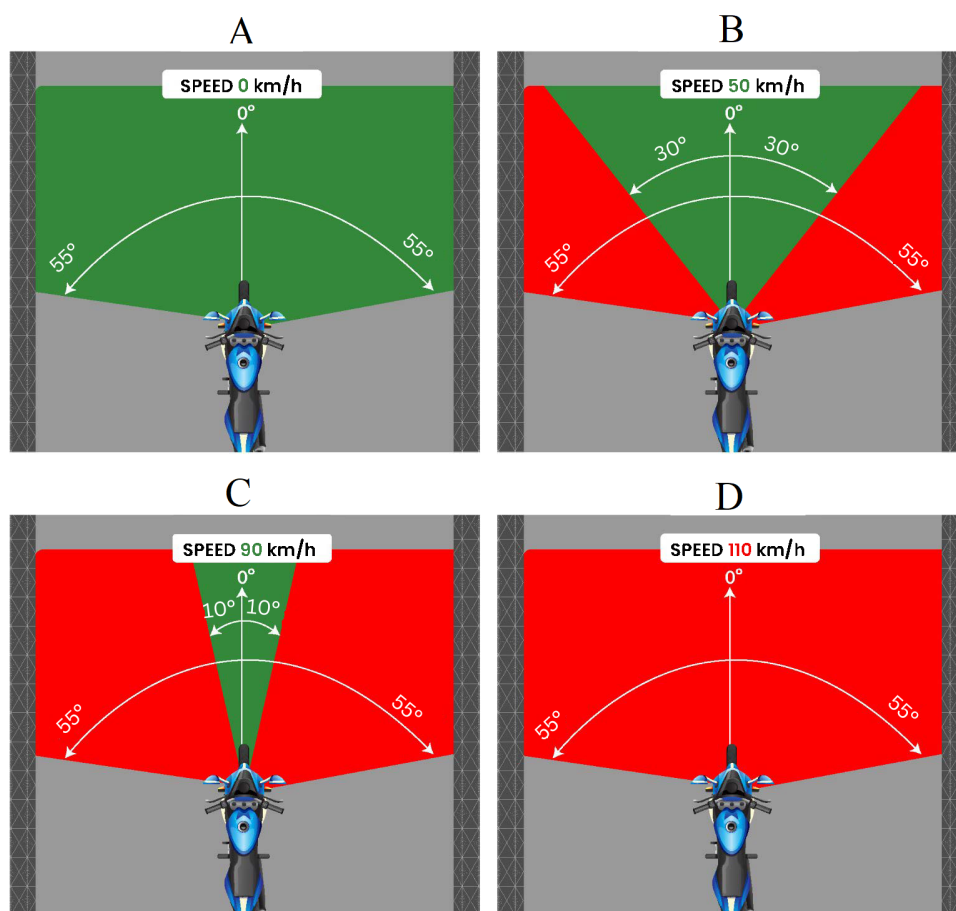


Figure 4. Warning Triggers in Red Zone

The total viewing area is the green zone for a rider if the speed is minimum in Fig. 4. He will be able to turn full head in a certain green zone while riding the bike at a certain speed. As the speed of the bike increases, the green zone for the rider will keep getting smaller Fig. 4. Then, the limit of turning his head left and right will be smaller. If the angle difference inadvertently moves from the green zone to the red zone, the rider will be warned to adjust his speed. So, if there is any uncertainty, he will be less likely to get into an accident. He'll have more time to react to get the bike under control. When the speed increases and reaches its maximum, the rider should not turn his head even one degree at that moment Fig. 4. When the speed is 110 km/hr, the bike covers about 30.5 meters in one second. So, if he turns his head even for a second, the chances of an accident are high. The rider will then be alerted for the slightest movement of the head. So, whenever the angle difference between the rider's head and the bike goes to the red zone between 55 degrees to the right and 55 degrees to the left, the rider will be alerted, and if

it is in the green zone, no alert will be given. On the display of the bike unit device Fig. 5, the rider can be alerted by seeing the safe angle and angle difference according to his speed.

3.8. Bike Unit Device Implementation

Figure 4 demonstrates the Bike Unit Device, which takes the input of the bike sensor Z axis angles and helmet sensor riders' head angle, then processes with a safe angle formula and produces the result which produces the value that indicates whether warning need or not. To do this, first, according to the component list Fig. 2, each hardware component has been checked to see if it is ok. Then, according to the algorithm 1 and flowchart Fig. 3, the program is ready, and the hardware component has been set on the breadboard. Then, all the functionality was checked individually by uploading the program to NodeMCU. After everything worked properly on the Breadboard, all the components were set up and soldered in verobord. Two more green and blue LED's have been added to the bike unit device Fig. 5 along with the red LED's. As the reading continues to come from the sensor, the green light will continue to blink. When the reading does not come from the sensor, the blue light will continue to blink. Finally, when the warning begins, the red LED will blink. The system uses rechargeable functionality. It is possible to recharge two devices with a Universal Serial Bus type B Charger in the TP4056 module on two devices. While starting up the bike, the device's sensor assumes the initial position as a 0 degree angle, so if someone accidentally turns on the device without sitting in a straight alignment with the bike, the 0 degree angle will be wrongly assumed. To eliminate this problem, 2 calibration buttons have been used in both bike and helmet unit devices. So, if the sensor gives a wrong reading, sitting in straight alignment with the bike and pressing these buttons will restart the device. Then, take the initial position to 0 degrees and give the correct reading. Finally, after setting up everything, the helmet unit device Fig. 6 and bike unit device Fig. 5 are completed.

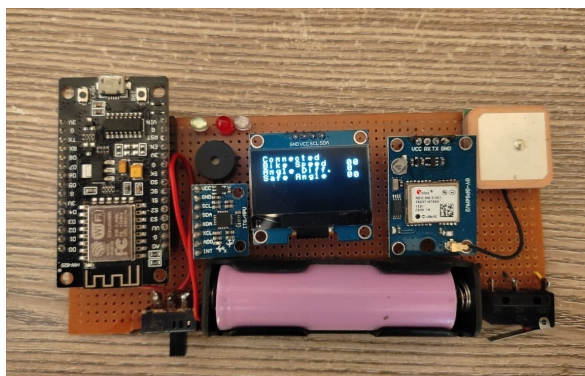


Figure 5. Bike Unit Device

4. Experimental Analysis

The results of the study indicated that the system was effective in detecting the head movements of the rider and providing warnings when necessary Fig. 4. The system was able to detect sudden and jerky movements and provided warnings to the rider in real time. The warnings were provided through visual and auditory cues that alerted the rider to the potential danger. The study also evaluated the effectiveness of the system in preventing accidents. In order to evaluate the effectiveness and reliability of the proposed helmet mounted head movement monitoring system, we conducted a series of systematic tests in multiple stages. Initially, we performed speed detection testing to validate the accuracy of the bike's speed measurement using GPS data. Following this, we conducted movement angle detection testing to ensure the proper functioning of the gyroscopic sensors in capturing both the rider's head angle and the bike's tilt angle. Once these core functional units were verified, we proceeded to the warning status testing to confirm that the system correctly triggered visual and audible alerts when the rider's



Figure 6. Helmet Unit Device

head movement exceeded the safe angle threshold. After confirming the successful operation of each individual module, we conducted an integrated on road testing phase, where the entire system was assembled on a motorcycle and tested under real riding conditions. This staged testing approach allowed us to ensure that each component performed reliably before assessing the complete system's performance in a practical riding environment. The results showed that the system was successful in preventing accidents in many cases. The system was able to predict potential crashes and provide warnings to the rider, allowing them to take corrective action and avoid a collision. The system proposed in the study has the potential to reduce a significant number of accidents and fatalities on the road, making it a valuable addition to motorcycle safety technology. However, the study has some limitations that should be noted. The study was conducted in a controlled environment and did not account for real world conditions such as weather, road conditions, and other factors that could affect the system's performance. Further research is needed to evaluate the system's effectiveness in real world scenarios.

4.1. Speed Detection Testing

As the first step in our series of system evaluations, we focused on testing the accuracy of the system's speed detection module, which is a critical component in calculating the safe head movement angle. Accurate speed measurement is necessary to ensure that the system can correctly determine the permissible head movement threshold during real time riding. The speed detection functionality is achieved using a Neo 6M GPS module integrated into the bike unit device. To validate its performance, we installed the speed detection unit on a motorcycle and conducted on road tests under normal riding conditions. Simultaneously, an action camera was mounted on the rider's helmet to capture both the system's speed readings and the motorcycle's built in speedometer for comparison. Data was collected during various speed intervals, and we compared the GPS derived speed with the motorcycle's speedometer readings. This method involved the GPS device continuously receiving location data from satellites and measuring the distance traveled over a specific time interval. Using this data, the average speed was calculated and compared to the speed displayed on the bike's speedometer to verify accuracy. The results of this testing phase are presented in Table 3, which demonstrates the comparison between the system's GPS based speed measurements and the bike's speedometer readings.

As indicated in Table 3, the Mean Absolute Error (MAE) was computed for every test scenario in order to quantitatively assess the accuracy of the GPSbased speed detection module. The system maintains a high degree of accuracy throughout the tested speed range, according to the analysis, which produced an overall MAE of 0.38 km/h. This small variation demonstrates the GPS based module's ability to consistently record speed data in real time, which is important for precisely figuring out the dynamic head movement threshold while riding.

Table 3. Test Data for Speed Detection Testing Phase

Test No.	Bike Speedometer Reading (km/h)	GPS Based System Speed (km/h)	MAE (km/h)	Observation
1	15	15	0.0	Accurate
2	25	25	0.0	Accurate
3	35	34.7	0.3	Slight Deviation, Acceptable
4	45	45	0.0	Accurate
5	55	54.4	0.6	Slight Deviation, Acceptable
6	60	60	0.0	Accurate
7	70	68.9	1.1	Minor Deviation
8	80	80	0.0	Accurate
9	90	90	0.0	Accurate
10	100	98.2	1.8	Small Deviation
Overall Mean Absolute Error	0.38 km/h			

4.2. Movement Angle Detection Testing

After confirming the accuracy of the speed detection module, the second step in our series of evaluations focused on verifying the movement angle detection capabilities of the system. This phase aimed to ensure that the gyroscopic sensors could accurately measure the rider’s head movement angle (helmet unit) and the bike’s tilt angle (bike unit) along the Z axis (yaw angle). Initially, indoor testing was performed to evaluate the head movement sensor’s accuracy under controlled conditions. The helmet unit was placed on a stationary surface, and the head angle readings were compared to a smartphone compass application as a reference. Similarly, the bike unit Fig. 5 was installed on the motorcycle’s handlebar, and the tilt angle was compared with the same smartphone compass by manually adjusting the handlebar from left to right. The accuracy of the angle detection was assessed at various tilt and head movement positions like slight, moderate, and extreme turns. The test results, as shown in Table 4, demonstrate the correlation between the system’s angle measurements and the smartphone reference values, validating the sensor module’s effectiveness.

As shown in Table 4, the Mean Absolute Error (MAE) was calculated for every test case in order to quantitatively evaluate the angle detection module’s performance. This statistical metric offers a trustworthy representation of the accuracy and stability of the sensor system at various angular positions. The analysis yielded an overall MAE of 0.25° which is very small. So it confirms the high accuracy of angular motion detection by the gyroscopic sensors. These outcomes show how well the system works for tracking rider head movement and bike tilt in real time.

4.3. Warning Status Testing

Following the successful evaluation of speed detection and movement angle detection, the third step in our series of system evaluations was to test the warning status functionality. This phase aimed to ensure that the system could accurately trigger visual and audible alerts when the rider’s head movement angle exceeded the calculated safe angle threshold. In this phase, controlled lab testing was carried out by simulating different speed inputs and head movement angles. Since real time GPS input was not practical in a stationary lab environment, we replaced the GPS module with a 5K Ohm potentiometer to simulate different speed values. This allowed us to observe how the system calculated the safe angle dynamically as speed varied. The helmet and bike units were placed side by side, and artificial angle differences were created to simulate head movements beyond safe limits. The system’s behavior was closely observed to see if it would trigger the buzzer and LED warning alerts whenever the angle difference surpassed the calculated safe angle. Table 5 presents the results of the warning status testing under various speed and angle conditions.

Table 4. Test Data for Movement Angle Detection Testing Phase

Test No.	Reference Angle (Smartphone) (°)	Helmet Unit Angle (°)	Bike Unit Angle (°)	MAE (°)	Observation
1	0	0.5	0.2	0.35	Accurate, Minimal Drift
2	10	10.0	10.0	0.00	Accurate
3	20	19.9	20.1	0.10	Slight Deviation, Acceptable
4	30	29.8	29.8	0.20	Accurate
5	45	44.2	44.8	0.40	Slight Deviation, Acceptable
6	-10	-9.9	-10.5	0.30	Minor Deviation, Acceptable
7	-30	-30.0	-30.0	0.00	Accurate
8	-45	-45.0	-45.2	0.10	Slight Deviation, Acceptable
9	-12	-12.5	-12.8	0.35	Minor Deviation, Acceptable
10	-17	-16.6	-16.2	0.30	Minor Deviation, Acceptable
Overall Mean Absolute Error	0.25°				

Table 5. Test Data for Warning Status Testing Phase

Test No.	Simulated Speed (km/h)	Angle (Degrees)	Difference	Safe Angle Threshold (Degrees)	Warning Status Observation
1	10	5		50	No Warning (Expected)
2	30	15		38.5	No Warning (Expected)
3	50	45		30	Warning Triggered (Correct)
4	70	10		18.5	No Warning (Expected)
5	90	25		10	Warning Triggered (Correct)
6	60	28		25	Warning Triggered (Correct)
7	20	35		45	No Warning (Expected)
8	80	12		14	No Warning (Expected)
9	100	20		5	Warning Triggered (Correct)
10	62	31.5		24	Warning Triggered (Correct)

4.4. Integrated On Road Testing

The Integrated On Road Testing phase was conducted as the final step after the successful validation of each individual module in the previous testing phases. Each of these units was evaluated independently under controlled conditions and simulated scenarios to confirm their accuracy and reliability. Upon achieving satisfactory results in all unit level evaluations, we proceeded to the on road testing phase, integrating the entire system into a motorcycle and helmet. The integrated system was tested during real world bike riding across different speed levels and head movements. The primary objective of this phase was to ensure that the speed detection, angle detection, and warning modules work seamlessly together in practical riding conditions. During the trials, the speed detection module accurately measured the bike’s speed, the gyroscopic sensors consistently detected the rider’s head movement and bike tilt angle, and the warning system successfully triggered audio and visual alerts whenever head movement exceeded the calculated safe angle threshold. To diversify the evaluation and improve the reliability of our findings, we involved several volunteers with their informed consent. Each volunteer was briefed about the system and the testing procedure before participating. The authors of this study actively participated in the tests, allowing first hand observation and evaluation of the system performance during actual bike rides. An image from one of the volunteer 7 testing sessions has been included in the paper. Fig. 7A shows the bike unit device mounted on the bike’s instrument panel. Fig. 7C illustrates the helmet unit device mounted on the helmet for testing. Fig. 7B

presents the overall setup, where a volunteer conducts on road testing with both the helmet unit and bike unit activated. Throughout the on road testing process, the system consistently demonstrated its effectiveness, provided timely warnings whenever the rider’s head movement exceeded the speed dependent safe angle. This reinforced the suitability of the system to improve the safety of the two wheeler driver. The results of this final integrated evaluation are summarized in Table 6, showing that the system successfully detected unsafe head movements that can lead to potential crashes and provided real time alerts under various speed conditions. The system proposed in the study has the potential to reduce a significant number of accidents and fatalities on the road, making it a valuable addition to motorcycle safety technology. However, the study has some limitations that should be noted. Initial tests were carried out in a controlled environment, followed by real life road evaluations. The LEDs and sound device used to warn the rider in the prototype was effective at normal speeds. As the speed increased, it became difficult to hear this sound over the sound of other vehicles on the road. As the engine noise increased with the speed, the sound of this small device became less audible. In the future, it is necessary to test using better speakers in order to develop an improved version or at mass production level. However, extensive testing is necessary under various real world conditions, including varying weather, road surfaces, and traffic scenarios, to fully assess the robustness and performance of the system.

During on road testing, several real world challenges were observed that highlighted areas for further improvement. In urban environments with high rise buildings, the GPS module occasionally lost signal. But in the same environment, another copy of the GPS module worked fine. When the GPS signal is lost, it temporarily affects the speed measurement. On the other hand, during long journeys, the MPU6050 gyroscope constantly exhibited slight drift under engine vibrations. After adding an additional vibration absorbing rubber grip, the sensor worked fine, the sensor drift was significantly reduced. As with the GPS module, we encountered the same hardware issue as some copies of the MPU6050 sensor worked perfectly in all conditions and some of them required calibration after an interval of 40 to 45 minutes. During a turn, a rider must turn their head more than the bike’s lean angle to look through the turn. At that time, the bike’s speed is typically lower, and the head movement angle is higher. During turn, no false warning was detected. Overall, we got good results from our system using good quality hardware devices, and some faulty hardware created some problems during testing.

Table 6. Test Data for Situations, Angle Differences, Safe Angles, and Results

Situation	Angle Difference (°)	Safe Angle (°)	Expected Result	Reported Result
Speed 28 km/h	1	41	No Warning	No Warning
Speed 35 km/h	10	37.5	No Warning	No Warning
Speed 42 km/h	20	34	No Warning	No Warning
Speed 54 km/h	5	28	No Warning	No Warning
Speed 60 km/h	48	25	Warning	Warning
Speed 70 km/h	15	21.25	No Warning	No Warning
Speed 80 km/h	30	15.5	Warning	Warning
Speed 90 km/h	19	10	Warning	Warning
Speed 100 km/h	8	5	Warning	Warning
Speed 110 km/h	2	0	Warning	Warning

5. Discussion and Limitations

Our approach deliberately omits redundant factors like drunk driving, over speeding, triple riding, crash detection, sending crash locations to hospitals, and helmet usage, which have been extensively covered by previous research. We present a distinct and innovative perspective on the causes of bike accidents. Our study introduces a novel factor which is the effect of unnecessary head movements while riding a bike at certain speeds. We provide insight into the relationship between rider speed and safe movement angles to determine how many degrees they can safely turn their head left or right while riding. The proposed system’s accuracy and practical performance were thoroughly evaluated through a multi stage testing approach, as detailed in the Results Section. Each module speed detection, movement angle detection, and warning status was tested individually before integrating the system into

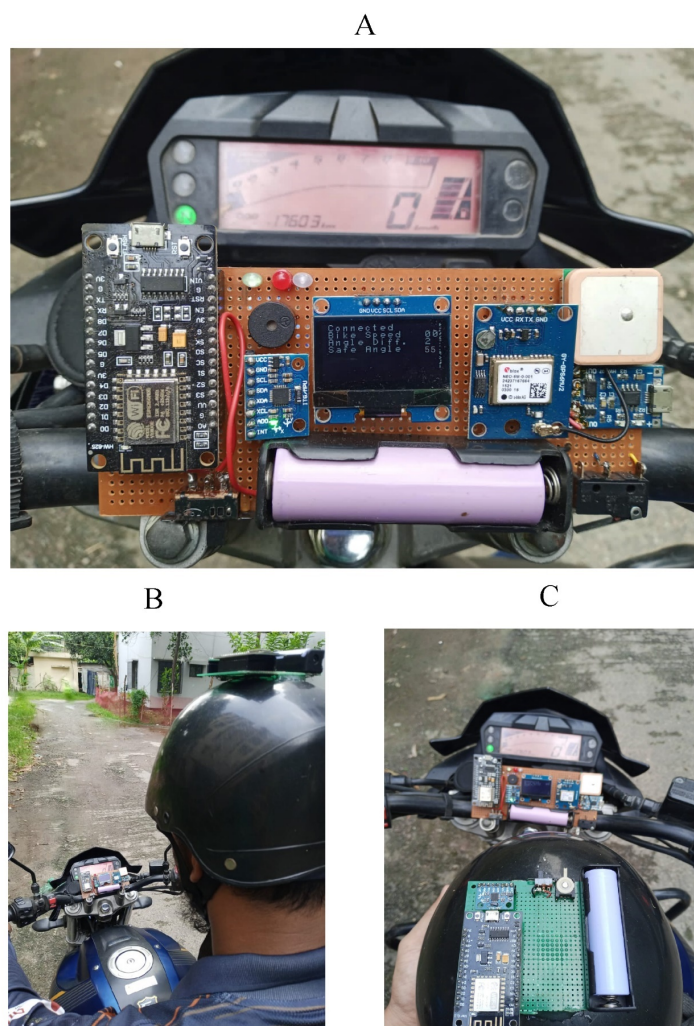


Figure 7. Field Testing the Proposed System. On Road Trials and Implementation

an on road setup. The speed detection module demonstrated high accuracy when compared to the motorcycle's built in speedometer, with minor deviations in a few cases, within an acceptable margin of less than 1 km/h. This ensured reliable speed input for the calculation of the safe angle threshold. The movement angle detection module using mpu6050 sensors also showed precise measurements during comparison with a smartphone compass application. The angular readings for both the helmet unit and bike unit matched the reference values closely, with only slight deviations observed in some cases, all within a range of 1 degrees. This demonstrates the system's capability to accurately detect head and bike tilt angles. The warning status module, which is responsible for triggering alerts when unsafe head movements occur, is performed as expected in all simulated scenarios. The system accurately activated the warning whenever the head angle exceeded the calculated safe angle. This validates the system's sensitivity and responsiveness in real time conditions. The final integrated on road testing phase further confirmed the system's reliability in practical riding environments. Despite promising results, the current prototype has several limitations that warrant further development. As we use a buzzer as our primary warning device, in high traffic conditions with engine and wind noise, its sound was sometimes not loud enough. However, we also integrated a vibration motor in the helmet unit to provide tactile feedback to the rider in case of unintentional head

movement. The safe angle relationship serves as a heuristic approximation of visual field reduction at speed. It has not yet been empirically validated and will be refined through controlled human factor studies and sensitivity analysis. The bike and wearable unit's 2.5 W power draw allows around 15 hours of operation with the current battery pack, and it takes about one and a half hours to fully recharge. Future iterations will employ optimized power management and hardware miniaturization to extend battery life. The system may generate warnings during deliberate head movements, such as checking mirrors or blind spots. We did not introduce an override or pause function for these situations, as the rider can slow down and check the blind spot safely. We prioritized safety rather than taking risks. The combined weight of the helmet mounted components are 180 g. It may affect comfort during prolonged rides. Lightweight design improvements and ergonomic balancing will be prioritized in future studies. The system successfully detected unsafe head movements across different speeds and issued real time alerts to the rider whenever the angle difference exceeded the safe threshold. Validation and optimization of this safe angle formula remain key objectives for future work. In the safe angle calculation the 55° parameter represents a biomechanical upper bound for comfortable gaze deviation and will be subject to future validation and sensitivity analysis.

No false warnings were observed during stable and safe head movements, further emphasizing the robustness of the system in real world use. The module level accuracy evaluations and the integrated system's performance concluded that the proposed system operates with a high degree of accuracy and reliability. One limitation identified during on road trials is the reduced audibility of the buzzer alarm at high speeds due to engine and wind noise. This limitation limits the effectiveness of the warning in the most critical situations. To address this, multimodal warning systems would be integrated in future studies. Improved visual cues such as in helmet LED indicators or HUD display modules. These enhancements will ensure robust, perceptible warnings in a variety of riding situations. In the table 7, we offer a thorough comparative analysis between the proposed system and existing models.

Table 7. Existing System VS Proposed System

Properties and Parameters	[14]	[15]	[16]	[17]	Proposed Model
Drunk Driving	✓	X	✓	X	X
Overload Driving	X	X	X	✓	X
Helmet Usage	✓	X	✓	✓	X
Speed monitoring systems	X	✓	✓	X	✓
Head movement tracking	X	X	X	X	✓
Safe head movement angle	X	X	X	X	✓
Real time monitoring	✓	✓	✓	✓	✓
Increased road safety	✓	✓	✓	✓	✓
Improved rider safety	✓	✓	✓	✓	✓

The distinctions between the suggested system and current smart helmet models are shown in Table 7. Our method presents a preventive framework based on continuous head movement tracking and speed dependent safe angle determination, whereas prior research has mostly concentrated on post hoc crash detection, ignition control, or pre start safety verification. Instead of responding after an incident, the system can now predict dangerous rider behavior thanks to the shift from reactive to proactive safety interventions. It's always better to prevent than to treat. Instead of attempting to lessen the amount of damage or injury in the event of an accident, we have attempted to prevent damage from happening. Our preference has been to develop a system that genuinely aids in prevention. Solutions to frequent human errors that result in accidents have been discussed for current systems. Nonetheless, adherence to all regulations can lower the likelihood of mishaps. Even if all the rules are followed, accidents may still occur because unintentional head movements are not always controllable and it depends on our subconscious mind. Our solution to this research gap has been put forth. A mean absolute error of 0.38 km/h for speed detection and 0.25° for head angle estimation have been shown in quantitative evaluation to have high measurement accuracy, guaranteeing precise real time threshold calculation. Our system uses the biomechanical limits of head orientation in relation to speed to dynamically monitor the rider's attention. The suggested helmet mounted solution is positioned as a substantial addition to rider centric, behavior aware crash prevention technology because of this innovative integration of cognitive safety factors.

6. Conclusion

This study presents a real time sensor based safety system to prevent accidents caused by inadvertent head movements in two wheeler safety. Our approach combines real time rider head orientation monitoring with a dynamic, motion sensitive safe angle model. Unlike most current IoT powered helmet systems that focus on reactive safety measures or post accident detection, the system's ability to increase rider awareness and reduce distraction related incidents has been validated through controlled experiments and road tests. The test results have shown high measurement accuracy and reliable warning effectiveness. Beyond its immediate use, this study lays the foundation for incorporating behavioral and cognitive parameters for future intelligent transportation systems. Our approach for rider centric accident prevention by linking the limits of human vision with vehicle dynamics. Future research should focus on improving multimodal warning systems for different types of vehicles and environmental conditions. Future research should focus on fine tuning this safe angle formula through larger scale human factors studies. This work advances the larger goal of intelligent, behavior aware mobility systems by moving motorcycle safety design away from reactive responses and toward predictive prevention.

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List of Abbreviations

AI - Artificial Intelligence

GPS - Global Positioning System

GSM - Global System for Mobile Communications

IoT - Internet of Things

IR - Infrared

kmh - Kilometers per hour

LED - Light-emitting diode

MPU - Motion Processing Unit

NodeMCU - Node Microcontroller Unit

OLED - Organic Light-emitting Diode

RF - Radio Frequency

SMS - Short Message Service

WiFi - Wireless Fidelity

Declaration of Generative AI and AI-assisted Technologies in the Writing Process:

During the preparation of this work the authors utilized Grammarly in order to improve language and readability. After using this tool/service, the authors reviewed and edited the content as needed and took full responsibility for the publication's content.

Declaration of Competing Interest:

The authors declare that they have no competing interests.

Data Availability:

The source code is available via the GitHub link. The proposed approach and schematic diagram are shared with the scientific community for public access: <https://github.com/rahatTamzid/Enhancing-Two-Wheeler-Rider-Safety>

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