Gyro sensor based smart helmet for automated early accident detection

Ayan Bin Rafaih

Aitchison College, Lahore, Pakistan

---***---

Abstract

The number of worldwide motorcycle accidents is increasing every year, which necessitates the need of safety procedures such as wearing helmets. The integration of Internet of Things (IoT), Artificial Intelligence (AI), Automated Detection and Machine Learning (ML) into this field has improved safety and efficiency, with the help of smart helmets. Our approach proposes an Arduino-based helmet that provides early accident-detection through the use of a gyro sensor to measure the accelerations in all directions. This system continuously monitors for any variations from the gyro offsets and the upper and lower thresholds defined for each direction (x, y and z): a positive detection would lead to the GSM module connecting to a pre-defined SIM network, along with the GPS module for location coordinates, to send a message to the user's emergency contact as soon as the accident is detected. Thus, the message would act as an early warning system that would also include the map latitude and longitude coordinates. This setup provides high accuracy and precision, with constant monitoring of the angular velocities at a set frequency.

Key Words: Smart helmet, Accident detection, Gyro sensor, Arduino GSM, Arduino GPS

1.INTRODUCTION

Rapid urbanization globally has led to a significant increase in the number of motor vehicle accidents that occur every year, especially motorcycle accidents. These severe accidents often lead to unusually high mortality rates and morbidity resulting in temporary or permanent disabilities. For example, 28,356 motorcycle accidents were reported over a 6-year period by the Legal Medicine Organization [1] which included severe and non-severe fatalities such as head trauma, fractures and internal bleeds. Similar statistics collected from studies in Kenya revealed 1073 motorcycle accidents over a 6-month period that led to patients under intensive care at the hospitals, with a morbidity rate of 6.8% [2]. The most frequent and major injury to the people admitted to the hospitals after motorcycle accidents is head injury, with the lack of the helmet being the primary contributing factor to the high mortality rate. In comparison, motorcyclists wearing helmets are less frequently involved in life-threatening head injury situations as the helmets provide an active protective mechanism.

Most of the people using a motorcycle in developing and underdeveloped countries don't wear a helmet, which puts them at risk for severe head injury in the event of an accident. A lack of awareness of traffic rules and road limits, inadequate infrastructural developments and non-adherence to speed limits lead to fatal injuries among motorcyclists. Over speeding leads to higher impact velocity, increasing the chances of head, chest, abdominal and limb injuries. In many of these countries, there have been a multitude of safety strategies and policies that have been introduced yet have not been fully implemented. As covered in the World Health Organization Global Status Report [3], traffic deaths have continued to rise since the past decade, which directly obstructs the goal of reducing traffic accidents and injuries by 2030. Road traffic injury has remained a leading cause for the death of young people aged 30 or less [3].

Helmets typically consist of an outer shell made of a thermally stable material to protect from combustion fire. This is lined on the inside by an energy-absorbing layer of material to help reduce the impulsive force experienced on the head due to a sudden fall. Following that is a comfort layer consisting of additional polymers along with a strap to help provide firm grip to the head [4]. Motorcyclists wearing helmets are particularly less likely to have severe head injuries that may lead to permanent disabilities. There have been multiple approaches to address this issue. For example, governments such as in Bangladesh [5] have taken stringent actions such as increasing awareness and legislations regarding driving limits for motorcyclists. Additionally, there have been efforts to integrate the Internet of Things (IoT) into this field by making smart helmets that would help in detecting accident such as described by Shabbeer et al and Kumar et al [6] [7]. However, some of these helmets provide false detection of accidents or the trigger mechanism for the micro-controllers don't work as expected - accidents are sometimes not detected properly and timely for the motorcyclists. In the event of head injury from motorcycle accident, time to treatment by the emergency services is critical. An early detection and response by the emergency services lead to better clinical outcomes for the patient thus reducing the morbidity and mortality. If implemented properly, smart helmets can help reduce the number of accidents that happen annually by a great amount and save many lives through this process. Smart helmets, if combined with deep learning techniques, help to provide many useful features such as messaging, accident detection and real-time learning.

Our approach in this study utilizes Arduino components, an automated satellite messaging system and a continuous angular velocity sensor to take readings that would be processed by the micro-controller. These values help determine when the helmet wearing motorcyclist has fallen off – specific accident position reference frames are defined that would be read and then processed to determine if there has been an accident. The messaging system helps to automatically notify the user's emergency contact of the occurrence so that they can be given immediate medical attention. Our proposed helmet utilizes a Global System for Mobile Communication (GSM) module and Global Positioning System (GPS) module to help send the message containing the accurate GPS coordinates to identify the location of the accident. Based on pre-defined tilts and rotations during an accident in each reference frame for the helmet and a pre-set timer, if the helmet satisfies the criteria set for accident detection, then the message would automatically be sent. This study presents a new, simplified approach to make smart early accident-detection helmets using Arduino components.

2. LITERATURE REVIEW

There have been many efforts to help propose different ideas for smart helmets that could be utilized for accident prevention. Some of those focus on using force-detection sensors while others use a Machine Learning (ML) approach. For example, Rasli [8] presented an approach where the microprocessor processed the data collected by the Force-Sensing Resistance (FSR) and a speed sensor (BLDC Fan), along with a radio frequency module for signal transmission between the circuits used. The mechanism set up ensured that the engine of the motorcycle would not start until the helmet was fully worn and the speed sensor would limit the maximum safe speed for the motorcyclist. Similarly, Chandran et al [9] proposed a smart helmet that used an accelerometer sensor, measuring the acceleration of the head continuously in all cartesian directions x, y and z. A conditional check was enabled on the values which if exceed the set value would correspond with the WIFI Enabled module that would be able to communicate a sense of emergency which also includes the use of cloud computing infrastructures.

Furthermore, there have been efforts by Rahman [5] to combine the Infrared sensor to detect the presence of the helmet on the head, along with an alcohol sensor to detect the level of alcohol in the driver' breadth: this was connected to a Graphical User Interface (GUI) application and alert system. A review by Impana et al [10] found that most smart helmets mostly comprised of two main parts; a motorcycle part and a helmet part where the former was often connected to the battery circuit of the engine preventing it from turning it on in case of any abnormalities and the latter consisted of an array of sensors, such as Hall-Effect Sensors (HES) for positioning and speed detection using the principle of the change in voltage due to its presence in a magnetic field. However, such approaches heavily rely on the presence of a power supply, which indeed was not ideal. Mhatre et al [11] utilized a similar modular approach for their design of a smart accident detection system. Their bike module used a vibration sensor to take readings on a constant sampling rate to be sent to the micro-processor through the receiver-transmitter communication channel. Kurkute [12] used a unique approach. Instead of using Arduino or a PIC controller, they use a Raspberry Pi Module, a pressure sensor and image processing algorithms. They used the Haar Cascade system with frontal face tracking, contour tracking algorithms and canny edge detection algorithm with gaussian filters to carry out image processing. The method used a verification system whose filters would output whether in the image the driver was wearing the helmet or not, by focusing only on relevant pixel data and shades. In conjunction with the previous approach [5], a study by Ahuja [13] used a tilt and a NC sensor to create a sensitive infrared system, which however faced problems with tilting as the microcontroller was not fully able to process when the tilt is greater than the boundaries set.

Jeong [14] used a mixture of multiple detection and relay systems to help increase the accuracy of the accident-detection. They did this by using an electro-optical camera for the same purpose defined by Kurkute [12], oxygen residual sensors to detect the driver's health in the case of an emergency and alter the command centre, a smart watch that aids in the communication process and a 6-axis inertial sensor to detect the relative motion of the driver's head. Behr [15] proposed the hazard detection element of the helmet worn by drivers, especially miners, in a three-fold manner; prevention against helmet removal using an Infrared (IR) Sensor to detect when it's on the head and when it's not, collision detection in case the miners are struck or bit by an object causing an injury that exceeds the value of 1000 in the Head Injury Criteria (HIC) and detecting the concentration of harmful gases in the atmosphere by the use of multiple gas sensors and the final communication between the components and emergency alert is sent using ZigBee, instead of WIFI or Bluetooth in the paper. Desai [16] used a fall detection algorithm governed by Optical Character Recognition System (OCRS) that would send an automatic alert to the nearest hospital and emergency services, in tandem with a helmet detection algorithm governed by a Hough Transform Descriptor (HTD). Apart from this, there have also been some applications of Machine Learning (ML) and Deep learning (DL) such as two-dimensional and three-dimensional convolutional neural networks (CNNs) to perform multi-task learning as described in the approach by Lin et al [17]. They created a new local dataset using the incidents in their areas, which was then used for similarity learning in each incident and helmet use classification, to be subsequently evaluated through metrics such as precision, accuracy and

Receiver Operating Characteristic (ROC) Curves. Similarly, Vishnu et al [18], used CNNs for detection of motorcycle drivers who were not wearing helmet by feature extraction from the pixels and head localization.

3. METHODOLOGY

Our Accident-detection helmet uses a Gyro sensor to help detect the occurrence of accidents. The following section explores the technical apparatus used in our helmet.

3.1. MPU 6050 Gyroscope and Accelerometer Sensor

The MPU6050 sensor module consists of a 3-axis gyroscope sensor component with Micro Electro Mechanical System (MEMS) technology and is used to detect and flag rotational tilts in either of the cartesian axes by measuring the value of the rotational velocity. For example, in our case when the motorcycle driver's head tilts through an accident and the helmet lands in a disturbed position rather than landing on its base, the gyroscope detects a rotation around the x, y and z axes. This rotation is caused by the Coriolis effect which produces a detectable vibration for the MEMS inside the module. We can define the Coriolis force (F_c) that leads to gyro sensor's working as:

$$F_c = -2m(\omega \times v')$$

Where m is the mass of the body (in our case the helmet), ω is the angular velocity of the helmet and v' is the tangential velocity of the helmet relative to the inertial reference frame. This is supplemented by the 3-axis accelerometer in the MPU6050 which helps to detect the angle of tilt that has occurred relative to the normal frame and initial coordinate positions. Angular tilts displace the movable mass from its original position, which is registered as an output amplitude from the capacitor in the module. These two modules help to calculate the degree of tilt ϕ and direction of tilt. Thus, we can obtain the angular velocity and the relative acceleration along each of the axes, which are continuously sampled by the microprocessor.

3.2. Arduino Nanoboard

We use the Arduino provided Nanoboard, which has the ATmega328P microcontroller from the 8-bit AVR family, which utilizes an operating voltage of 5V for our helmet and has a 2KB Static Random Access Memory (SRAM). The micro-controller is directly interfaced and connected to both the sensor (the receiver end for all the data values) and other components to provide complete functionality. The sensor data is compared with the upper and lower limits set to detect when an accident has occurred, and this is done continuously, with its power supply connected to a rechargeable battery.

3.3. Global System for Mobile Communication (GSM) Module

We use an automated Short Message Service (SMS) system in the case of an accident after the data from the gyroscope sensor is analyzed. For this purpose, we utilize a SIM800L GSM Module. Operating on a quad-band GSM network, it connects and communicates with the internet using a Transmission Control Protocol/Internet Protocol (TCP/IP). The user would have provided the program with an emergency number in the case of an accident. The GSM module would automatically send a SMS message on that number, letting the emergency contact know that the user has been involved in an accident. The information of the message would contain two elements: an indication that there has been an accident and the map coordinates which would be provided by the GPS interface. GSM's antenna is connected to its NET pin, while the Arduino microcontroller's Transmit Pin (TXD) is connected to its Receiver Pin (RXD). The TXD pin defined is 11 and RXD is 10.

3.4. Global Positioning System (GPS) Module

To supplement the message that is sent to the emergency contact, the location of where the accident has occurred is also sent in the message. For this, we used the NEO-6M GPS module with antenna that would register and send two cartesian coordinates: longitude and latitude. These coordinates would be sent along with the warning system, which can be processed by any map app to show the location.

3.5. LM2596 DC-DC Step Down Power Supply Module

We use the LM2596 Buck-Convertor module to help step the battery voltage down to a suitable voltage for the SIM800L GSM Module so its voltage is in its required range. The voltage is stepped down from 8 volts to between 3.3 and 4.2 volts.

3.6. Buzzer System

An Arduino piezo buzzer is also attached which would make a beep sound when the message is sent and an accident is successfully detected by the microcontroller.

4. WORKING PRINCIPLE

The Arduino Nanoboard and module is connected to a rechargeable battery which acts as its power source. The MPU6050 module determines the gyro offsets to make the inertial reference frame, which are crucial for determining the relative angular velocities in the next part. A check is introduced that ensures that G_x, G_y and G_z are calculated, the gyro offsets for the x, y and z directions respectively. If the gyro offsets are not calculated, it will recalculate and initialize the reference frame after a delay of 500 milliseconds. The gyro sensor measures the angular velocity in all the cartesian directions relative to a normal inertial reference frame for the helmet and the motorcycle driver's head. These angular velocities are differentiated to calculate Acc_X, Acc_Y and Acc_Z, the accelerations for the x, y and z directions respectively.

Boundary threshold values are introduced to determine when the acceleration in each direction go out of bounds. The upper and lower bounds are determined through brute-force experimentation – Any tilt of ϕ greater than 15 degrees is classified to be a valid case to determine the values for the gyro accelerations. These gyro accelerations are collected and then analyzed to determine the base value. Maximum and minimum fluctuations either side of the middle, assuming a normal distribution, are noted and help form the set of possible accelerations that should lead to the correct classification of an accident thus eliminating the occurrence of false positive signals. For both acceleration in the x-direction and in the z-direction, if Acc_X or Acc_Z is greater than 0.40 or less than -0.40, or for acceleration in the y-direction, if Acc_Y is greater than 0.45 or less than -0.45, a flag would be raised. A count variable, that has already been initialized immediately after the flag, would increment sequentially per second. When 30 seconds have elapsed, the procedure "*EmergencyMessage ( )*" would be called. A buzzer would also sound in the helmet to alert any people walking nearby. If the values of the variables Acc_X, Acc_Y and Acc_Z are not out of the threshold values, then the loop would iterate indefinitely if the Arduino Nanoboard is turned on through the attached switch in the helmet.

The Procedure "*EmergencyMessage ( )*" consists of a main procedure as well as an in-built procedure. The in-built procedure would be linked to the GPS Module – connecting with the satellite. The GPS module would introduce 2 global variables into this procedure: Longitude and Latitude measures which correspond to the location of the accident on a map. For the main procedure, the SIM network would be contacted through the use of the GSM module. The emergency number would already be saved in the procedure and finally the message is sent to the specified contact number with a warning prompt such as "Accident Detected". The working principle is explained in **figure 1** and **figure 2**.

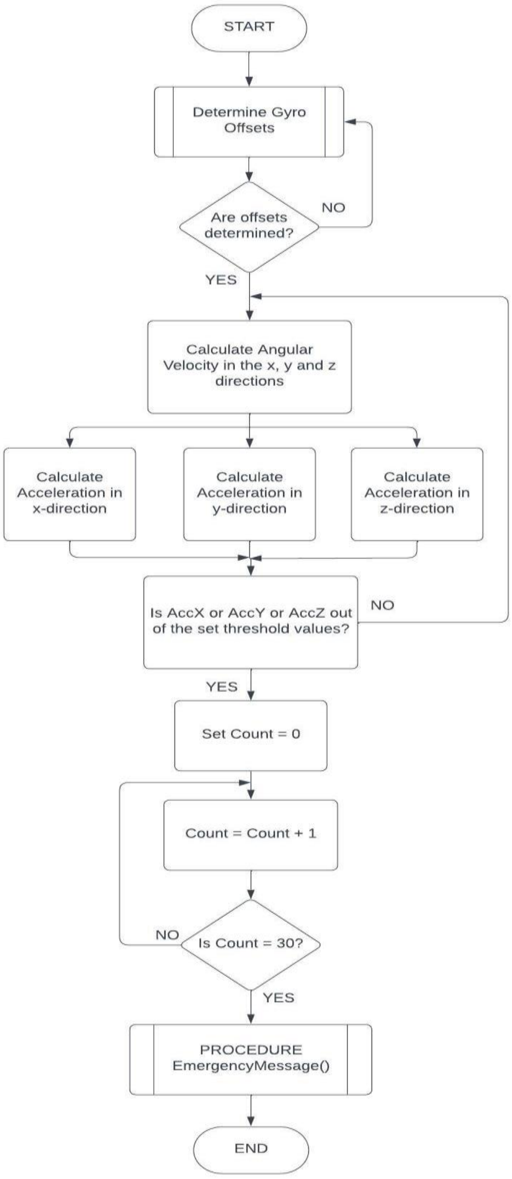

Figure 1: Working Principle of the Arduino Accident-Detection Helmet

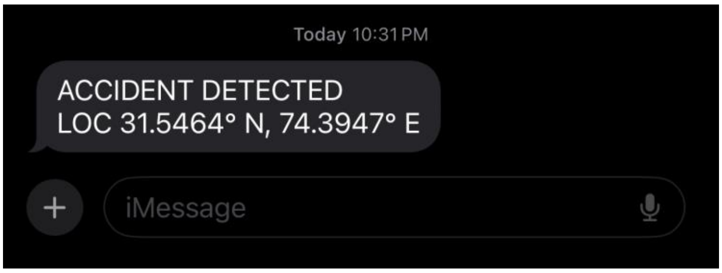

Figure 2: Warning Prompt with location coordinates for the emergency contact

5. RESULTS

A series of trials were conducted to help set accurate threshold values for the accelerations derived from the gyro sensor. These preliminary trials helped us choose the threshold values for each acceleration value **(table 1)**.

	Acceleration in x-direction	Acceleration in y-direction	Acceleration in z-direction
Upper Threshold Value (>=)	0.40	0.45	0.40
Lower Threshold Value (<=)	-0.40	-0.45	-0.40

Table 1: Threshold values for acceleration in x, y and z directions

With the conditional statement defined in the methodology section, this helmet acts as a successful early accident detection method. The NEO-6M GPS Module used in this study has a tracking sensitivity of -162 dBm, which helps in better tracking, if the accidents occur. The MPU 6050 Gyro sensor used for angular velocities and accelerations has a very high accuracy - the values are sampled each second and continuously checked for the accident condition. The sensor has a bandwidth rate of 100Hz, with its respective tolerance band. Once the accident is detected, the local network for the provided phone number is contacted through which a message is generated as a flag for the occurrence of the accident. This message is sent through the SIM network with the location coordinates.

6. CONCLUSION

The results and methodology of this project present a new, simplified approach to making a smart accident-detection helmet that can be accessible to everyone. This paper has presented a novel way to make a helmet through basic materials, which will help reduce the amount of severe injury people often receive when they are driving a motorcycle, especially in remote locations. Our helmet enables immediate medical care and alerts to family members for all motorcyclists. Additionally, the use of the GPS modules helps to identify the exact location of the accident.

The project can be adapted with reinforcement learning, adaptive feedback or deep learning techniques with back-propagation to enable live-detection of accidents and live-learning of new situations. Such improvements could increase the cases where it flags an accident correctly and improve its accuracy reducing the number of false positive signals generated.

7. REFERENCES

1. Abdolrazagh Barzegar, Masoud Ghadipasha, Mehdi Forouzesh, Samira Valiyari, Ali Khademi, Epidemiologic study of traffic crash mortality among motorcycle users in Iran (2011–2017), Chinese Journal of Traumatology, Volume 23, Issue 4, 2020, Pages 219-223.
2. Wilberforce Cholo, Wilson Odero, and Japheths Ogendi. "Epidemiological characteristics of crashes and pattern of motorcycle injuries presenting to hospitals in Kisumu City, Kenya: a cross-sectional study." *Pan African medical journal* 45.1 (2023).
3. World Health Organisation “Global Status Report on Road Safety 2023” https://www.who.int/teams/social-determinants-of-health/safety-and-mobility/global-status-report-on-road-safety-2023 .
4. Michelle Aiello, Ugo Galvanetto, and L. Iannucci. "Numerical simulations of motorcycle helmet impact tests." *International journal of crashworthiness* 12.1 (2007): 1-7.Rahman, Md Atiqur, et al. "Iot based smart helmet and accident identification system." *2020 IEEE Region 10 Symposium (TENSYMP)*. IEEE, 2020.
5. Md Atiqur Rahman, S. M. Ahsanuzzaman, Ishman Rahman, Toufiq Ahmed, and Abid Ahsan "Iot based smart helmet and accident identification system." *2020 IEEE Region 10 Symposium (TENSYMP)*. IEEE, 2020.
6. Shoeb Ahmed Shabbeer, and Merin Meleet. "Smart helmet for accident detection and notification." *2017 2nd International Conference on Computational Systems and Information Technology for Sustainable Solution (CSITSS)*. IEEE, 2017.
7. M. Kiran Kumar, Aniruddha Balbudhe, and CH Sai Karthikeya. "Smart Helmet based Accident Detection and Notification System for Two-Wheeler Motor Cycles." *E3S Web of Conferences*. Vol. 391. EDP Sciences, 2023.
8. Mohd Khairul Afiq Mohd Rasli, Nina Korlina Madzhi, and Juliana Johari. "Smart helmet with sensors for accident prevention." *2013 international conference on electrical, electronics and system engineering (ICEESE)*. IEEE, 2013.
9. Sreenithy Chandran, Sneha Chandrasekar, and N. Edna Elizabeth. "Konnect: An Internet of Things (IoT) based smart helmet for accident detection and notification." *2016 IEEE Annual India Conference (INDICON)*. IEEE, 2016.
10. H. C. Impana, M. Hamsaveni, and H. T. Chethana. "A review on smart helmet for accident detection using IOT." *EAI Endorsed Transactions on Internet of Things* 5.20 (2019).
11. Kimaya Mhatre, Raj Nandwadekar, Aditya Patil, Rushikesh Shinde, and Pradnya Kamble "Smart helmet With Intercom Feature." *Proceedings of the 3rd International Conference on Advances in Science & Technology (ICAST)*. 2020.

12. Swapnil Kurkute, Nikita Ahirao, R. G. Ankad, and V. B. Khatal "IOT based smart system for the Helmet detection." *Proceedings of International Conference on Sustainable Computing in Science, Technology and Management (SUSCOM), Amity University Rajasthan, Jaipur-India*. 2019.
13. Prashant Ahuja, Ketan Bhavsar. "Microcontroller Based Smart Helmet Using GSM & GPRS." *2018 2nd International Conference on Trends in Electronics and Informatics (ICOEI)*. IEEE, 2018.
14. Mingi Jeong, Hyesun Lee, Myungnam Bae, Dong-Beom Shin, Sun-Hwa Lim, and Kang Bok Lee. "Development and application of the smart helmet for disaster and safety." *2018 International conference on information and communication technology convergence (ICTC)*. IEEE, 2018.
15. C. J. Behr, Anuj Kumar, and Gerhard P. Hancke. "A smart helmet for air quality and hazardous event detection for the mining industry." *2016 IEEE International Conference on Industrial Technology (ICIT)*. IEEE, 2016.
16. Maharsh Desai, Shubham Khandelwal, Lokneesh Singh, and Shilpa Gite. "Automatic helmet detection on public roads." *International Journal of Engineering Trends and Technology (IJETT)* 35.5 (2016).
17. Hanhe Lin, Jeremiah D. Deng, Deike Albers, and Felix Wilhelm Siebert. "Helmet use detection of tracked motorcycles using cnn-based multi-task learning." *IEEE access* 8 (2020): 162073-162084.
18. Chalavadi Vishnu, Dinesh Singh, C. Krishna Mohan, and Sobhan Babu. "Detection of motorcyclists without helmet in videos using convolutional neural network." *2017 International joint conference on neural networks (IJCNN)*. IEEE, 2017.