Accident and Alcohol Detection in Bluetooth enabled Smart Helmets for Motorbikes

Sayan Tapadar
Department of Computer Science and Engineering
Institute of Engineering and Management, Kolkata, India
saytap.tapadar5@gmail.com

Shinjini Ray
Department of Computer Science and Engineering
Institute of Engineering and Management, Kolkata, India
shinjini.ray@gmail.com

Arnab Kumar Saha
Department of Electrical and Electronics Engineering
Institute of Engineering and Management, Kolkata, India
arnab.saha.95@gmail.com

Robin Karlose
Department of Computer Science (2010-2014)
PricewaterhouseCoopers Private Ltd (PwC)
robin.karlose91@gmail.com

Dr. Himadri Nath Saha
Department of Electrical and Electronics Engineering
Institute of Engineering and Management, Kolkata, India
himadri@iemcal.com

Abstract— **With the growing number of 2-wheel motor vehicles, frequency of accidents is on the rise. A major portion of the fatalities occur because the person was either not wearing a helmet, or his accident was not reported in time, and he could not be saved because of the delayed admittance to a hospital, or because he was riding while drunk. We propose mechanisms that can detect if one is wearing the helmet, detect accidents, and detect whether the person has over-consumed alcohol. For this purpose, we use onboard sensors – flex sensor, impact sensor, accelerometer (ADXL355) and breath-analyzer (MQ3). The accelerometer measures the change in tilt, in X Y and Z axes respectively, and sends the data to a server via an online application programming interface (API). The breath analyzer senses the amount of alcohol present in the breath of a person wearing the helmet and reports if it is beyond the legal limit. The server also uses the data gathered from the accelerometer and the pressure sensors, to train a support vector machine (SVM).This can help optimize accident detection in the future when enough data is gathered to provide reliable accuracy. The helmet can connect to any smartphone via Bluetooth, to communicate with the online API, using the internet connection of the smartphone. This will ensure the holistic safety of the rider at all times.**

Keywords—Internet of Things; Smart Helmet; Support Vector Machine; Accident detection; Alcohol detection

I. INTRODUCTION

Motorcycles and bikes form an integral part of personalized transportation in India. However, unfortunately, it also involves innumerable accidents and subsequent loss of lives. Every year, about 300,000 teenagers go to the emergency department because of bike injuries, and at least 10,000 teenagers have injuries that require a few days in the hospital. Statistics say, motorcycle deaths accounted for 15 % of all motor vehicle crash deaths in 2015 and were more than double the number of motorcyclist deaths in 1997. Through an ONEISS survey conducted by the Department of Health, it was found that 90% of the motorcycles rider killed in accidents were not wearing a helmet at the time of impact. This, along with drunken driving are a major reason of accidents. We aim to mitigate these problems and hence the associated casualties by ensuring that the rider will wear the helmet all the time during his/her ride, thus ensuring safety. The helmet can understand if the person is wearing the helmet, using the pressure sensors, fitted inside the padding foam.

The helmet can detect a possible accident, using the onboard accelerometer and pressure sensor. If the values detected exceed a threshold, it is reported as an accident. Emergency contacts, specified by the rider during app setup, are informed about the possible accident, via a system generated email and text message, containing the address and GPS coordinates where the accident had been detected. The values of the accelerometer are also constantly sent to a remote server using an online application interface (API), and the server trains a support vector machine (SVM).

An onboard alcohol sensor also analyzes the breath of the rider to detect if the current intoxication level is above the legal threshold. If it is so, he is first warned to not ride the motorbike. If he rides it anyway, his emergency contacts are informed, so that they may handle the situation.

The helmet can connect to any smartphone via Bluetooth [1] so that it can communicate with the server using the smartphone's internet access.

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II. RELATED WORKS

In the literature, we found several smart helmet system but with different approach and proposed solution.

Wilhelm Von Rosenberg et al [1] has Proposed a smart helmet with embedded sensors for cycling and moto racing to monitor both vital signs and the electroencephalogram (EEG) simultaneously. They have embedded multiple electrode within a standard helmet and a respiration belt around the thorax for validation and a reference ECG from the chest. Also a multivariate R-peak detection algorithm has been applied to get data from real life noisy environment.

Sreenithy Chandran et al [2] monitored the value received from accelerometer embedded in helmet and detects an accident by analysing those values and sends an emergency notification to contacts with Global positioning system location.

C. J. Behr et al [3] has developed a smart helmet for the mines industry keeping focus air quality, helmet removal and collision. It detects the presence of hazardous gases like CO, SO2, NO2 and detects the helmet removal using an off-the shelf IR sensor. An accelerometer is implemented to detect

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accident by calculating the HIC (head injury criteria) by software using those reading.

Sudhir Rao Rupanagudi et al [4] has made a helmet which monitors the real life traffic scenario behind the motorcycle rider and a intimation system to inform him / her. A MATLAB based algorithm is implemented to perform the task along with a cost effective setup and priority has been given to some special cases such as turning and all.

A. Ajay et al [5] has proposed a smart helmet with 4 different functionality : accident identification and alert system, voice based navigation system using map, a bluetooth device based voice call which uses voice recognition to attend cellular call and a solar panel for external power source. A GSM module attached arduino board is used for accident alert system and a smart mobile phone is interfaced with the helmet to serve the navigation process.

Mohd Khairul Afiq Mohd Rasli et al [6] has designed a PIC16F84a microcontroller controlled smart helmet with force Sensing Resistor (FSR) to detect rider's head and a BLDC Fan for speed detection. Helmet starts it's alarm system whenever the speed crosses a certain limit and motorcycle's engine will start only after the rider buckles the helmet.

Muthiah M et al [7] proposed an helmet which contains a automatic safety headlight that reacts according to riders facial movement with the help of accelerometer and other sensors and motors.

III. Materials and Methods

A. Hardware Components

TABLE I. List of Hardware

Components	Specification
Microprocessor	Arduino NANO with Atmega 328
Flex sensor	Robodo Electronics FSENS Flex Sensor
Impact Sensor	Keyestudio Collision Crash Sensor Module
Accelerometer	ADXL355
Global Positioning System (GPS) Module	SIM 28ML module with Antenna
Breathsensor	MQ3 module
Bluetooth	BLE HM-10
Votage Regulators	9V to 5V Regulator IC L7805

B. Microcontroller (Arduino NANO with Atmega 328)

This is the core of the device, a cheap and easily available and programmable Arduino NANO clone, with Atmega 328. It provides limited processing capability, but it is enough for our purpose. It is small, and compact, which is an important factor because the entire hardware needs to be fitted inside a helmet.

When the device is started for the first time, the application prompts to calibrate the helmet. Upon calibrating, the calibrated values of the accelerometer are stored in the microcontroller's ROM. This is used to calculate the 'tilt' of the helmet while riding the motorbike. The microcontroller performs other operations as shown in the flowcharts later in this section.

C. Flex Sensor

Flex sensors are strips with metal pads. On bending, the resistance of the metal pad changes. When used with an Arduino, it can be plugged into an analog pin. The analog pin reads values between 0-1023, and the value depends on how much the strip is bent.

One such strip is attached to the interior of the helmet. This when the user wears the helmet, this head bends the strip, and the helmet is able to detect if the helmet has been worn. Our threshold value is set at 100 so that it can accurately detect the wearing of the helmet.

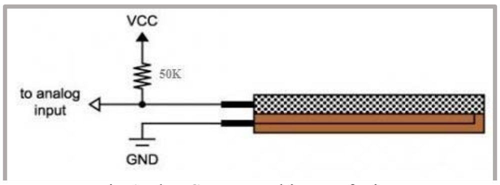


Fig 1 Flex Sensor and it Interfacing

D. Impact Sensor

We use the Keyestudio Collision Crash Sensor Module as the impact sensor. Collision Sensor can detect whether any collision movement or vibration happens. It outputs a low pulse signal when vibration is detected. To make the output signal more reliable and neat, a necessary exterior circuit is present to reduce the noise impact. Thus, normal shaking will not cause any output.

This module is attached to the exterior of the helmet. When the helmet falls down, there should be a vibration from the impact of falling down on the ground. The collision sensor detects this vibration and outputs analog output in the range 0-1023. Here too we have set a threshold of 100 so that it accurately detects the falling down of the helmet.

Fig 2 Impact Sensor

E. Accelerometer (ADXL355)

The accelerometer we use is a 3-axis accelerometer that measures tilt of the device with respect to the earth, in 3 axes- X, Y and Z. Since it measures the tilt with respect to the earth, we need to store the corresponding values when the helmet it normally worn. This is the calibration we require. The values are stored in the ROM, and the difference of current readings and the stored readings are used to detect a possible accident.

Fig 3 Accelerometer

F. GPS module (SIM 28ML)

This module helps to get the present GPS coordinates of the device. The coordinates are required when an accident is detected or high alcohol consumption is detected. The phone GPS could be also used, but having a GPS module build in the helmet guarantees the accuracy of the reported location. The module we use follows the NMEA protocol, and thus the output coordinates need to be converted into a more usable form. Thus we use tiny GPS library to perform the necessary conversion. It is an open source library for Arduino, for NMEA GPS data.

Fig 4 GPS Module

G. Breath Analyzer (MQ3)

This module uses an Alcohol Gas sensor MQ3. It is a low-cost semiconductor sensor and can detect the presence of alcohol gases at concentrations from 0.05 mg/L to 10 mg/L. The sensitive material used in this sensor is SnO2, whose conductivity is lower in clean air. Its conductivity increases as the concentration of alcohol gases increases. It has high sensitivity to alcohol and has a good resistance to disturbances due to smoke, vapor, and gasoline. This module provides both digital and analog outputs. MQ3 alcohol sensor module can be easily interfaced with microcontrollers.

Fig 5 MQ3 Breath Analyzer

H. Bluetooth Module (BLE HM-10)

The HM-10 is a Bluetooth 4.0 Low Energy module containing the TI produced CC2540 or CC2541.It provides reliable and low power consuming Bluetooth connectivity. We use it for the communication between the device and the smartphone, and thus it is our medium of data communication. Another important reason why we use this particular Bluetooth module is that it is power efficient and low on cost.

I. Support Vector Machines (SVM)

Support Vector Machines are widely used means of supervised machine learning. These are associated with learning algorithms that analyze data and recognize patterns and are widely used for classification and regression analysis. To use an SVM, we require a set of training data, that includes positive and negative data. The SVM maps the data into space and tries to derive a hyperplane that divides the space in the best way possible, such that in one side of the plane, positive data exists, and on the other side, negative data exists. During prediction, if data lies on the positive side, it is predicted as positive, and if it lies on the negative side, it is predicted as negative.

J. Block Diagram

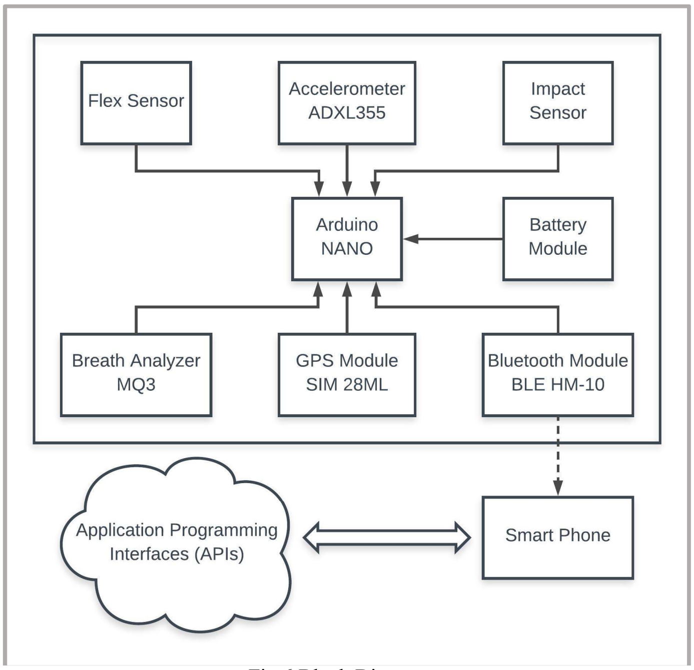


Fig 6 Block Diagram

The Arduino NANO requires a voltage input of 5V. A 9V battery, connected to LM7805 5V voltage regulator IC, can be used to power the NANO.

The flex sensor accelerometer and the impact sensor outputs analog data, and are thus plugged to the analog pins of the microcontroller. The breath sensor has an analog output pin too, but we only require the digital output pin. It is thus connected to a Digital pin of the microcontroller. The GPS module and the Bluetooth module require 2 digital input pins, for their RX and TX.

The Bluetooth module sends data wirelessly to the smartphone via Bluetooth, and the smartphone calls the appropriate online API method. Thus an active internet connection in the smartphone is essential.

K. Smartphone Application

Development of a Smartphone application and our device's communication with the smartphone application is what makes our device so powerful, without compromising the affordability of the device. The application has several roles, as mentioned below:

1. Register the user's name, email address, phone number for security.
2. Register the user's emergency contacts, to inform about the accident detected, and if high alcohol consumption is detected.
3. Calibrate the helmet's accelerometer. The first time the user wears the helmet, he will be prompted to look straight and click the calibration button.
4. Communicate with the device, and perform HTTP request operations to the online API.

L. User Interface

The rider communicates with the device through his smartphone. Thus the following features in the user interface are essential and have been implemented.

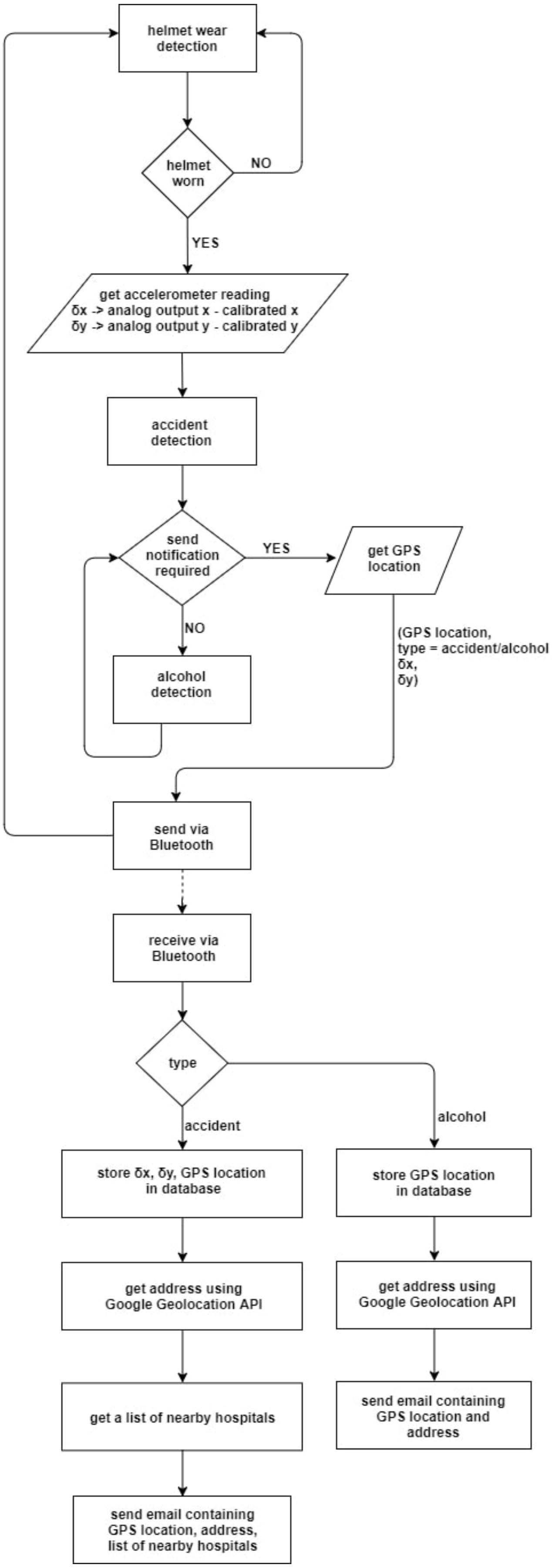
1. Screen to enter the user's details.
2. Screen to enter details of emergency contacts.
3. Prompt to calibrate helmet, when first used.
4. Warning to not drive if high alcohol consumption is detected
5. Email notification to emergency contacts in case of an accident.
6. Email notification to emergency contacts in case of drunken driving.
7. Track the rider using the application, in case any of the above notifications have been sent.

M. Calibration

Calibration of the helmet is performed when the rider first wears the helmet and connects it to his smartphone via Bluetooth. He is prompted to calibrate his helmet by sitting normally and looking straight. He is then asked to click the button on his helmet to perform the calibration. The values of the accelerometer are stored in the NANO's ROM. These values are later utilized to calculate the instantaneous tilt of the helmet.

N. Flowchart of the Sequence of Functionality

FLOWCHART I: SEQUENCE OF FUNCTIONALITY



The above flowchart shows all the functionalities in sequence. Each method is explained in detail in its respective sections.

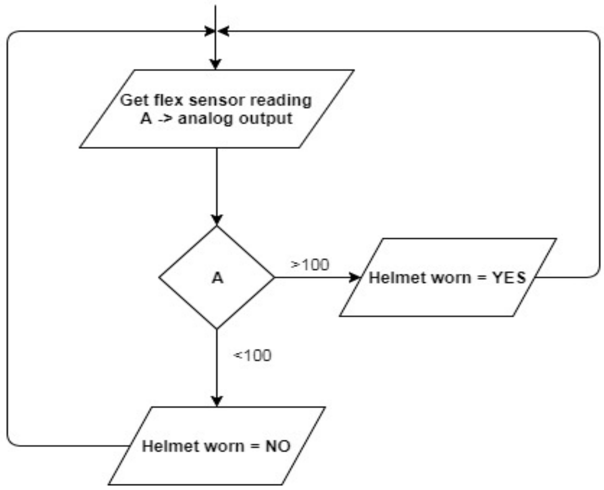
O. Helmet Wear Detection

The flex sensors installed inside the helmet will bend to an extent, once the helmet is worn because it has been installed in the helmet inside the protective foam in a way that the head will press against it to be worn. Thus the sensor can accurately detect when the helmet is worn, and when it is taken off.

The flex sensor outputs analog data in the range of 0-1023, based on how much the strip has been bent. Our threshold for wear detection is 100. It is low so that a slight bend from the pressure against the protective foam is enough to be detected accurately.

As shown in the Flowchart I, the other functionalities of the helmet are only checked if the helmet is worn. This is essential so that emergency contacts are not falsely reported about an accident or drunken driving when the rider is not wearing the helmet. Suppose the rider drops the helmet from his hand, it meets the criteria of our accident detection. But the rider is not wearing the helmet, thus no action will be taken.

FLOWCHART II: HELMET WEAR DETECTION



P. Accident Detection

Accident Detection requires a pre-calibrated helmet. The device constantly monitors the analog output values of the accelerometer, as well as the impact sensor fitted to the exterior of the helmet. The difference between the current accelerometer values and the calibration values indicate its tilt. The tilt is checked with a particular threshold, which in our case is

$$|\partial x| > 40, \qquad |\partial y| > 40$$

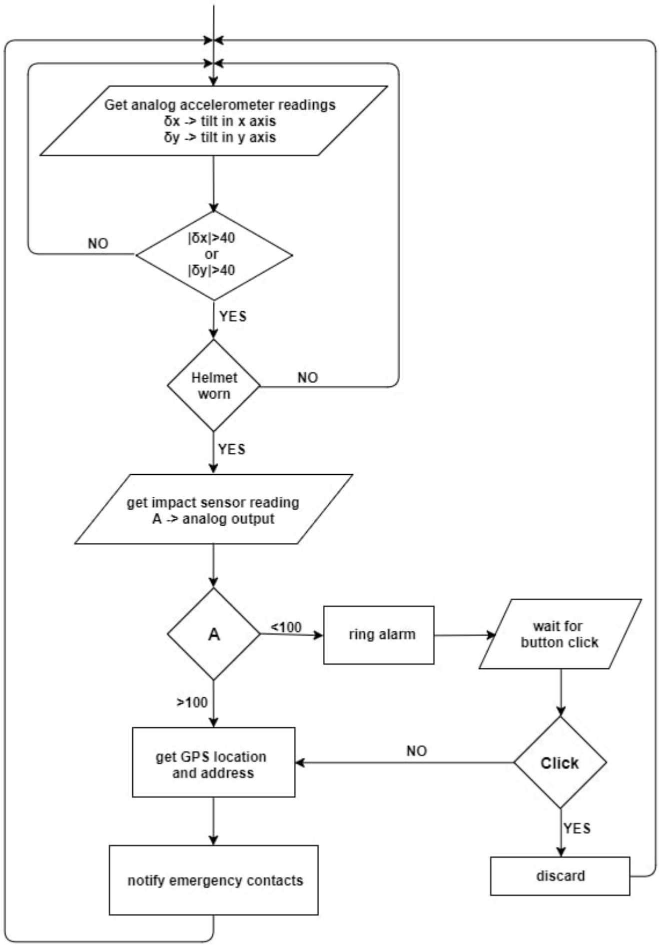
∂x - difference between current accelerometer reading and calibrated reading for X axis

∂y - difference between current accelerometer reading and calibrated reading for Y axis

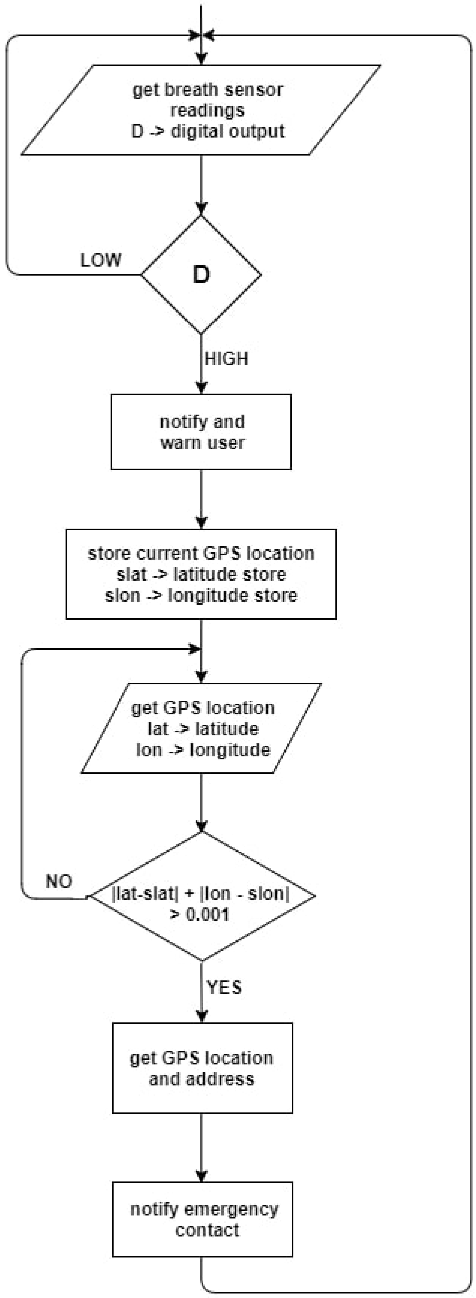
If the tilt is beyond the threshold, the situation is considered as a candidate for accident detected. The impact sensors are then checked. If the impact sensors report a sudden "impact" too, the situation is immediately reported as an accident, and all the emergency contacts are immediately informed about it, and the location of the detection.

If the impact sensors do not report any such "impact", an alarm is rung in the phone to notify the user that the device has detected a possible accident, and the user may click the provided button on the helmet, to indicate that it is a false alarm. If the user does not press the alarm in 30 seconds, it is reported as a true accident, and the emergency contacts are informed.

FLOWCHART III: ACCIDENT DETECTION



FLOWCHART IV: ALCOHOL DETECTION



Q. Alcohol Detection

The MQ3 sensor is a breath analyzer, that is fitted in the bottom of the helmet, near the mouth, concealed in the protective foam near the mouth. It can detect the alcohol content in one's breath if the user breathes on it. The sensor is fitted in such a way that the user will always breathe in it. If the alcohol content detected, causes the digital output pin of the sensor to become HIGH, the user is notified and warned to not drive the bike. If the user drives the bike anyway, the emergency contacts are informed about it, so that they may handle the situation.

The movement is detected by observing the change in GPS coordinates of the bike. Once the microprocessor is informed about the alcohol detection, it stores the current GPS coordinates. It then constantly checks the difference between the current coordinates and the stored coordinates. If the difference exceeds a threshold of 100m, we can say that the rider has been driving the bike, in spite of being warned. Thus the emergency contacts are informed, so that they may handle the situation, because of driving while intoxicated, is a major cause of accidents.

R. Proposal for Optimisation of Accident Detection

We propose an experimental mechanism to use SVM to optimize accident detection. While testing the accident detection, we noticed that the alarm was being triggered on many occasions, which might be cumbersome for riders to keep responding to while driving the motorbike. As already shown previously, if the alarm is rung, and the rider clicks the button, the device discards the detection and takes no action. If the button is not clicked, then the device assumes that it is a true accident, and takes action accordingly.

Every time the alarm is rung, and the button is clicked by the rider, we send the tilt data (∂x, ∂y) to the servers as negative data. If the rider does not click the button, the tilt data(∂x, ∂y) is sent to the server as positive data. This is how we propose to train the SVM.

For accident detection, the device follows the aforementioned mechanism. If the alarm is needed to be triggered, the tilt data is first sent to the server. The server checks which side of the hyperplane does the values lie and predicts if it is an accident or not.

We propose to train the SVM using a real-time simulation of accidents. The data set should be unique for every physical device, as the values will vary depending on physical design.

IV. Results and Discussion

A prototype has been developed using the materials mentioned earlier. It has been calibrated and then tested in several test cases. The data for the following metrics are calculated.

A. Accuracy

$$Accuracy = \frac{TP + TN}{P + N}$$

where, TP - True Positive, TN - True Negative, P - Positive instances, N - Negative instances

We consider a situation to be a true positive or negative if the detection matches the expectation. Suppose our test case was intended to be an accident, and our detection correctly detected it as an accident, it is reported as a true positive. Similarly, if our intention was not an accident, and the system does not report an accident, it is a true negative.

B. Precision

Precision is the ratio of the correct True instances, to the total number of True instances reported by the detection system.

$$Precision = \frac{TP}{TP + FP}$$

where, TP - True Positive, FP - False Positive

C. Recall

Recall is the fraction of True instances, as reported by the detection system.

$$Recall = \frac{TP}{TP + FN}$$

where, TP - True Positive, FN - False Negative

D. F1 score

F1 score is the harmonic mean between precision and recall.

$$F1\ score = \frac{2TP}{2TP + FP + FN}$$

where, TP - True Positive, FP - False Positive, FN- False Negative

Tests were performed for each of the three detection systems we propose. Each situation has been performed and observed in sets of 10, so that accurate results can be obtained. The results of the mean of the 10 sets are tabulated below.

E. Analysis of Tests for Helmet Wear Detection

TABLE II. HELMET WEAR DETECTION TEST RESULTS

Situation	Flex Sensor value	Expected Result	Reported Result
Helmet is worn	331	True	True (all 10 cases)
Helmet in hand	49	False	False (all 10 cases)
Helmet hung in bike steering	87	False	False (8 cases of 10)

The following table summarizes the values of the parameters for the above test results.

TABLE III. ANALYSIS OF HELMET WEAR DETECTION

Accuracy	Precision	Recall	F1 Score
0.933	0.833	1.0	0.9088

F. Analysis of Tests for Accident Detection

The following set of data was generated by physically driving a motirbike while wearing the helmet, and performing the situations mentioned below.

TABLE IV. ACCIDENT DETECTION TEST RESULTS

Situation	∂x	∂y	Helmet worn	Impact Sensor value	Expected Result	Reported Result
Lying on ground face up	39	-12	Yes	524	True	True (6 of 10 cases)
Lying on ground right sideways	-50	94	Yes	551	True	True (10 cases)
Lying on ground left sideways	-53	-89	Yes	546	True	True (9 of 10 cases)
Lying on ground face down	-105	-8	Yes	312	True	True (10 cases)
Look down at phone	-52	6	Yes	71	False	False (4 of 10 cases)
Look right	-35	35	Yes	26	False	False (9 of 10 cases)
Look left	-36	-38	Yes	24	False	False (7 of 10 cases)
Look up at signal	15	2	Yes	19	False	False (10 cases)
Sharply look right	-15	19	Yes	56	False	False (10 cases)
Sharply look left	-15	-12	Yes	64	False	False (10 cases)
Look backwards	-20	9	Yes	18	False	False (10 cases)
Bend neck right	-23	-73	Yes	93	False	False (1 of 10 cases)
Bend neck left	-41	55	Yes	84	False	False (3 of 10 cases)

Here, we have tabulated the reported result, as the sensor detection. The ringing of the alarm and subsequent action of the rider has not been counted.

In every case where impact sensor value < 100 the alarm is rung, and the rider clicks the button and accident are not reported. The following is the list of instances when the alarm was rung, and the button was also clicked to discard the detection.

- Look down at phone – 6 cases
- Look right – 1 case
- Look left – 3 cases
- Bend neck right – 9 cases
- Bend neck left – 7 cases

In the above cases, once the user clicks the button, the accident is reported as FALSE.

The following table summarizes the values of the parameters for the above test results.

TABLE V. ANALYSIS OF ACCIDENT DETECTION WITHOUT BUTTON RESPONSE

Accuracy	Precision	Recall	F1 Score
0.7615	0.5737	0.875	0.693

However, the alarm was rung for many cases as shown above, and the subsequent click of the button regarded the reported detection as FALSE. Thus, taking into the rider's response, the values of the parameters are:-

TABLE VI. ANALYSIS OF ACCIDENT DETECTION WITH APPROPRITE BUTTON RESPONSE

Accuracy	Precision	Recall	F1 Score
0.9615	1.0	0.875	0.933

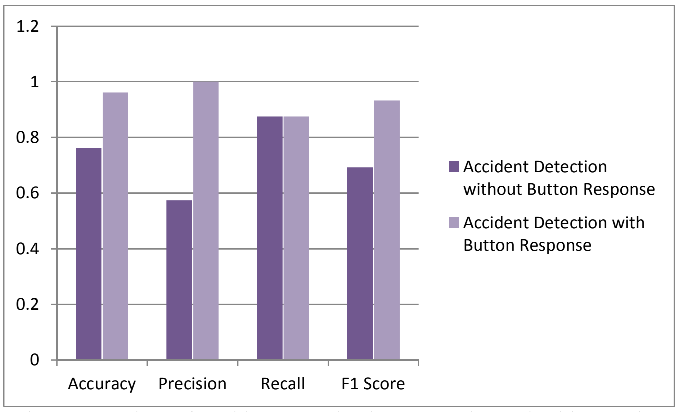


Fig 7 Comparison of Accident Detection between Using and Without Using Button Response by the Rider

The above chart to compare the parameters of analysis for accident detection, with and without the use of an alarm shows the necessity of the alarm in our mechanism.

G. Analysis of Tests for Alcohol Detection

The following set of data was generated by consuming commonly consumed alcohol and then putting the helmet on. The results are tabulated below.

TABLE VII. ALCOHOL DETECTION TEST RESULTS

Alcohol	Volume Consumed	Expected Result	Reported Result
Regular Beer (4.2% alcohol)	330ml	False	False (10 cases)
Regular Beer	660ml	False	False (7 of 10 cases)
Regular Beer	990 ml	True	True (9 of 10 cases)
Regular Whisky/ Vodka / Rum (40% alcohol)	60ml	False	False (30 cases)
Regular Whisky / Vodka / Rum	90 ml	False	False (27 of 30 cases)
Regular Whisky / Vodka / Rum	120 ml	True	True (26 of 30 cases)
Wine (12.5% alcohol)	150 ml	False	False (10 cases)
Wine	300 ml	False	False (6 of 10 cases)
Wine	450 ml	True	True (10 cases)

The following table summarizes the values of the parameters for the above test results.

TABLE VIII. ANALYSIS OF ALCOHOL DETECTION

Accuracy	Precision	Recall	F1 Score
0.9	0.8181	0.9	0.857

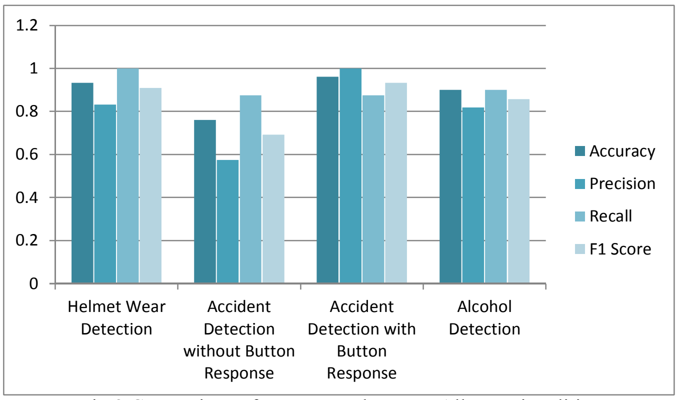


Fig 8 Comparison of Parameters between All Functionalities

V. CONCLUSION

The prototype developed yielded satisfactory results. The accuracy and precision are high, which shows that our proposed mechanism is accurate in detecting an accident and high alcohol consumption.

However, during accident detection, there have been many cases, where the alarm has been rung. The comparison of the parameters for accident detection, with and without the use of the alarm, shows how important the use of an alarm is, to report false accident detection. However, repeated unwanted need to respond to the alarm while driving can cause discomfort and distraction. Therefore, this is not safe either. Thus, we are currently trying to use Support Vector Machines to predict if the values of the sensors correspond to an accident or not, by training the device using real-time simulation, as mentioned earlier.

REFERENCES

[1] Saha, Himadri Nath, Abhilasha Mandal, and Abhirup Sinha. "Recent trends in the Internet of Things." Computing and Communication Workshop and Conference (CCWC), 2017 IEEE 7th Annual. IEEE, 2017.

[2] Wilhelm Von Rosenberg, Theerasak Chanwimalueang, Valentin Goverdovsky, David Looney, David Sharp, Danilo P. Mandic, Smart Helmet: Wearable Multichannel ECG and EEG, IEEE Journal of Translational Engineering in Health and Medicine (Volume: 4)

[3] Sreenithy Chandran ; Sneha Chandrasekar ; N Edna Elizabeth, Konnect: An Internet of Things(IoT) based smart helmet for accident detection and notification, India Conference (INDICON), 2016 IEEE Annual

[4] C. J. Behr; A. Kumar; G. P. Hancke , A smart helmet for air quality and hazardous event detection for the mining industry, 2016 IEEE International Conference on Industrial Technology (ICIT)

[5] Sudhir Rao Rupanagudi ; Sumukha Bharadwaj ; Varsha G. Bhat ; S. Eshwari ; S.Shreyas; B. S. Aparna ; Anirudh Venkatesan, Amrit Shandilya, Vikram Subrahmanya, Fathima Jabeen A novel video processing based smart helmet for rear vehicle intimation & collision avoidance, 2015 International Conference on Computing and Network Communications (CoCoNet)

[6] A. Ajay ; G. Vishnu ; V. Kishoreswaminathan ; V. Vishwanth ; K. Srinivasan ; S. Jeevanantham, Accidental identification and navigation system in helmet, 2017 International Conference on Nextgen Electronic Technologies: Silicon to Software (ICNETS2)

[7] Mohd Khairul Afiq Mohd Rasli ; Nina Korlina Madzhi ; Juliana Johari, Smart helmet with sensors for accident prevention, 2013 International Conference on Electrical, Electronics and System Engineering (ICEESE)

[8] Muthiah M ; Aswin Natesh V ; Sathiendran R K, Smart helmets for automatic control of headlamps, International Conference on Smart Sensors and Systems (IC-SSS)