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IOT-Based Smart Helmet with Accident Identification and Logistics Monitoring for Delivery Riders †

Alyssa Dainelle T. Alcantara, Ramon Balancer H. Balbuena III, Venlester B. Catapang, John Patrick M. Catchillar, Rick Edmond P. De Leon, Steven Niño A. Sanone, Charles G. Juarizo, Carlos C. Sison and Eufemia A. Garcia

Department of Electronics Engineering, Pamantasan ng Lungsod ng Maynila, Manila, Philippines; email1@email.com (A.D.T.A.); email2@email.com (R.B.H.B.III); email3@email.com (V.B.C.); email4@email.com (J.P.M.C.); email5@email.com (R.E.P.D.L.); email6@email.com (S.N.A.S.); email7@email.com (C.G.J.); email8@email.com (C.C.S.); email9@email.com (E.A.G.)

* Correspondence:

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Abstract: The study developed a smart helmet prototype that prioritizes delivery rider safety and facilitates logistical communication for small businesses. It is achieved with the smart helmet, utilizing IoT equipped with crash detection and logistics monitoring functions. Various sensors such as accelerometer and alcohol sensors are calibrated to improve accuracy and minimize errors. A mobile application was introduced to coordinate delivery logistics and track the location of drivers. The system returned 90% accuracy in distinguishing from real accidents, and it also had drunk driver detection with an accuracy of 88%. An ATTM336H GPS module was used for geolocation tracking, and a mobile application built with Bubble.io and Firebase was integrated into the helmet to send alerts the shop owners of Roger's Top Silog House who provided delivery drivers as participants for the study, which gave us positive feedback indicating that Smart Helmet performed very well and exceeded expectations.

Keywords: Bubble.io; Crash Detection; Firebase; Internet of Things; Logistics Monitoring; Smart Helmet

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1. Introduction

The use of commercial transportation such as motorcycles has been increasing; with their purpose of collecting, transporting, and delivering documents, parcels, and packages from various sectors (i.e., mail, food, and carrier) – this has become a main driver to augment the necessities in the delivery industry [1]. However, motorcyclists are associated mostly with injuries and fatalities. These involve behavioral conditions, such as substance abuse, helmet-wearing, violations [2], and even road environmental conditions [1]. According to a 2018 WHO Philippines report, 53% of the 11,264 road accident deaths were attributed to two-wheeled and three-wheeled riders and passengers, with 90% of them not wearing helmets. As of December 2020, there were 7,328,116 registered motorcycles, including 1,949,589 new units [3]. In 2018 alone, an average of 86 daily cases of motorcycle-related road crashes were recorded based on the annual report released by the MMARAS (Metro Manila Accident Recording and Analysis System) [4]. In 2021, there were 14,870 persons injured in motorcycle-related crashes, for an average of 41 individuals per day [5]. In 2022, accidents involving motorcycles alone consisted of 22.59% of total road accidents in metro manila, 31,124 of which were motorcycles accident count, 17,089 of those resulted to injuries, and 313 resulted into fatalities [6]. Even if road accidents are inevitable, humans involved in life-or-death situations rely heavily on the speed of emergency response. The study will design a smart helmet prototype that values the safety of the delivery rider and provides logistical information between the delivery rider and the management. By using IOT-based solutions, the objectives of the study consist of the following: (1) Design an IOT smart helmet accident detection system that gathers data from the accelerometer (2) Design a Breath Analyzer using MQ3 testing for the rider's drunkenness during the smart helmet's operation; (3) To create a mobile application which notifies management of the delivery history and GPS location status; (4) To assess smart helmet's operation quality upon usage by the delivery rider. The study only focuses on using a smart helmet with an embedded IoT system and Wi-Fi communication protocol. It enables data transmission through Firebase IoT cloud server for the backend and utilizes Bubble.io for the frontend. This system notifies management about delivery riders, including crash detection and logistics information.

2. Methodology

This section contains the overall view of the system's block diagram as a prototype of an IoT-based smart helmet with all of the relevant sensors, system design, as well as the processes behind its operation together with its circuit connection and implementation.

2.1. System Design

The smart helmet incorporates various sensors such as accelerometer, vibration, alcohol and pressure resistive sensors, and GPS for point-to-point logistics tracking. The data collected by these sensors is transmitted to the ESP32C3 microcontroller, which then relays it to Firebase as the backend database. This information is reflected in the Bubble.io mobile application for end-users, including the Administration (Admins) who can monitor delivery manpower and potential accidents, delivery riders who use the app to accept deliveries and locate destinations, and customers who can track their deliveries.

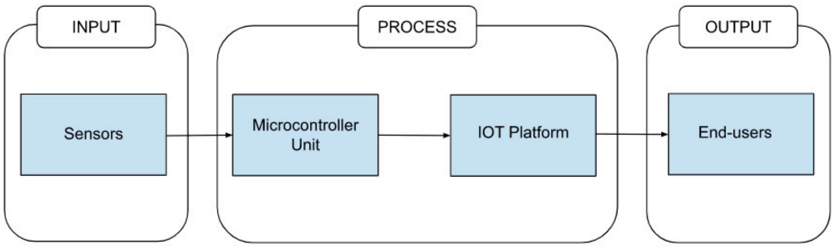

Figure 1. General Block Diagram of the System.

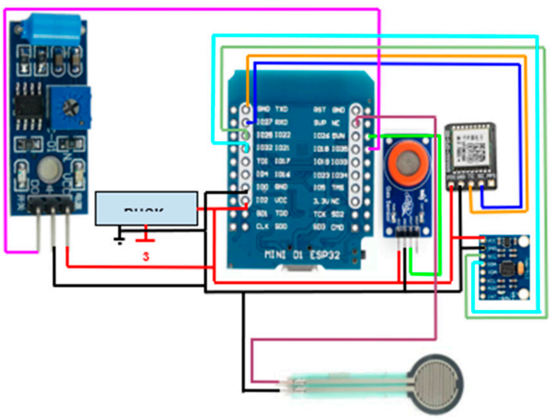

Figure 2. Circuit Diagram of the Embedded System.

2.2. System Architecture

This includes calibration of the two (2) main sensory component systems for the creation of the smart helmet, Crash & Alcohol Detection System and GPS System. The primary data that will be determined here will be sent to Firebase before it reflects any of those data onto the application. Figure 3 displays the flow of information of the accelerometer, vibration, and alcohol sensor. All data is sent to the MCU to be stored in Firebase. This data is interpreted and is displayed unto the mobile application interface.

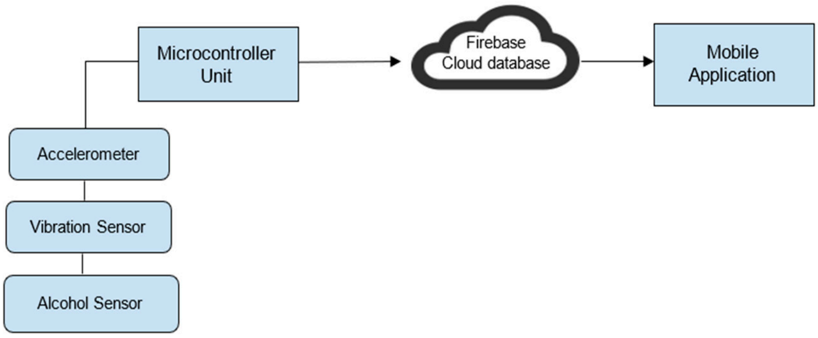

Figure 3. Crash Detection System.

Figure 4 shows the communication of the GPS module to the MCU. Data is sent to Firebase to undergo external API map routing in order to properly display on the mobile app, which will reflect as shown on Figure 5 below.

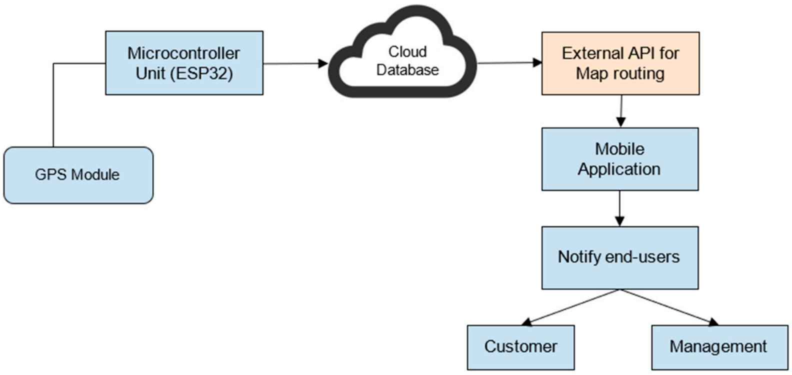

Figure 4. GPS Design.

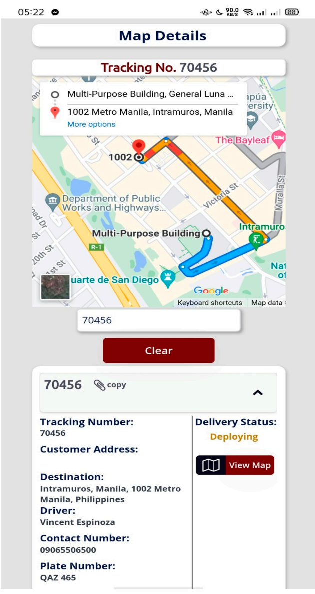

Figure 5. Mobile Application for Notification System.

2.3. Testing Procedure

The steps taken for the implementation of the smart helmet are as follows: The admin and delivery rider (1) create an account and connects the smart helmet via pocket Wi-Fi. (2) delivery rider wears the helmet to begin calibration of the accelerometer, vibration and alcohol sensors for initialization. (3) After approximately 2 min of warm-up time for GPS, the admin can start placing orders for the delivery rider to accept. (4) After order is accepted for delivery, the alcohol sensor samples their breath. If determined to be sober, they can proceed with delivery. If not, notify the admin that the delivery rider is drunk. (5) The smart helmet continuously sends all sensor data for potential accidents/crashes, intoxication detection, as well as track the location of the delivery using GPS. (6) Once the delivery is confirmed to be successful through the mobile app, the sensors would still run in the background to check for accidents, intoxication, and location of the delivery rider, ready to notify the admin of their logistics.

1. Accelerometer Threshold

   An accident is determined by the smart helmet whenever the accelerometer responds with x, y, and z values that go over the threshold of 12G or roughly 117.6 m/s^2 [7]. It then counterchecks with the vibration sensor's output, determining whether the rider has been involved in an accident or not as shown on Equation (1).

$$|a| = \sqrt{(ax^2 + ay^2 + az^2)} \tag{1}$$

   where $|a|$ is the magnitude of linear acceleration; a = acceleration

2. Confusion or Error Matrix

   To examine the reliability of the accelerometer and vibration sensor in accident detection, the accuracy shown in Equation (2), precision, as the true instances of true positives shown in Equation (3), Recall, as the True Positive Rate on Equation (4), and F1 score, as the harmonic mean between Precision and Recall on Equation (5) in terms of the Error Matrix of the results recorded from ten trials.

$$\text{Accuracy} = (TP + TN)/(TP + TN + FP + FN) \tag{2}$$

$$\text{Precision} = TP/(TP + FP) \tag{3}$$

$$\text{Recall} = TP/(TP + FN) \tag{4}$$

$$\text{F1 Score} = 2TP/(2TP + FP + FN) \tag{5}$$

   where TP = true positive results FP = false positive results TN = true negative results FN = false negative results

3. Calibration of MQ3 Sensor

   To calibrate the MQ3 Sensor as a breath analyzer, we extract the analog values from the sensor with a range of 0 to 4095 (with a resolution of 12 for the ESP32C3). R2 is taken from the physical resistor on the sensor, Ro (resistance of the sensor at normal conditions) is taken from the MQ3 datasheet, and Rs (output resistance of the sensor to alcohol) to be then used to acquire the Blood Alcohol Content (BAC), computed using Equation (6). This value should be less than 0.05% to qualify as "sober".

$$BAC = ab^{(\text{ratio})} \tag{6}$$

   where a is the BAC-intercept; b = slope

4. Root Mean Square Error

In order to assess the accuracy, the researchers compare the proposed system (smart helmet) over the conventional system (smartphone) and compute the difference between the resulting two values using Equation (7).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Conventional_i - Proposed_i)^2}{n}} \quad (7)$$

5. Time Delay, Likert Scale, and Standard Deviation
The time delay from the entirety of the data communication of the proposed system – from the Embedded IoT Device up until the data is reflected upon the Mobile Application is calculated using Equation (8). The questions will be subdivided into three categories: (1) reliability, (2) usability, and (3) functionality, wherein responses will be following a scale of 1 to 5, with 1 = strongly disagree & 5 = strongly agree, to undergo Likert Scale evaluation. The standard deviation can be used to provide additional information about the variability or consistency of the data shown on Equation (9).

$$\text{Mean time delay} = \text{sum of trials/number of trials} \quad (8)$$

$$\sigma = \sqrt{\frac{\Sigma(xi - \mu)^2}{n-1}} \quad (9)$$

where x_i is the individual values from sample; μ = sample mean; n = sample size.

3. Results and Discussions

This section is divided to present the results for each objective of the testing and implementation of the prototype's system to identify accidents and logistics monitoring.

3.1. Design of an IOT Smart Helmet Accident Detection System That Gathers Data from the Accelerometer

In Table 1, the crash detection was tested using the accelerometer and vibration sensor that determined whether the impact is a crash or not attained with 10 trials for a situation with an expected result then comparing it with the obtained result whether the smart helmet succeeded in detecting an accident.

Table 1. Crash Detection from Accelerometer & Vibration Sensor Data.

No. of Trials	Situation of Test	Expected Output	Obtained Output	Interpretation
Trial 1	Helmet dropped 2 m above ground	T	T	Success (TP)
Trial 2	Helmet dropped 2 m above ground	T	T	Success (TP)
Trial 3	Helmet dropped 2 m above ground	T	T	Success (TP)
Trial 4	Helmet placed on the ground	F	F	Success (TP)
Trial 5	Helmet dropped 2 m above ground	T	T	Success (TP)
Trial 6	Helmet placed on the ground	F	T	Failed (FP)
Trial 7	Helmet dropped 2 m above ground	T	T	Success (TP)
Trial 8	Helmet dropped 2 m above ground	T	T	Success (TP)
Trial 9	Helmet placed on the ground	F	F	Success (TP)
Trial 10	Helmet dropped 2 m above ground	T	T	Success (TP)

In Table 2, the accuracy of the system in detecting the situation as a crash yielded 90% while having a precision of 87.5%, a recall of 100%, and an F1 Score of 93.3% from drop testing the smart helmet over 10 trials.

Table 2. Analysis of Crash Detection Data.

Accuracy	Precision	Recall	F1 Score

0.90	0.875	1.0	0.933

3.2. Design of a Breath Analyzer Using MQ3 testing for the Rider's Drunkenness during the Smart Helmet's Operation

In Table 3, the accuracy of the MQ3 sensor to act as a breath analyzer had an accuracy of 89.09% while having a precision of 87.87%, a recall of 96.03%, and an F1 Score of 91.78% from testing with different concentrations of alcohol readily available in the market.

Table 3. Analysis of Alcohol Detection.

Accuracy	Precision	Recall	F1 Score
0.890909	0.878787	0.960264	0.917721

3.3. GPS Location and Status of the Delivery

In Table 4, The lower the RMSE value is, the better fit it is. Based on the calculations, the RMSE of the latitude equates to 0.000051274. Meanwhile, the longitude is 0.00017925, implying that the Smart Helmet is on par with GPS from smartphones.

Table 4. Comparison of Longitude and Latitude Between GPS.

	GPS from Smart Helmet		GPS from Smartphone	
No. of Trials	**Longitude$_1$**	**Latitude$_1$**	**Longitude$_2$**	**Latitude$_2$**
Trial 1	121.1922234	14.4668264	121.191716	14.4668255
Trial 2	121.1898427	14.4656059	121.1896703	14.4656555
Trial 3	121.1923470	14.4655427	121.1923521	14.4655419
Trial 4	121.1925436	14.4661518	121.1925606	14.4661125
Trial 5	121.1922318	14.465562	121.1922424	14.4655219
Trial 6	121.1936799	14.4655621	121.1936354	14.4655812
Trial 7	121.1908917	14.4654065	121.1908906	14.4653565
Trial 8	121.191133	14.4650616	121.1910309	14.4650906
Trial 9	121.19221	14.4645827	121.1923497	14.4645032
Trial 10	121.193271	14.4641768	121.1932287	14.4640736
RMSE = 0.000051274 (*Latitude*); 0.00017925 (*Longitude*)				

(**a**) (**b**) (**c**)

Figure 6. Field Implementation of the Helmet; (**a**) rider receiving order; (**b**) rider equipping smart helmet; (**c**) rider confirming delivery.

In Table 5, the Mean Time Delay from 10 trials is 2.37 s, considered as real-time.

Table 5. Time Delay from the Helmet to Application.

No. of Trials	Data from Helmet to Application (s)	Mean Time Delay (s)
Trial 1	3.764	2.37480108
Trial 2	1.449	
Trial 3	1.66	
Trial 4	2.024	
Trial 5	3.915	
Trial 6	1.256	
Trial 7	2.185	
Trial 8	6.657	
Trial 9	3.059	
Trial 10	1.423	

3.4. Assess the Smart Helmet's Operation Quality upon Usage by the Delivery Rider

In Table 6, the actual mean and S.D. for reliability of the smart helmet and mobile application is 4.24 and 0.469. The actual mean and S.D. for usability of the smart helmet and mobile application is 4.12 and 0.561. The actual mean and S.D. for functionality of the smart helmet and mobile application is 4.36 and 0.570. The smart helmet and mobile application performed greatly for the 3 categories.

Table 6. Weighted Mean of Responses from 5-point Likert Scale.

Category	Questions	Responses	Actual Mean	Standard Deviation	Interpretation
Reliability	5	5	4.24	0.469	Great
Usability	5	5	4.12	0.561	Great
Functionality	5	5	4.36	0.570	Great

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