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The Prototype of Smart Helmet with Safety Riding Notification for Motorcycle Rider

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Abstract— **Motorcycle is the highest contributor of a traffic accident in Indonesia which 83% of it caused by human factors. These human factors include traffic signs violation and riding above the speed limit. Besides that, road condition also affects traffic accident, such as a pothole, speed bump and lack of traffic signs. In the case of a fatality, the highest proportion of fatalities is 22.4% of the total 145,478 victims occurred in 2011. Head injury is the main factor of casualties by 70%. Based on these statistics, the role of a helmet as a head protector must be worn by motorcycle riders and make sure the strap perfectly locked. To overcome this problem, this study introduces a smart helmet system to warn the rider when they meet dangerous factors that risk causing traffic accident. These factors are when the rider has not worn the helmet and lock the strap and speeding above the speed limit. Other than that, this study offers a new feature to warn the rider when passing through the obstacle such as potholes or speed bump at unsafe speed. This feature is offered because of the bad road condition in Indonesia contributes to traffic accidents. From the test's results, the smart helmet system in this study has an average response time of 1.4 seconds in the helmet use and strap lock detection system and 0.3 seconds in speed and shock detection system. In addition, the average difference of speed calculation between smart helmets and GPS is 3.3 km/hour.**

Keywords—smart helmet, motorcycle accident, notification.

I. Introduction

According to the study [1], there are three factors that contribute to the traffic accident such as, agent (human factor), host (vehicle condition) and environment (road and weather condition). If the rider is in good health and both vehicle and environment are in perfect condition, traffic accident should not occur.

Based on the data from 2010 until 2014 the highest traffic accident of 117,949 cases occur in 2012. Then, 22.4% fatalities from 145,478 victims occur in 2011 which 75.4% of it caused by head injuries. Furthermore, based on the type of vehicle, motorcycles always occupy the first position with 70%. In 2013, human factors accounted for 83% of the total accidents where the drivers were not obeying the traffic signs (46%) followed by driver negligence (32%) and speeding above the speed limit (14%). Still, in the same year, the highest road factors caused the accidents were damaged and perforated roads (26%) followed by lack of traffic signs (21%) [1].

According to the study [2], if the rider wearing the helmet correctly (the strap perfectly locked) can reduce the probability the rider will get injured when encountering an accident by 25%. In addition, if the driver also wears a safety jacket, the probability will be reduced further to 50%.

Based on the data above, the number of traffic accident cases in Indonesia each year is quite high with a fatality rate up to 22.4 percent. From year to year, there was a slight decrease in traffic accident cases, but the percentage of fatality actually increased.

Human error is the main factor causing accidents such as violate traffic signs and speeding above the speed limit. These factors are reasonable because speeding could reduce the driver's response time to avoid unexpected obstacles. In addition, judging from the high percentage of deaths where head injury as the main cause and the reduction in injury probability by 25% can be concluded the importance of the rider to wear the helmet correctly. When an accident occurs, especially at high speed, a helmet strap that did not lock properly could be released before the head hit the road. It will have a fatal impact like a rider who did not wear a helmet at all.

In addition to potholes and speed bump that doesn't meet the standard could also cause the accidents. Pothole and speed bump will affect the stability of the motorcycle if the rider passthrough with an unsafe speed.

Compared to road factors, it is clear that human factors are relatively easier to control. By giving warnings to the rider to be careful when encountering dangerous factors that could cause accidents. Therefore, we need a system that can remind the rider when doesn't wear the helmet properly and when speeding above the speed limit. Also, in the case of damaged roads, another approach is needed besides to repair the road. The solution is to remind the rider if pass through a damaged road with unsafe speed, so they could reduce the speed and keep the stability of the motorcycle.

II. Related Works

In this study, a comparison of 10 studies is done. In 9 studies which are [3]-[11], the intervention features of the ignition system are offered so that the motorcycle cannot be ignited when the driver does not wear the helmet. However, only [11] which offer a feature to detect the helmet strap locking mechanism. In addition, study [6] and [9] offers additional features to detect the rider under the influence of alcohol. In study [7], there is an additional feature which can detect the biker who falls over then send a notification via SMS (Short Message Service).

On the other hand, study [5] propose an anti-theft system that prevents the ignition system with a fingerprint scanner and GPS coordinate to track the location of the motorcycle. And then, study [8] propose a blind spot monitoring system which provides a shock on the both of motorcycle handlebars when there is another vehicle moving closer to the motorcycle from the left or right side.

Based on the feature from the literature mentioned above, there are several features which can be adapted for designing smart helmet system that can be seen in Table I.

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TABLE I. THE SMART HELMET FEATURE.

Feature	The Level of Interest
Detecting the helmet usage	Mandatory
Determining the motorcycle speed	Mandatory
Detecting the locked buckle	Mandatory
Recognizing the rider which is drunk	Optional
Locking/Unlocking the engine started by using the rider fingerprint	Optional
Detecting the motorcycle theft	Optional
Marking the falling rider	Optional
Sending the SMS notification	Optional
Monitoring the blind spot area	Optional
Moving the headlamp adaptively	Optional

Fingerprint ignition system and theft detection are not used in this study because the focus of this study is the safety of riders. Then the detection of drunk riders also not applied in this study because according to [1] in human factors, alcohol only contributed 6 percent in traffic accidents. In addition, the motorcycle ignition system feature is also not applied in this study because of the consideration of the need for modification of the electrical motorbike that risks burning the warranty.

Furthermore, safety features such as blind spot monitoring system and adaptive headlamp which are commonly found on the car are interesting to be applied to smart helmets. Blind spot monitoring system will detect vehicles approaching behind so will help the rider when changing the line. Even so, this feature could be ignored because the size of a motorcycle is much smaller than a car, so the blind spot is narrower. Furthermore, the adaptive headlamp feature is also considered to be less effective because a static direct light is more than enough for the motorcycle that smaller than a car.

Based on Table I, there are some aspects considered in this study. First, the smart helmet must have the capability to detect the presence of the rider's head when it is worn or not. It also must be able to detect the buckle locking mechanism. Another feature is the smart helmet must have the capability to detect when the rider speeding above the speed limit. Admittedly, a new feature is introduced in this study. It is a feature to detect the shock when the motorcycle passes through the obstacle such as a pothole and speed bump. If one of the above factors occur, then a notification is sent to warn the rider to be more careful when riding the motorcycle.

A. *Traffic Accident*

The traffic accident is a collision event that involves a vehicle with another vehicle or object. The results of this collision are vehicle damage, human injury, and fatality. There are three factors that could lead to a traffic accident [12]:

- Human factor — this is the main contributor to traffic accidents. For example, careless, drunk, tired, unskilled, undisciplined and over speeding.
- Vehicle condition — this factor is related to the vehicle that is not maintained well. Several malfunctions such as a brake failure, flat tire, and broken lights could lead to a fatal accident.
- Environment — this factor is related to the road condition and weather condition. For example, potholes, damaged road, slippery road, lack of road lighting, and heavy rain.

B. *Helmet*

A helmet is a safety tool which can be used to protect the head and is usually made of metal or other materials such as a carbon kevlar, fiberglass, or plastic. The helmet is usually used for outdoor activities such as sports, mining and exploration, infrastructure project, and driving. The helmet could protect the head from collision with another object.

Several countries obligate the rider and the passenger to wear a helmet including in Indonesia. Besides that, obligation, there is necessary to wear a standardized helmet that meets regulation and has been assessed properly. Actually, there are several helmet standards such as SNI, DOT, and SNELL which are considered proven to be used in Indonesia.

Based on the helmet design there are two types of helmet, half face, and full face. The half face helmet does not protect the jaw. Contrastingly, the full-face helmet more protective includes protecting the jaw. However, for daily usage in the city, the half face helmet is more comfortable because it is lighter and is cooler than the full-face helmet.

III. PROPOSED SYSTEM

A. *Proposed System Summary*

This followed figure is the summary of the proposed smart helmet system.

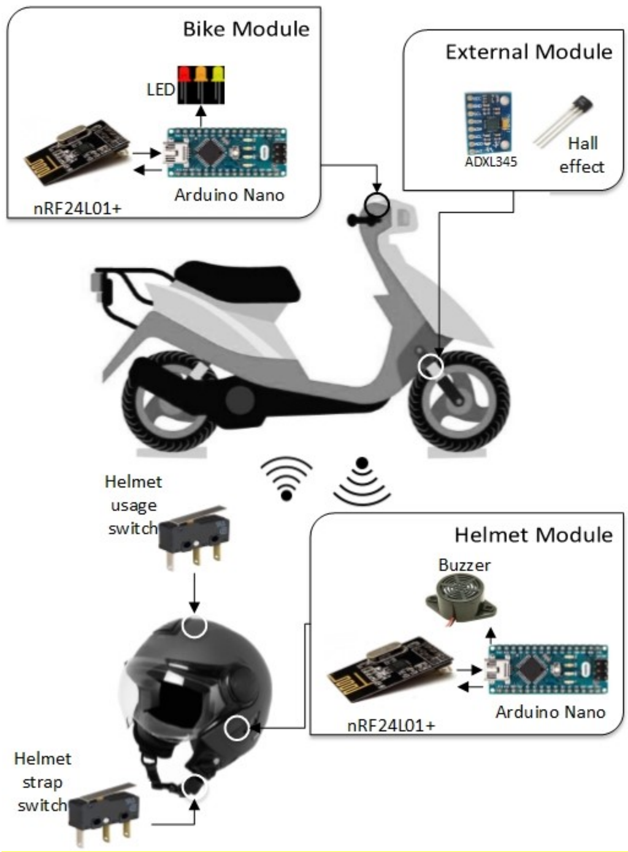

Fig. 1. The proposed system scheme.

As described in Figure 1, this smart helmet system is divided into two modules which both of the modules are mounted on the side of the helmet and mounted on the motorcycle dashboard. Each module is controlled by the Arduino and the communication between the module use nRF24L01+.

B. Hardware Requirement

The specification of the hardware used is listed in Table II below.

TABLE II. THE SPECIFICATION OF THE SMART HELMET DESIGN.

Component & Specification	Functionality
Arduino Nano • Microcontroller: ATmega328 • Operating voltage: 5V • Input voltage: 7V ~ 12V • Flash memory: 32KB, 2KB used by bootloader • Clock speed: 16Mhz	This device is used as a control center and processes the data that is sent by the sensor and then send the output to the output device.
ADXL345 GY-291 • Input voltage: 2V ~ 3,6V • Tap/double tap detection • Freefall detection • SPI or I2C communication interface • 3-axis • Measurement up to 16g ($\pm 17 m/s^2$) • Accuracy up to 13-bit	This device is used to sense a shock when the motorcycle passes through the obstacle. This sensor is chosen because of its size and it has a good accuracy and wide range measurement.
nRF24L01+ • Input voltage: 3,3V ~ 7V • On-board ceramic 2.4GHz Antenna • 250Kbps to 2Mbps bandwidth • Auto Acknowledge • Auto Re-Transmit • Buffer - 6 Data Pipes • 32 Byte separate TX and RX FIFOs • 5V tolerant input pins • Software selectable channel from 2400MHz to 2525MHz (125 Selectable channels) • The communication via I2C	This device is used for communication between the helmet module and the bike module. nRF24L01+ is chosen because it's very low power consumption so does not overload the Arduino. In addition, the nRF24L01+ also extend the battery life which is very useful for a smart helmet that has a limited power source.
Switch	This device is made from zinc plate which is used to detect the helmet strap locking system and detect the helmet usage.
Helmet	As a smart helmet base.
Magnet	The magnet is attached on the side of the front wheel so the hall effect sensor can detect it.
Hall effect A3144 • Maximum operating temperature up to 150 °C • Input voltage: 4.5V ~ 24V • Current: 4.4mA ~ 9mA • Reverse battery protection • Solid-state reliability • Digital output • Non-latching	This device is used to calculate the motorcycle speed. This device can detect the presence of the magnet which is attached to the front wheel. So, the wheel rotation can be calculated into linear velocity (km/hour).
Buzzer • Input voltage: 5V • Active (internal oscillator)	This device is placed on the helmet module to give a warning sound notification to the rider.
LED • Input voltage: 3V ~ 5V • Operating voltage: 1.8V ~ 3.3V	This device is placed on the bike module to give a warning light notification to the rider.

C. Software Requirement

This smart helmet system use hardware that requires specific software to use that hardware which is shown on the followed lists:

- Arduino IDE — is a platform which is used to program the Arduino. This IDE has a text editor, compiler, and flasher to upload the program to the Arduino board. This IDE also has a serial monitor to help debug the program.
- Sparkfun ADXL345 library — this library is used to read raw acceleration value from ADXL345. In addition, this library also has a capability to configure some parameters of the ADXL345 such as measurement range, interrupts etc.
- TMRh20 NRF24L01+ library — this library is used to send and to receive messages and to configure the nRF24L01+. Parameters which can be configured such as bandwidth, radio power rate, timeout etc.

The explanation of the smart helmet system process flow is described in the followed list below:

1. The initialization connection between the helmet module and the bike module is started. If the connection is failed, then the reconnection process will be started. If the connection is success, then the light will light up constant but if failed the light will blink.
2. The helmet module sends a helmet usage status and helmet strap lock status to the bike module. The buzzer and the helmet light notification will light up when one of the status condition is not fulfilled.
3. The speed of the motorcycle is calculated by converting the wheel rotation into linear speed. If the speed is above the speed limit, then the speed light notification and the buzzer will light up.
4. The shock detection is done when the motorcycle passes through the road obstacle. If the shock above the safe shock limit, then the shocking indicator light will light up.

D. Testing Scenario

In this study, the assessment of the helmet functionality feature is performed to ensure the system that is designed will work as expected according to the functions that specified before. In addition, accuracy and performance testing also required to know how the capability and reliability of the system. There are three testing scenarios which are going to be conducted such as functionality testing, accuracy testing, and performance testing.

1) Functionality Testing Scenario

The smart helmet designed in this study has four main functionalities which detect the helmet usage, helmet strap locking system, motorcycle speed, and shock when ride passes through the obstacle like pothole and speed bump.

- Helmet usage detection testing — to ensure the system can detect the presence of the rider head when the helmet is worn or removed. This testing is going to be done 30 times.
- Helmet strap locking detection testing — to ensure the system can detect when the helmet strap is locked or unlocked. This testing is going to be done 30 times.
- Hall effect sensor testing — to ensure the system can detect the wheel rotation by reading the presence of the magnet that attached on the side of the front wheel. 30 times forward and backward are done for the testing.
- ADXL345 accelerometer testing — to ensure the system can detect the shock of the motorcycle when it passes through the obstacle. It is going to be done 30 times.

- Communication testing of nRF24L01+ — to ensure both the helmet module and the motorcycle module well connected. The testing is done by sending two-way messages that each module will act both as a sender and a receiver. The testing is going to be done 30 times as a sender and receiver.

2) Accuracy Testing Scenario

To find out how well the accuracy of the system then the testing is performed on the devices and sensors which are used by this smart helmet.

- Speed detection accuracy — is executed to test the accuracy of the speed detection system by comparing it with GPS speed reading. GPS is considered because it can be recorded into a log file so that it will be easier to compare it with the speed from the smart helmet.
- Shock detection accuracy — is done to get the maximum acceleration threshold which is considered safe. It is going to be tested by passing through the motorcycle over the obstacle (speed bump) at a different speed. The testing is done from 5 km/h until 40 km/h in accordance with the speed limit in the residential area that written in Indonesia Ministerial Regulation of Transportation No.111 of 2015.

3) Performance Testing Scenario

This testing scenario is conducted to see the performance of the system in the actual environment. This performance parameter is the response time of the system. The response time is calculated on four smart helmet functions which are the helmet usage, helmet strap locking system, speed detection, and shock detection. Time calculation is started when the event happens until the notification in both modules appears.

IV. Analysis and Discussion

A. Helmet Module Implementation

The followed figure is the smart helmet prototype.

Fig. 2. The prototype of the smart helmet module.

Based on Figure 2, the helmet module is attached to the left side of the helmet, so it will not disturb the rider. This helmet module is powered by a 3.7-volt Li-ion battery with 800 mAh capacity in line with battery charger and DC step-up module. The step-up module is required because Arduino Nano only needs minimum input voltage (5 volts).

Fig. 3. The helmet strap buckle switch.

Based on Figure 3, to detect the locking mechanism of the helmet strap, the switch is used by attaching the zinc plate on both sides of the buckle hole. If the buckle head which is made from the conductor is inserted into this hole, then it will connect these two zinc plates.

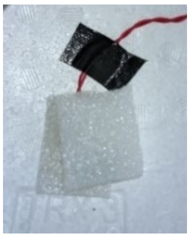

Fig. 4. The helmet usage switch.

Based on Figure 4, to detect rider head, the switch is used by attaching the zinc plate which is flanked by the foam. When the foam is pressed by the rider head, this zinc terminal is going to be connected. The foam is used because it is more comfortable and it can minimize the probability of the zinc plate hurt the rider.

This helmet module prototype is quite easy to mass produce because it's plug and play design. To mass produce, this module first thing to do is build custom PCB and case so the module will be much smaller. The next step is to build and redesign custom buckle and helmet usage (pressure switch) so it will be easier to attach it. The final product could be a smart helmet or a kit that turn an ordinary helmet to smart helmet.

B. Bike Module Implementation

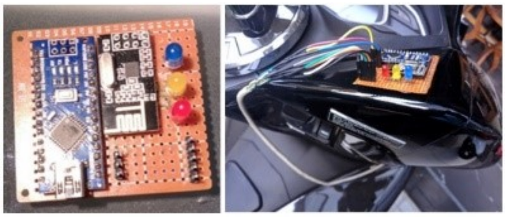

Fig. 5. The prototype of the bike module.

Based on Figure 5, this bike module equipped with three LED for warning light notification and eight external pins to connect with ADXL345 and hall effect sensor. The power source comes from the external power bank that connected to the mini USB port in the Arduino.

Fig. 6. The external bike module.

The ADXL345 accelerometer is used to measure the shock and the hall effect sensor is used to measure the speed. Based on Figure 6, both devices have to be placed on the front fork as closest as possible to the front wheel. These separate modules connected with a modified RJ45 cable. In order the hall effect sensor to detect the rotation of the wheel, the neodymium magnet is attached on the outer side of the front wheel.

Same as helmet module, this bike module also quite easy to mass produce. Build a custom PCB both of the bike and external module and also a holder and case so the module will be easier to attach on the motorcycle.

C. *Testing Result.*

After the prototyping is completed, the testing is conducted to ensure it works properly.

1) *Functionality Testing Result.*

This testing scenario is done by using four features of the smart helmet plus the communication between the bike module and the helmet module.

TABLE III. THE RESULT OF THE FUNCTIONALITY TESTING.

Functionality	Test	Success Rate
Helmet usage	Remove the helmet	100
	Wear the helmet	
Helmet strap lock	Remove the strap	100
	Lock the strap	
Wheel rotation (hall effect sensor)	forward	100
	backward	
Shock (ADXL345)	Shock the ADXL345	100
Communication Module	Helmet to the bike	98,3
	Bike to the helmet	

The observation focuses on the ability of the sensors to detect the event which is performed 30 times. The testing tends to be isolated without taking the consideration of the notification which is sent between the two modules. For example, if the helmet buckle is successfully detected by the helmet module but the notification does not arrive in the bike module, this event is still going to be considered as a successful event.

The communication testing is done at 30 cm between the helmet module and bike module (which is attached on the motorcycle dashboard).

Based on Table III, the 100% success rate which is resulted in the testing of four functional helmet features indicates the system be able to detect the events properly, so the possibility of false warning is very small. The communication result gets 98,3% success rate. There are several possibilities why the message cannot be sent such as:

- The receiver is not ready to receive the message because it is still in Tx (transmitter) mode.
- The receiver cannot receive the message because it is still in sleep mode or delay mode.
- There is a radio interference or a noise because of the nRF24L01+ working on 2.4 GHz frequency that quite crowded.

However, the communication failure is not too problematic because at least there is one notification that is a light notification or sound notification which comes up from one module.

2) *Accuracy Testing Result.*

The test is done in 10 minutes, so it gets 590 lines of data (1 line per second). This test is done by recording the speed from the smart helmet module by using the serial USB terminal and followed by recording the GPS data speed from the smartphone app at the same time.

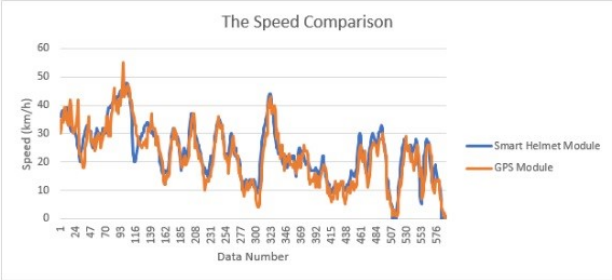

Fig. 7. The speed comparison graph.

Figure 7 shows the comparison between the smart helmet speed and the speed which is recorded by the GPS. The flow is quite similar but there are still several big deviations in several points. The average speed deviation is 3.31 km/h. These deviations can be caused by several factors:

- The GPS accuracy of the smartphone depends on the strength of the signal which is received.
- Overall radius of the wheel is changed because when the bike is loaded it is going to be a bit deflated. So, the speed conversion calculation from the wheel rotation into the linear velocity is drifted.
- Unsynchronized data logging between the smart helmet and the GPS (even in millisecond) can make different speed data reading between both modules.

Even though the accuracy of smart helmet speed is not perfect, the deviation of about 5 km/h still can be tolerated because this speed calculation functionality is just for the speed limit notification.

The next testing is the accuracy of the shocking detection. The raw acceleration value from the ADXL345 will be taken by riding the motorcycle passes through the obstacle (speed bump) in various speeds from 5 km/h until 25 km/h.

When the observation is executed, it is difficult to maintain the constant speed when the motorcycle hits the obstacle, especially at low speed. At 25 km/h, it starts to feel uncomfortable for the rider and it tends to harm the rider because the bike feels unbalance. Because of this reason, the test which is planned until 40 km/h, is forced to stop at 25 km/h.

Based on the testing, the value which is going to be used as a threshold value for shocking is around 11,000 mg because the rider feels uncomfortable and the motorcycle started to feel unbalanced. This value is going to be used as a threshold in this smart helmet system.

3) *Performance Testing Result.*

TABLE IV. THE RESULT OF SYSTEM PERFORMANCE TESTING

Test	Response Time
Wear and remove the helmet	1384 ms
Lock and unlock the helmet strap	1475 ms
Ride above the speed limit	326 ms
Ride pass through the obstacle unsafely	221 ms

Table IV describes the overall response time result of the smart helmet four functionalities. For example, the time is started when the strap is locked and then detected by the helmet module until the notification arrives at the bike module.

The average response time of the helmet strap locking detection and the helmet usage detection is 1.4 second. This response time is quite long because the 1-second tolerance is needed by the smart helmet program to prevent false warning when the helmet is shocked.

The average response time of the shock detection and speed detection is much quicker at 0.3 seconds because this detection does not need a time delay tolerance.

V. Conclusion

This study succeeded designed a smart helmet that has several features which are functioned properly. The warning notification is generated to notify the rider when meets the unsafe condition such as the rider does not wear the helmet, the helmet strap is not locked correctly and the motorcycle is over the safe speed limit. This study also introduces a new feature to warn the rider when passing through the obstacle at an unsafe speed that caused strong shocks and compromised the stability of the motorcycle.

In the functionality test, it is obtained a 100% success rate in the four smart helmet features to detect the events. 98.3% success rate in the communication test between the two modules. And then in accuracy test, it is collected that the average speed deviation at 3.3 km/h between the smart helmet module and the GPS. It is also obtained the threshold of the shock value at 11,000 mg. In the performance test, it is obtained the average response time of 1.4 seconds for the helmet usage detection and the helmet strap locking detection. This response time is 70% quicker than [10] which is 4.57 second. And then the average response time at 0.3 seconds in speed and shock detection.

VI. Future Work

Based on the test's result, there are several improvements that could be done for future works. First is redesign another method to detect helmet usage and helmet strap locking mechanism that more reliable so the response time will be much smaller. Next improvement is dynamic speed limit that changes when passing through different road that has different speed limit. The last improvement is mapping location coordinates of the obstacle so the system could give early warning to the rider when passing through that road next time.

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