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An IoT-powered smart helmet to avoid drowsiness and theft protection

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Abstract

Helmets are mandatory equipment for motorcyclists, but current helmets only serve to reduce injuries during accidents. Accidents often occur due to human error, such as drowsiness while riding which endangers the rider and others. In addition, helmets are also vulnerable to theft if they are far from the owner. This research aims to reduce these problems by adding drowsiness warning and theft detection features to the helmet. The drowsiness warning feature uses MAX30102 sensor to detect heart rate as a parameter of drowsiness condition, while the theft detection feature uses magnetic reed switch sensor as a switch with magnet as a parameter of theft. Both features are integrated with the Internet of Things (IoT). IoT is a technology that allows control, communication, and cooperation between various hardware devices via the internet network. The microcontroller used in this study is ESP32-C3, which functions as the brain of the system. Through IoT technology, drivers can monitor their heart rate in real time using the Blynk application and receive WhatsApp notifications in the event of theft. Trials showed that the drowsiness warning feature had an error rate of 3.23% in detecting microsleep, while the theft detection feature was able to send warning messages with an average time of 8 seconds.

Keywords:
Helmet;
ESP32-C3;
IoT;
Blynk;
WhatsApp;

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1. Introduction

Currently, the most common means of transportation on the roads of developing countries is motorcycles. Motorcycles are the vehicle of choice for the majority of people, especially in Indonesia. Apart from being more affordable, motorbikes are also easier to drive on small roads [1]. But to ride a motorcycle, of course, it must have standard equipment to support the safety of the rider. One of the most important equipment in riding a motorcycle is a helmet. Helmets have an important role in protecting the head from the risk of injury in the event of unwanted things such as traffic accidents in driving.

Most helmets today generally only function as head protection from injury. However, with the advancement of technology, helmets can now be equipped with additional useful features. The added features include drowsiness warnings [2] and theft detection [3]. Based on research conducted by Rahmadiyani and Widyanti [4] it was found that some drivers were unaware that they were entering a phase of drowsiness. This can be dangerous for drivers if it cannot be detected early on. Then, based on research conducted by Sang-Ho Jo et al [5] using six volunteers as a sample, it was found that the average heart rate of drivers when drowsy decreased by 9.3% from the initial 89.9 bpm to 81.5 bpm. Therefore, the drowsiness detection system uses the driver's heart rate as input.

By utilizing the Internet of Things (IoT) in its design, it aims to increase the safety of the rider and the helmet itself. Helmets that were previously only used to protect the head can now be integrated with features that can answer problems that often occur for two-wheeled riders.

IoT is a technology that allows control, communication, and cooperation between various hardware devices via the internet network. Not only limited to controlling devices remotely, IoT also includes the process of sharing data and realizing virtual representations of real objects in the digital world, which are also influenced by other technologies, such as computer network protocols, Augmented Reality, and so on [6].

The basis of the research conducted is certainly inseparable from similar research that has been done before. Utama et al. [2] conducted research in the form of designing a helmet that can detect pulse and serves to prevent drowsy riders. This design uses a pulse sensor as a sensor and a micro flat vibrator as an actuator. The system works when the rider's pulse is below the setpoint which makes the vibrator vibrate. However, the weakness in this research is the absence of an IoT platform so that it does not add to the functionality of the helmet.

Nugraha [7] conducted research in the form of designing a helmet that can detect a pulse to prevent drowsy motorcycle drivers and is equipped with brake and turn signal indicators in the form of lights attached to the back of the helmet. This design uses Arduino Nano as the main microcontroller with heart rate sensor as input and buzzer as actuator. The system works when the sensor detects a heart rate of less than 60 bpm, so the buzzer will issue a warning sound to the rider. However, the weakness in this research is that the heart rate sensor only functions optimally when the rider is not moving, so when the rider moves, the sensor reading will experience noise interference which is enough to interfere with system performance.

Aryaviocholda et al. [3] conducted research in the form of designing a helmet that can detect theft to increase vehicle safety. This design uses magnetic reed switches as sensors, Bluetooth HC-05, and Arduino Nano integrated with the MQTT protocol to send notifications to smartphones and activate speakers. The system works when the helmet is kept away from the rider's motorcycle at a certain distance, so that theft can be detected immediately and generate alerts via messages and sound. The distance between the motorcycle and helmet is determined by how far two HC-05 Bluetooth devices can pair. However, the weakness in this research is the communication flow that requires the installation of a special application made by the author on the rider's smartphone, so the functionality of the system is limited if the application is not published.

Based on previous research, this research develops an IoT-based system that integrates heart rate monitoring and messaging into two features, namely drowsiness warning and theft detection. Previous research by Utama et al [2] and Nugraha [7] used Arduino Nano and pulse rate sensors, while this research utilizes ESP32-C3 and MAX30102 sensors that can be monitored through the Blynk application. Meanwhile, Aryaviocholda et al [3] applied Arduino Nano, two Bluetooth HC-05 modules, and the MQTT protocol to send alerts, while this study chose ESP32-C3 and WhatsApp with the HTTP protocol because ESP32-C3 is more suitable for small-scale IoT projects and WhatsApp is a popular instant messaging application [8].

The research conducted certainly has goals that must be achieved. The purpose of this research is to produce a rider helmet that can warn users and other drivers around when they are in a sleepy condition and produce a rider helmet that can detect and warn users and other people around when there is an act of theft.

2. Methods

Research methods are needed so that the ultimate goal of this research can be achieved as it should. The method applied is an experimental method where this research is the design of a helmet which will then be tested to determine the reliability of the system that has been made so that it can be analyzed [9].

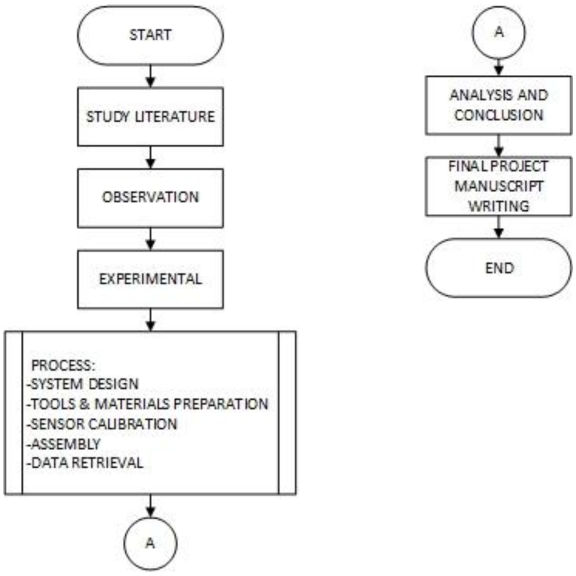

Figure 1. Flowchart of Research Stages

The figure above shows the stages of the research. Literature study aims to learn the concepts and working principles of the system to be created based on similar research that has been done before [10]. Observation is carried out to further understand the design to be made so that the information needed to continue the research can be obtained [11]. Furthermore, the experimental stage is carried out to find out the working principles of the components used in the design through direct testing [9].
In the process stage, the research is divided into several sub-processes, namely system design, preparation of tools and materials, sensor calibration, assembly, and data collection. The description of the sub-processes is as follows.

2.1 System Design

System design aims to produce a design for the research to be made [12]. The system design includes block diagrams, flowcharts, prototype design, electronics, and IoT. The block diagram in the study can be seen in the figure below.

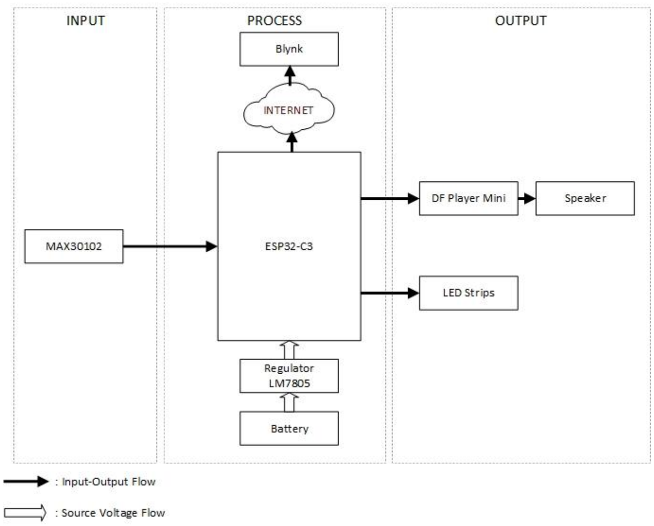

Figure 2. Block Diagram of Drowsiness Warning Feature

Figure 2 shows the block diagram of the drowsiness warning feature. This research uses ESP32-C3 as the microcontroller, MAX30102 sensor as input, and speaker and LED strip as output.

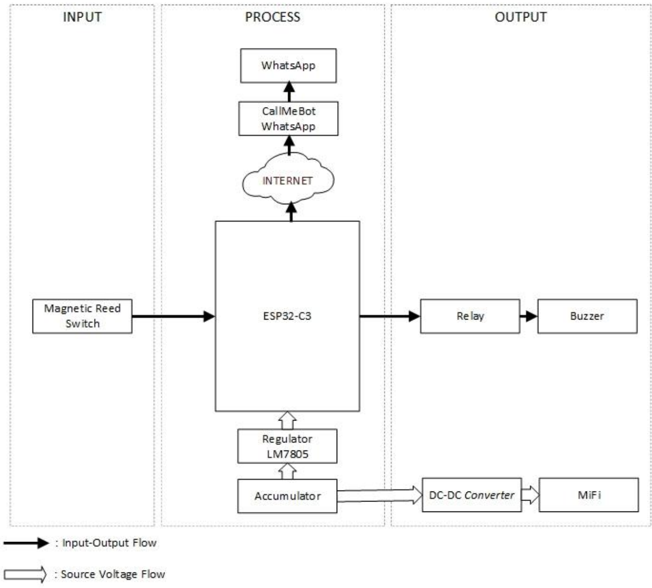

Figure 3. Block Diagram of Theft Detection Feature

Figure 3 shows the block diagram of the theft detection feature. There is a magnetic reed switch sensor as input and buzzer as output. Then the working principle in this study is described in a flowchart that represents each feature.

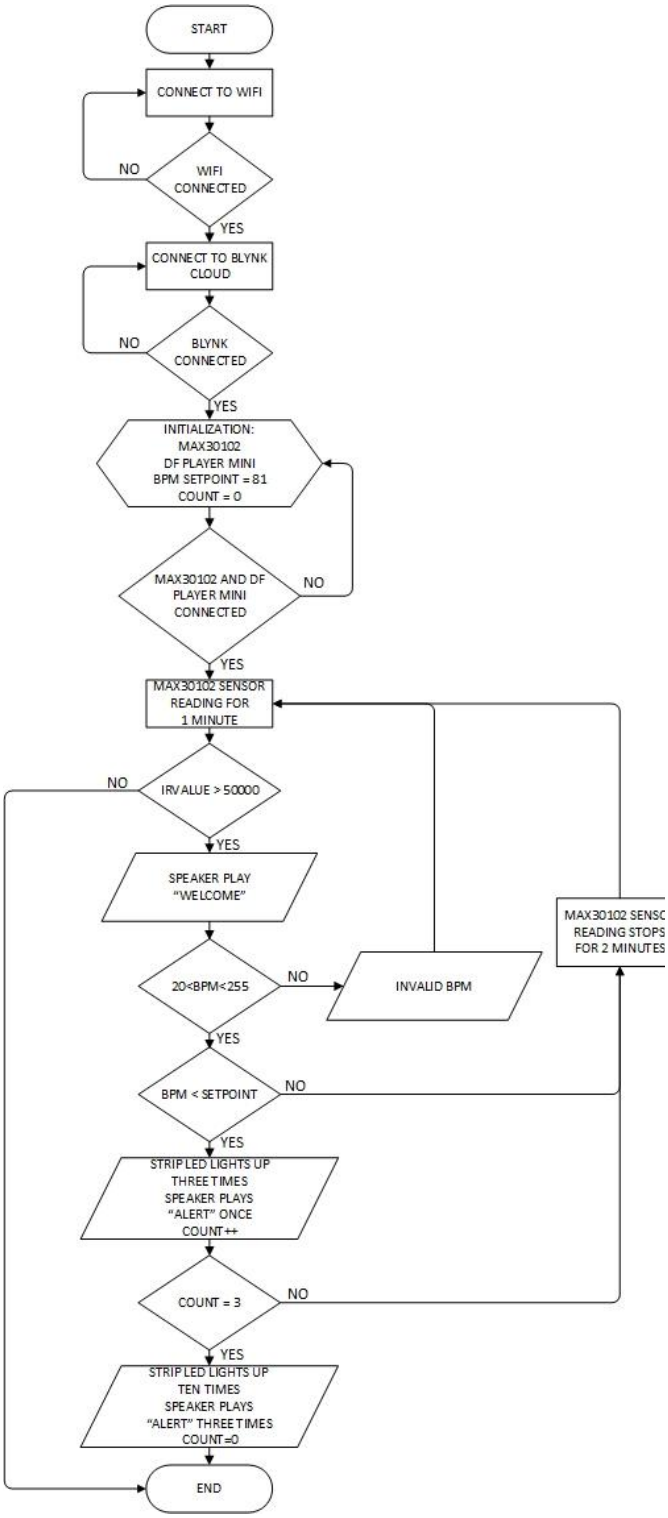

Figure 4. Flowchart of Drowsiness Alert Feature

Figure 4 shows the flowchart of the drowsiness alert feature. The bpm setpoint value is obtained from research conducted by Sang-Ho Jo et al. [5] who conducted research on changes in heart rate when driving in a drowsy state. Then is the flowchart of the theft detection feature shown in Figure 5.

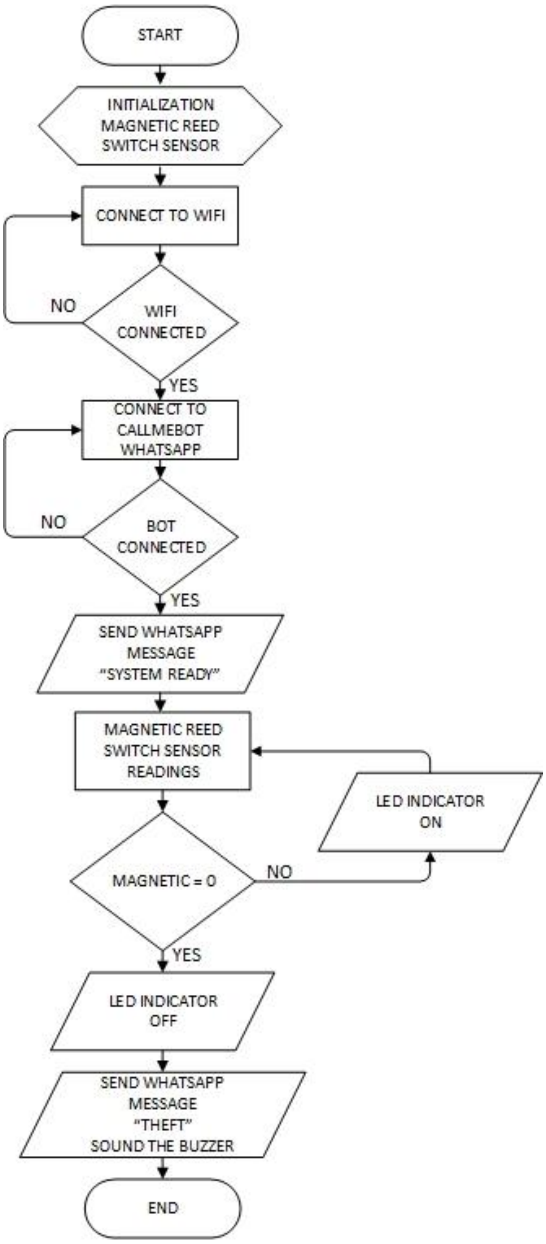

Figure 5. Flowchart of Theft Detection Feature

Furthermore, each feature has a prototype, electronics, and IoT design. The prototype design shows the 3D shape of the research to be made.

Figure 6. Layout of Components in the Helmet

Figure 6 shows the layout of the components in the helmet. The placement is not done arbitrarily because it can affect

the performance of each component. The following is a description of the components shown in Figure 6:
a. Magnet
b. Speaker
c. Microcontroller and battery box
d. LED strip
e. MAX30102
f. Charging port type-C
Then, Figure 7 shows the layout of the components on the motorcycle. The components are placed based on function so that they can work optimally.

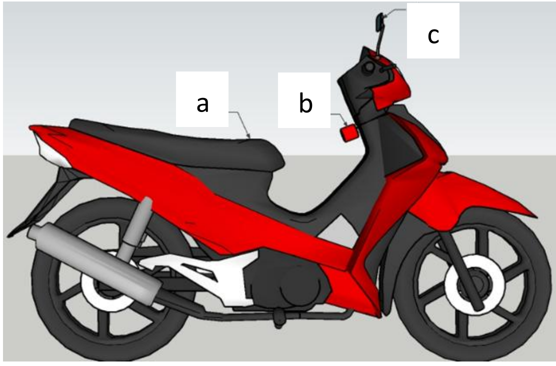

Figure 7. Layout of Components on a Motorcycle

The following is a description of the components shown in Figure 7:
a. Microcontroller box
b. Buzzer
c. Magnetic reed switch sensor
In its design, each component must be connected and integrated to become an electronic system. The following is the wiring of the electronic system made in this study.

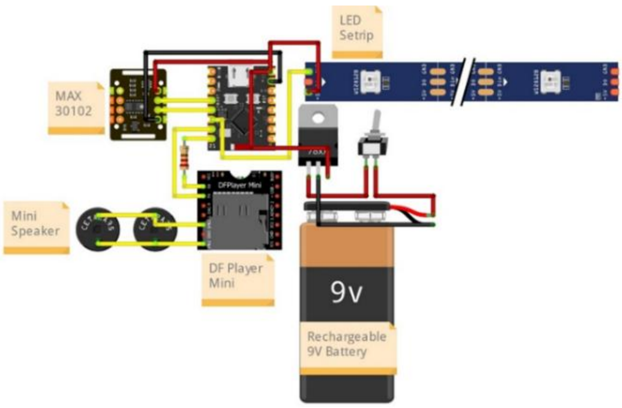

Figure 8. Wiring Components in the Helmet

Figure 8 shows the wiring of the components in the helmet. Wiring gets a voltage supply from a battery of 9 V. In order for the microcontroller to get the appropriate voltage, a voltage regulator is used.

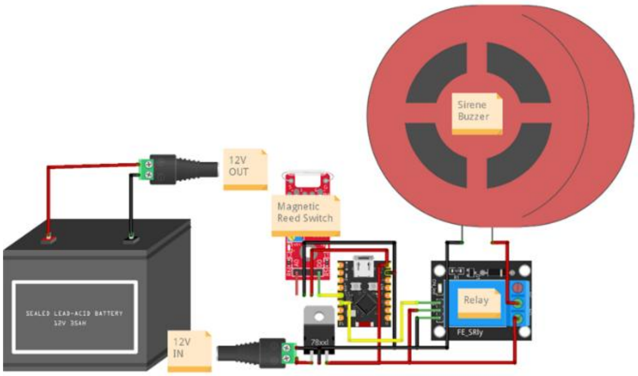

Figure 9. Wiring Components on a Motorcycle

Figure 9 shows the wiring of the components found on the motorcycle. The source voltage is obtained from the motor battery of 12 V. In order for the microcontroller to get the appropriate source voltage, a voltage regulator is also used. Next is the IoT design which is the main topic in this research. The application of IoT uses two different platforms, namely Blynk and WhatsApp.
Blynk is a cloud IoT platform that is useful for controlling various types of boards such as Arduino, ESP32, Rasberry Pi, and various types of similar boards using the internet network. By using Blynk, users can customize the application interface using widgets available easily [6]. In this research, Blynk is used to facilitate monitoring the driver's heart rate through a smartphone on the drowsiness warning feature.
WhatsApp is an application available for smartphones and the web, serving as a means of communication for its users. In addition to being used for communication, this application is also utilized as a platform in the fields of education, business, and entertainment [13]. In order to be used as an IoT platform, a bot is needed as a gateway, namely CallMeBot. In this research, WhatsApp is used as an application for receiving notification messages on the theft detection feature.
Each platform requires a protocol in order to communicate with the hardware. On the Blynk platform, the protocol used is MQTT. Message Queuing Telemetry Transport (MQTT) is a communication protocol in IoT that works in Transmission Control Protocol/ Internet Protocol (TCP/IP). This protocol has a small data packet size so that it only consumes a small power supply. This protocol uses the publish/subscribe method where the data sender is called a publisher and the data receiver is called a subscriber [14].

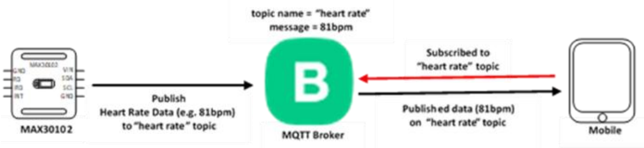

Figure 10. MQTT Protocol Concept on Blynk

Blynk acts as a broker. The broker is an intermediary responsible for organizing the communication flow between the data sent by the publisher to the subscriber [15]. The MAX30102 and ESP32-C3 sensors connect to the MQTT server as clients and send heart rate data with the topic "heart rate". The process of sending data to the broker is referred to as publish, where the device sends data in the form of heart rate values to the broker through a predetermined topic. The broker plays a role in processing or filtering all messages so that messages only reach subscribers with the appropriate topic, namely "heart rate".

Meanwhile, on the WhatsApp platform, the protocol used is HTTP. Hypertext Transfer Protocol (HTTP) is the foundation of communication on the World Wide Web that regulates the request and response process between client and server. In general, an HTTP client initiates a connection by sending a request via TCP/IP to a specific port. Next, the HTTP server will listen to the request and wait for the client to send a command such as "GET/HTTP/1.1". Once the server receives the request, it will respond with a code such as "200 OK" and then send the requested data to the client [16].

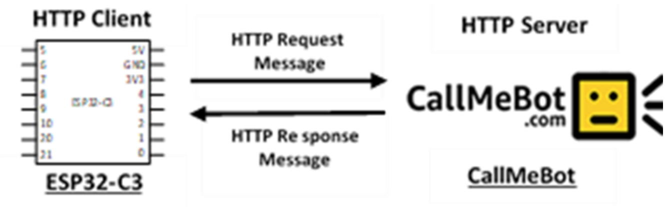

Figure 11. HTTP Protocol Concept on Whatsapp

In Figure 11, ESP32-C3 acts as a client while CallMeBot acts as a server. The client sends an HTTP request (GET) to the server to be able to send a message to the registered WhatsApp number. The server then processes and responds to the request with success/failure status. Next, the server translates the HTTP request into a WhatsApp message. Since CallMeBot also acts as a gateway, it uses the registered user's API key as an authentication method. Application Programming Interface (API) is an interface technology designed by system developers to allow simultaneous access to some or all system functions efficiently [17]. If the API key has been validated, the message can be forwarded and received by the rider's WhatsApp application. The WhatsApp application acts as an end-user client that receives messages.

2.2 Tools and Materials

In conducting research, a number of tools and materials such as sensors and output devices are needed. This research uses two types of sensors, namely MAX30102 and magnetic reed switch sensors. The output devices used are buzzers, speakers, and LEDs. The source voltage used is two, namely from a 9 V battery and a 12 V battery.

MAX30102 is a module capable of measuring heart rate and temperature simultaneously. This module consists of two main components, namely the transmitter source and signal receiver. When the sensor is connected to a voltage source, the transmitter will emit infrared waves, while the receiver in the form of a photodetector will detect changes in light intensity that occur, which is then used to measure heart rate. The main advantage of the MAX30102 sensor lies in its low noise level, making the calibration process easier [18].

Magnetic reed switches are electrical sensors that operate by utilizing magnetic fields as a trigger for changes in conditions. In other words, this sensor is also known as a magnetic sensor because it will be active when exposed to a magnetic source. Magnetic reed switches are composed of metal plates connected by a glass tube. When a magnetic field forms between the two plates, the plates are attracted to each other allowing the flow of electric current to occur. When the magnetic field is lost, the plates return to their initial position and the current flow is cut off again [19].

Buzzer is an electronic component that functions to convert electrical signals into sound vibrations. The working principle is similar to a loudspeaker, namely by using a coil mounted on a diaphragm. When current is applied to the coil, the coil works as an electromagnet and moves in or out depending on the direction of the current and the polarity of the magnet. The movement of this coil directly moves the diaphragm back and forth, resulting in air vibrations which are then heard as sound [20].

Just like a buzzer, a speaker is a device that converts electrical signals into sound [21]. The speaker functions as a producer of warning sounds in the form of a voice with mp3 format stored on a memory card. So that the voice can be played, a mini DF player module is used [22].

Light Emitting Diode (LED) is an electronic component that produces one-color light when electrified. LEDs are made from semiconductor materials so that the color produced depends on the type of semiconductor. In addition, LEDs can also emit infrared rays that are invisible to the eye as commonly used in TV remote controls and other electronic devices [20].

A battery is an energy storage device composed of one or more electrochemical cells and equipped with an external connection to conduct electricity to the device. One type of rechargeable battery that is commonly used is the lithium ion battery, also known as Li-ion (LIB). When in use, lithium ions move from the negative electrode to the positive electrode and the process is reversed when the battery is recharged. Unlike non-rechargeable batteries that use metallic lithium, Li-ion batteries use lithium intercalation compounds as their electrode material [21].

A battery or accumulator is a secondary electrochemical cell that produces direct electric current by converting chemical energy into electricity. There are several types of batteries such as wet batteries, hybrid batteries, calcium batteries, maintenance-free batteries, and sealed batteries. As an electrochemical element, a battery affects the chemical reactions in its components, so it is called a secondary element. In batteries, the positive pole uses an oxide plate while the negative pole is made of a lead plate with an electrolyte solution in the form of sulfuric acid [23].

3. Results and Discussion

The results and discussion section presents and discusses the research findings concerning the objectives outlined in the introduction. The data obtained from the research and the corresponding discussions must exhibit a logical relationship that directs focus toward the conclusions drawn.

Research results may also be presented in the form of images or graphs in this section to enhance clarity and accessibility for the reader. Tables and figures should be clear, legible, accurate, and high-resolution.

3.1 Hardware Manufacturing Results

The following are the results of making hardware that has been adjusted to the prototype design.

Figure 12. Microcontroller Box in the Helmet

Figure 12 shows the shape of the microcontroller box on the helmet. The contents of the box can be seen in Figure 20.

Figure 13. Microcontroller Box on Motorcycle

Figure 13 shows the shape of the microcontroller box on the motorcycle. The contents of the box can be seen in Figure 21. Then, the position of the sensors and modules in this study are shown in Figures 14 to 19 below.

Figure 14. Led Strip Position

Figure 15. MAX30102 Sensor Position

Figure 16. Charging Port Type-C Position

Figure 17. Motorcycle Microcontroller Box Position

Figure 18. Buzzer Position

Figure 19. Magnetic Reed Switch Sensor Position

3.2 Electronic Device Manufacturing Results

In making electronic devices, the result obtained after doing electronic design is in the form of a Printed Circuit Board (PCB). PCB is a thin board with fiber-like material used for stringing and soldering electronic components [24].

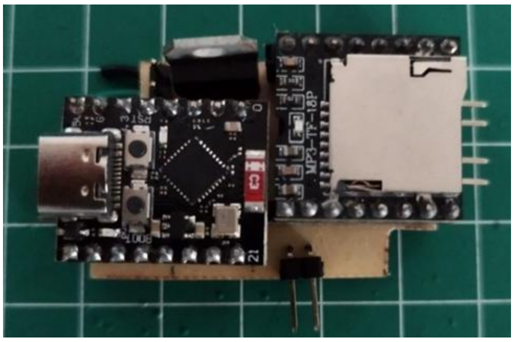

Figure 20. PCB With Components Installed

Figure 20 shows the shape of the PCB that has been installed ESP32-C3 and mini DF player module. Another additional component is a voltage regulator to reduce the voltage from the battery so that the microcontroller can be used.

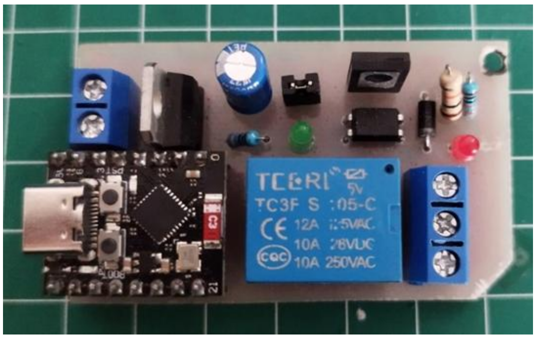

Figure 21. PCB with Components Installed

Figure 21 shows the shape of the PCB that has been installed ESP32-C3 and relays. Another additional component is a voltage regulator to reduce the voltage from the battery so that the microcontroller can be used.

3.3 Software Programming Results

The results of software programming are the results obtained based on the IoT design that has been done. Its function is to display data and output from working features. The following is the interface of the software that has been programmed based on the IoT design that has been done, shown in Figures 22 and 23.

Figure 22. View of the Blynk App When Measuring

Figure 23. View of the Blynk App When Not Measuring

In the image above, there is a gauge-shaped widget that shows the level and bpm value being measured. At the top of the gauge, there is an LED that serves as an indicator of the sensor status.

Then, Figure 24 is a display of the WhatsApp application. WhatsApp bot is the result of the IoT design that has been previously configured. WhatsApp bot can send messages independently as shown below when there is an act of theft.

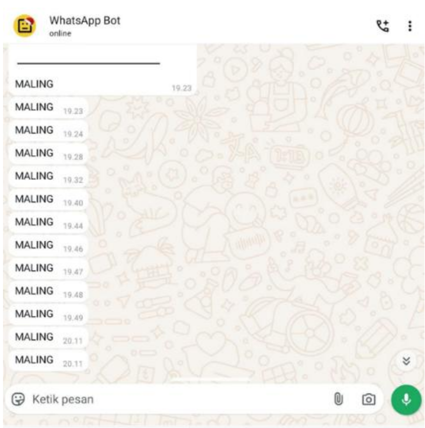

Figure 24. How the Whatsapp App Looks When the Theft Detection Tool is Active

3.4 Sensor Calibration

Before testing, calibration of each sensor is first carried out in order to determine the accuracy of the measurement results [25]. The MAX30102 sensor is placed at the bottom of the chin and touches the skin. As a comparison, a smartband with the Xiaomi Smartband 8 brand is used. To calculate the percentage error of the measurement, the following equation is used.

$$\%Error = \left\{\frac{|E - A|}{A}\right\} x\ 100 \quad (1)$$

Description:
A = Actual Value
E = Measured Value

The following measurement results are shown in table 1.

Table 1. MAX30102 Sensor Measurement

Measurement (bpm)		Difference	Error
MAX30102	**SmartBand**		
103	98	5	5.10%
85	85	0	0.00%
96	97	1	1.03%
105	100	5	5.00%
86	89	3	3.37%
96	95	1	1.05%
98	99	1	1.01%
78	88	10	11.36%
100	101	1	0.99%
87	90	3	3.33%
Average		**3**	**3.23%**

The measurement results that have been obtained in table 1 have a percentage measurement error of 3.23%. Next, on the magnetic reed switch sensor, measurements are taken to determine the maximum distance of the sensor in reading the magnetic field. Measurements using a ruler measuring tool. The following measurement results are shown in table 2.

Table 2. Magnetic Reed Switch Sensor Measurement

Magnet Distance (mm)	Magnetic Sensor Data	Buzzer Condition
0	1	No Sound
1	1	No Sound
2	1	No Sound
3	1	No Sound
4	0	Sound
5	0	Sound

The measurement results obtained in Table 2 show that the sensor cannot detect magnets at a distance of >3 mm.

3.5 Device Testing

After calibrating each sensor, the next step was testing the device. For the drowsiness warning feature, testing was carried out involving qualified subjects to evaluate the effectiveness of the system in detecting and preventing microsleep due to fatigue. The test was conducted on Jalan Sepakat 2, Pontianak City, with the test time divided into two sessions, namely daytime (07.00 WIB-18.00 WIB) and nighttime (18.00 WIB-02.00 WIB), so as to reflect the normal conditions of human activity and rest. Each subject is required to ride a motorcycle while wearing a helmet that has been equipped with a drowsiness warning feature, so that the data obtained can provide a comprehensive picture of the performance and reliability of the system in real situations.
The first test was conducted during the daytime. Subjects who have agreed can choose the time based on a predetermined range. Each subject will have 5 heart rate data collected. The test is conducted to determine the effectiveness of the feature in detecting and preventing microsleep due to fatigue at normal times of human activity, namely during the day. The following test results during the day are presented in Table 3.

Table 3. Testing During the Day

Subject	Age	Test Time (WIB)	Measured Pulse (bpm)					Average (bpm)	Number of Warnings
			1	2	3	4	5		
First Man	20	16:27:00	65	85	80	86	90	81.2	2
Second Man	21	16:38:00	69	102	86	88	91	87.2	1
Third Man	23	07:30:00	99	88	94	82	81	88.8	1
first Woman	21	17:19:00	73	74	107	114	113	96.2	2
Second Woman	21	13:24:00	104	99	103	102	99	101.4	0
Third Woman	22	14:46:00	91	96	88	90	89	90.8	0

In table 3, it can be seen that the measured bpm values in each subject have variations. The highest average bpm was in the second female subject who touched 101.4 bpm, while the lowest average was in the first male subject who touched 81.2 bpm. In the first and second men, the first reading drop occurred. Drop readings can occur due to the sensor receiving too much noise before touching the skin.
The second test was conducted at night. Just like the first test, willing subjects can choose the time based on a predetermined range. Each subject will have 5 heart rate data collected. The test was conducted to determine the effectiveness of the feature in detecting and preventing microsleep due to fatigue at human resting time, namely at night. The following test results at night are presented in Table 4.

Table 4. Testing During the Night

Subject	Age	Test Time (WIB)	Measured Pulse (bpm)					Average (bpm)	Number of Warnings
			1	2	3	4	5		
First Man	20	22:35:00	83	99	94	83	76	87	1
Second Man	21	22:49:00	94	82	87	74	83	84	1
Third Man	23	18:55:00	81	89	78	86	105	87.8	2
first Woman	21	20:04:00	46	102	108	103	101	92	1
Second Woman	21	20:30:00	76	87	92	97	91	88.6	1
Third Woman	22	19:12:00	84	93	89	76	88	86	1

It can be seen in table 4 that the measured bpm values in each subject have variations. The highest average bpm was in the first female subject who touched 92 bpm, while the lowest average was in the second male subject who touched 84 bpm. A similar thing also happened where the first woman had the first reading drop. Drop readings can occur due to the sensor receiving too much noise before touching the skin.
From the tests carried out, it can be seen that the system has run in accordance with the objectives. The heart rate measured during the day and night showed no significant difference. The variation in heart rate of each subject reflects the difference in pulse response to helmet use as well as other factors such as physical condition, health, emotional, and other external factors.
Testing on the device then continued on the theft detection feature. The test was conducted to determine how long a warning message can be sent to the rider's smartphone in the event of theft. The following test results are shown in Table 5.

Table 5. Testing the Theft Detection Feature

Testing	*Buzzer*	Message Sended Time	Message Received Time	Time Difference (s)
1	Sound	19:44:45	19:44:49	00:00:04
2	Sound	19:46:02	19:46:15	00:00:13
3	Sound	19:47:19	19:47:23	00:00:04
4	Sound	19:48:32	19:48:39	00:00:07
5	Sound	19:49:27	19:49:38	00:00:11
6	Sound	20:12:31	20:12:38	00:00:07
7	Sound	20:13:15	20:13:25	00:00:10
8	Sound	20:14:27	20:14:31	00:00:04
9	Sound	20:15:07	20:15:14	00:00:07
10	Sound	20:17:21	20:17:30	00:00:09
Average				**00:00:08**

In the table above, the test was conducted ten times. In ten trials, there is a time difference between sending a message and receiving a message. Message delivery in this test took an average of 8 seconds. The fastest message delivery took 4 seconds and the slowest message delivery took 13 seconds. Each experiment took a different time. This is influenced by the network availability of the provider used. Areas with low network availability may be a drawback to this feature. However, the alarm function still works well without being affected by the network.

3.6 System Analysis

Analysis is the final stage of testing before it can be concluded. Analysis aims to evaluate whether the system that has been created and developed can function in accordance with predetermined objectives. The following is a description of the system analysis of the drowsiness warning feature:

a. The measured heart rate values vary depending on the condition of each subject.
b. The number of alerts will be counted when the sensor detects a heart rate <=81 bpm. This indicates that the feature can output alerts if it detects signs of microsleep in the rider.
c. The first and second male subjects in table 3 show heart rate data on the first reading dropping. The same is the case with the first female subject in table 4. This can happen if the sensor first receives a lot of light noise before touching the skin.
d. Test subjects in the daytime above 15:00 WIB tend to have lower average heart rate values than those below 15:00 WIB. This indicates that the subjects are experiencing fatigue after doing their daily activities.
e. Test subjects in the evening time above 21.00 pm did not show lower average heart rate values than below 21.00 pm. This indicates that the subject has not experienced significant fatigue during the testing process.

Then, the description of the system analysis on the theft detection feature is as follows:

a. The fastest message delivery takes 4 seconds, while the slowest message delivery takes 13 seconds.
b. The average calculated message delivery speed is 8 seconds.
c. The existence of varying delivery speeds is influenced by the internet network speed of the provider used.
d. The buzzer on this feature can sound directly without being affected by internet speed.

4. Conclusions

This research successfully produced a rider helmet with two main functions that support rider safety and security. The helmet can provide early warning against drowsiness and detect signs of microsleep in riders with a measurement error percentage of only 3.23%. In addition, the helmet is also able to detect theft and send alerts via text message at an average speed of 8 seconds. These results show the great potential of sensor technology in improving rider safety standards and real-time helmet security.

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