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RESEARCH ARTICLE

IoT-Based Vehicle Monitoring System on LoRa Network: Addressing Community Needs in Indonesia

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Abstract

IoT technology is widely developed and applied for easy access and security solutions. In Indonesia, lots of security problems are found and one of which is in the vehicle security. Our IoT-based vehicle monitoring system emerged from a comprehensive survey among vehicle owners to address the needs of existing problems in the community. The device circuit is designed using GPS to detect location and speed, a vibration sensor to measure engine vibration, and a relay to disconnect the vehicle socket. The entire data transmission process uses LoRaWAN which can cover a vast distance and has low-power consumption so that it is safe to be powered by a vehicle accumulator. The designed system can display the location, speed, and condition of the vehicle consistently with a delay that will adapt based on vehicle condition to minimize power usage. The system can send a warning notification if the vehicle that is not being used is detected at a speed of more than 5.5 km/h with engine vibrations detected reaching 28 vibrations/5 seconds and it can receive 65% of the control signals to start and stop the vehicle engine which could be optimized further.

Keywords: IoT, Smart Monitoring and Control, LoRa

1. Introduction

IoT is defined as a collection of infrastructure that connects items so that they can gather data and share data over an interconnected network, typically using the internet to simplify access and management of the data [1].

The scope of IoT applications is not restricted to a handful of industries. In agriculture, finance, health, and transportation, it has been demonstrated that IoT implementation provides convenience and solves issues [2], [3], [4], [5]. Vehicle security is one of the author's primary concerns, particularly in the field of transportation and logistics [6], [7]. In Indonesia, vehicle security is one of the most common causes of criminal activity. According to data from Badan Pusat Statistik Indonesia, there were 18,557 vehicle thefts in Indonesia in 2020. This number does not include instances of violent vehicle crime and logistical vehicle theft [8].

Vehicle theft cases that occur are you caused by the difficulty of monitoring vehicles due to limited access of vehicle owners to their vehicles when it is not in use. Therefore, in this research, a vehicle security system is designed based on the Internet of things technology, making it easier for vehicle owners to access their vehicles. The system is designed based on the results of a community survey that has been carried out beforehand. The survey results show that most respondents want a vehicle security system that can detect the location and speed of the vehicle, provide warning alarms, and can easily control the engine on and off.

In previous research [9], [10], internet of things-based systems uses GPS to track the location of vehicles. GPS is used to determine longitude and latitude coordinates from satellite communications, the coordinates obtained can then be accessed easily by the vehicle owner. Therefore, the proposed system design will use GPS for vehicle location and speed detection. In addition to GPS, vibration sensors and additional actuators in the form of relays are also used. The vibration sensor is used to detect vehicle engine vibration which is then utilized to determine the state of the vehicle engine. While relays are used to turn off the vehicle engine via cellular phone without the need to turn it off using the vehicle key manually [6], [11], [12].

The information obtained through the sensor and actuator components used is processed by the ESP32 microcontroller. All information is sent to the Antares server via LoRa Antares Telkom network. LoRa uses spread spectrum chirp modulation so that it can transmit data with low power and at a considerable communication distance. The use of LoRaWAN is a novelty from similar IoT systems that use GSM as the communication system. All data stored on the Antares server can be accessed through end-user software to be used as information by the vehicle owner.

2. Research Method

The design of the vehicle safety system proposed in this study was developed based on a survey of people's needs for a reliable vehicle safety device. The survey results are then used as a reference in the development of the designed system before adding the novelty of the security system that is already spread in the market. The system is then tested for its ability to work under the desired function. The flow of the development process can be seen in Figure 1.

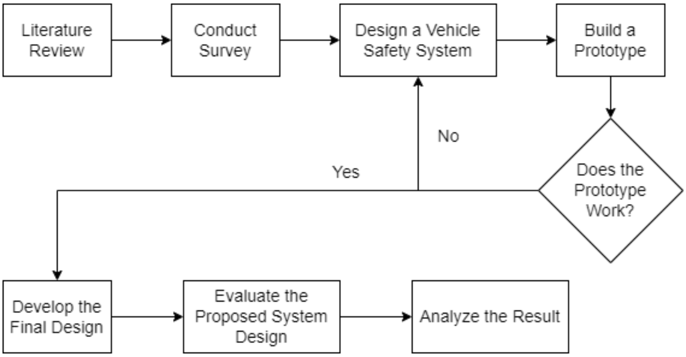


Figure 1. Flowchart of the research.

2.1 Survey: The Need for a Vehicle Safety System

The survey collected data on respondents' opinions regarding the security systems on the vehicles they own on a scale range of 1 – 5, where scale 1 indicates that the vehicle security system is minimal, scale 3 indicates that the vehicle security system is sufficient and 5 indicates that the vehicle security system is excellent. The survey results are shown in Figure 2.

Figure 2 shows that out of a total of 467 respondents, 178 respondents think that the security system on their vehicle is at the lowest end of the scale. 75 respondents chose a scale range of 2 as an indicator of the safety of their vehicle, 93 respondents felt that the current safety system on their vehicle was sufficient.

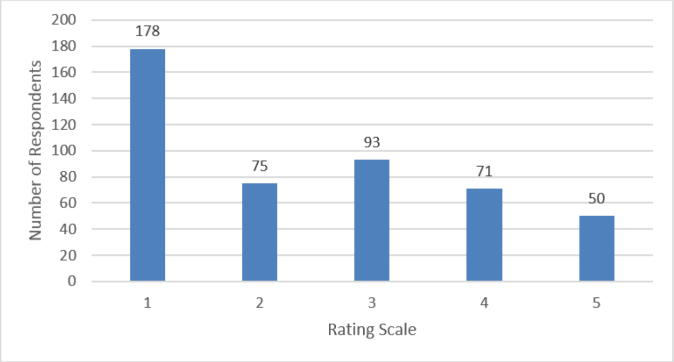


Figure 2. Results of the vehicle safety scale survey. The larger the scale indicates the better the vehicle safety system is.

Based on the survey results, 54% of respondents feel that the vehicle security system they currently have is less reliable and still needs to be improved. Therefore, in this study, a vehicle safety system was designed that functions following the wishes of the survey respondents. In the survey, voting was conducted in the form of respondents' suggestions regarding what functions are desired in a vehicle safety system that can be accessed easily through mobile applications.

Based on the survey results, there are 3 main functions that respondents want to be applied to the system. The three functions include the ability to detect the position of the vehicle, control the turning off of the vehicle engine through the application, and warnings in the form of notifications in case vehicle theft occurs. The results of the classification performed are shown in Figure 3. About 120 people want a vehicle detection function in the vehicle safety system to be designed. The vehicle detection function can be used to detect whether the vehicle is moving when it is not in use.

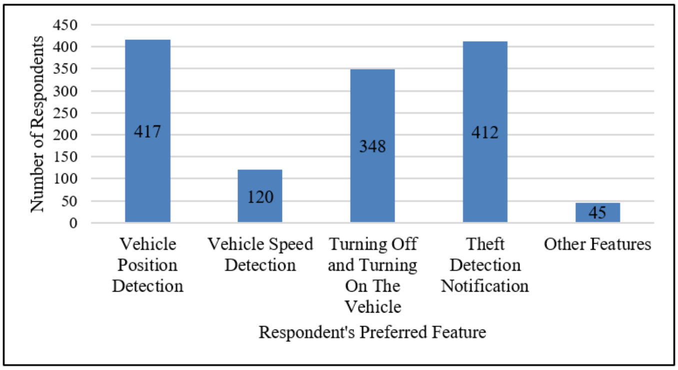


Figure 3. Desired utility based on survey results.

3. Proposed System Design

3.1 Vibration Sensor MPU6050

The MPU6050 sensor, powered by 3.3 volts DC, detects rotation and acceleration. In this study, the vibration sensor (MPU6050) is calibrated to identify engine start and stop events in vehicles. A MEMS system with a capacitive sensor serves as an attitude reader, providing the initial position value for the MPU6050. The capacitive reading is then converted into an electrical voltage. Additionally, each axis of the gyroscope and accelerometer undergoes 16-bit Analog-to-Digital Conversion (ADC) to derive digital signals from the analog voltage values.

3.2 Relay

Relays are used to connect and disconnect vehicle electrical cables. They operate based on electromagnetic induction. When the solenoid is energized, the lever is attracted due to the magnetic force generated around the solenoid. The magnetic force depends on the current, solenoid length, and magnetic field. When the current ceases, the magnetic force vanishes, causing the lever to return to its initial position and opening the switch contacts.

3.3 Long Range (LoRa)

LoRa is a low-power wireless technology protocol that uses radio spectrum and has a unique modulation format called Chirp Spread Spectrum (CSS) modulation. This technique operates by continuously changing the frequency of a transmitted signal over time. This varying frequency generates a waveform, allowing it to send signals over long distances without using a lot of power The application of CSS and the option of setting the spreading factor and bandwidth used can optimize the distance and data rate required.

The wide range of coverage makes LoRa suitable for use in rural areas that are widely spread in Indonesia. In addition, the use of LoRa can also prevent excessive power usage that can result in vehicle accumulator deficiencies.

3.4 Antares

Antares is an Internet of Things platform that provides cloud infrastructure and backend APIs for the development of IoT-based devices. Antares provides 3 protocols that can be used for IoT development, namely HTTP, MQTT, and COAP. In addition, Antares also supports LoRa-based IoT development that works at a frequency of 915 MHz with a maximum data capacity of 50 KB.

3.5 MOTRAV Application

The MOTRAV (Mobile Tracking Vehicle) application is a special application designed and integrated with the vehicle security system designed in this research. The application includes front-end software developed using the flutter framework and back-end software to store the user's username, email, and password as well as vehicle data stored by the user in the application.

3.6 System Design

The IoT-based vehicle safety system is designed to perform data collection using GPS components, relays, and MPU6050 sensors. GPS is used to collect data on vehicle longitude and latitude coordinates and vehicle speed. Relay is used to collect the electrical condition of the machine, and MPU 6050 is used as a vehicle vibration detector to determine whether the vehicle is on or not. The three data from GPS, relay, and MPU6050 module are processed and controlled by ESP32 to then be sent with the help of the LoRa module to the LoRa Antares server.

The MOTRAV application provides access to the information saved on the Antares server. The application has a function for tracking vehicles using internet mapping services. In addition, vehicle owners can turn off the vehicle and place it in parking mode via the application by disabling the vehicle's electrical system via a button. In parking mode, there is a feature that alerts the user if suspicious vehicle movement is detected. All feedback from the user to the device will be transmitted via the Antares gateway. The full process of the vehicle tracking, and control system is depicted in Figure 4 as a flowchart.

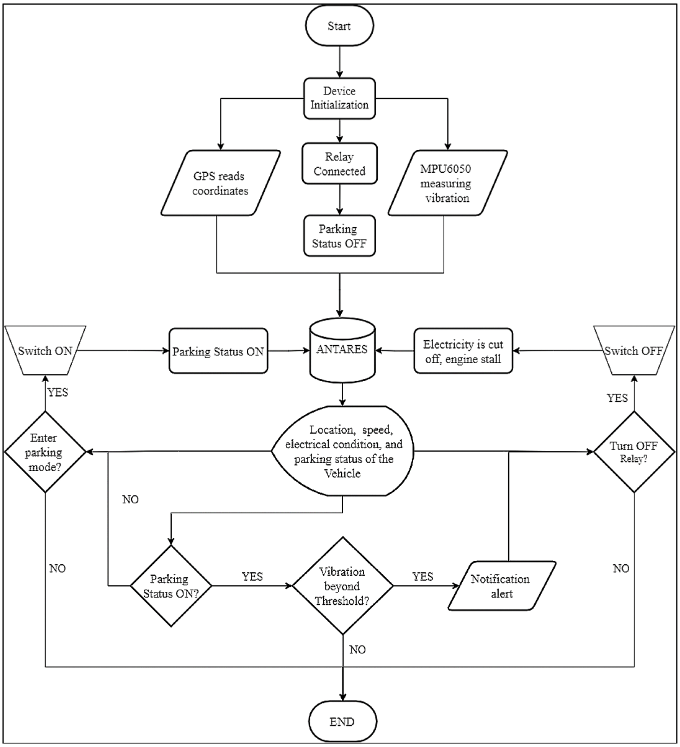
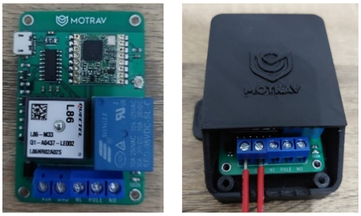


Figure 4. System Workflow.

The safety device circuit installed on the vehicle is designed and then printed into a printed circuit board. The necessary components such as ESP32, GPS, relay, LoRa, and vibration module are soldered to the circuit to obtain the device circuit shown in Figure 5(a). The device is also equipped with a case to protect the device from any impact that may occur during the testing process. The case is made using a 3D printer made from PLA. The shape of the case that has been made is shown in Figure 5(b).



(a) (b)

Figure 5. (a) Integrated device. (b) Device in case

In the section on the front view of Figure 5(b), there is a terminal to connect the input cable from the accumulator. These terminals are used as connection points for the cables connected to the vehicle. As seen from the left, there is a positive input cable terminal, a negative input battery cable terminal, a normally close cable terminal, a normally open terminal, and a pole terminal connected to the motor socket.

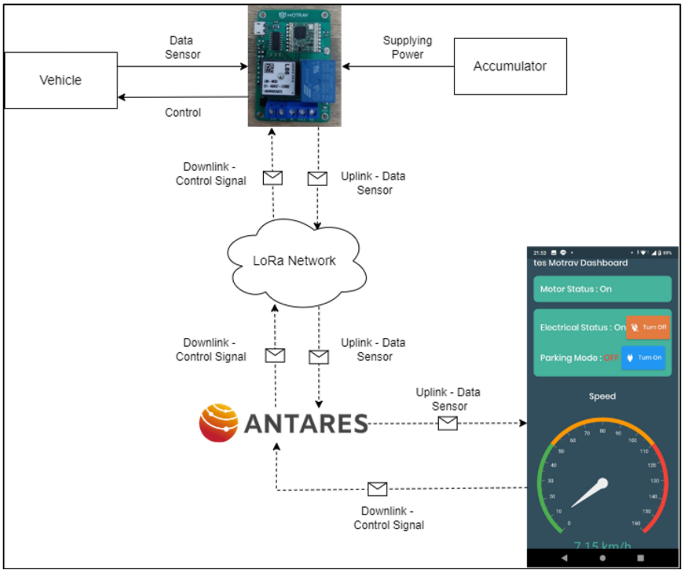


Figure 6. System Architecture.

The system's circuit architecture (depicted in Figure 6) facilitates both uplink and downlink data transmission. Uplink involves sending vehicle information from the device to the Antares platform, accessible via the MOTRAV application. Downlink transmits control signals from the MOTRAV application to the device via the LoRa Antares gateway. The MOTRAV application offers four distinct downlink control signals: relay on/off and parking mode activation/deactivation.

3.7 *System Testing*

The system underwent evaluation tests in two distinct scenarios. In the first scenario, we assessed the system's capability to detect the vehicle's location. During this test, a motorcycle equipped with the safety device was ridden along a specific track for 50 minutes. The evaluation process not only considered location detection but also analyzed the speed values recorded during the test. The success parameter was determined by the system's ability to display both the vehicle's location and speed within the MOTRAV application.

In the second scenario, we evaluated the system's responsiveness to downlink control signals from the application. These signals are used to connect and disconnect relays on the device. The success criterion was met if the number of failed downlink signals did not exceed 10% of the total signals sent.

Additionally, during this scenario, we tested the system's ability to detect vehicle engine vibration. The success parameter for this test was determined by measuring the delivery interval when the engine was on and when it was off, following a predefined program. Specifically, we conducted 20 downlink signal cycles to periodically turn the vehicle engine on and off.

4. Result

4.1 *Vehicle Location and Speed Monitoring*

Figure 7 shows the movement of the vehicle marked by a red dot for the duration of the test. This is indicated by the increase in red dots on the map. Figure 7 is the result of a sample plot every 10 minutes intervals from the latitude data read by the GPS connected to the system.

Figure 7. Vehicle Displacement Trace with 3D Map Coordinates.

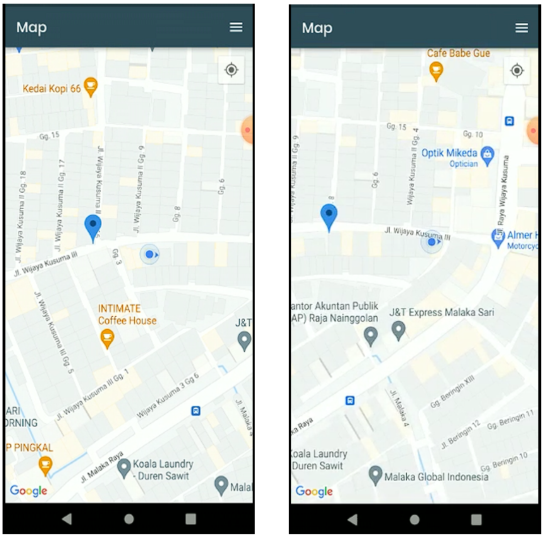


Figure 8. Vehicle location (blue pin) shown on MOTRAV Application.

In Figure 7, all the red dots represent the paths of vehicles equipped with tracking devices. This demonstrates that the GPS-based vehicle coordinate reading function within the system is functioning correctly. The longitude and latitude readings are also visible through the MOTRAV application. Figure 8 displays the vehicle location obtained via GPS in our designed system using a blue pin-shaped indicator. Additionally, the blue circle indicator, which appears multiple times in Figure 8, represents the vehicle's location based on the GPS signal from the user's cell phone. Upon closer examination, slight differences can be observed between the positions of the cell phone GPS indicator and the device GPS indicator in Figure 8.

The evaluation results also include data on the motorcycle's velocity during testing. These findings are visualized in Figure 9. The sensor recorded the vehicle's speed as 0 km/h multiple times. A speed of 0 km/h indicates that the motorcycle came to a complete stop. Several factors contributed to this outcome during the test, including red-light intersections and traffic congestion. Notably, the test was conducted during peak hours, specifically between 17:00 and 17:49.

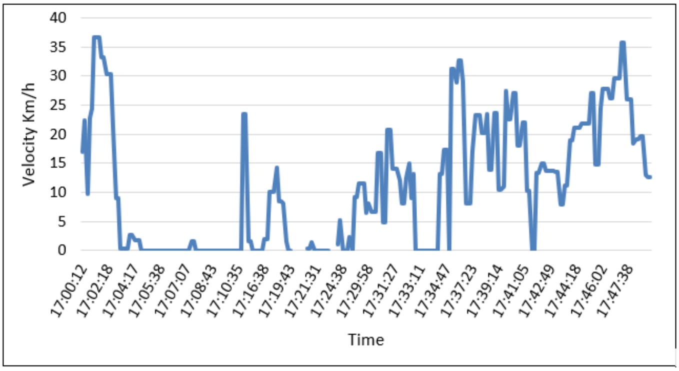


Figure 9. Speed changes during testing.

4.2 *Vehicle Control and Vibration Detection*

In 20 trials, only 65% or 13 times the signal was successfully received by the device, while the other 7 tests failed as shown in Fig 10.

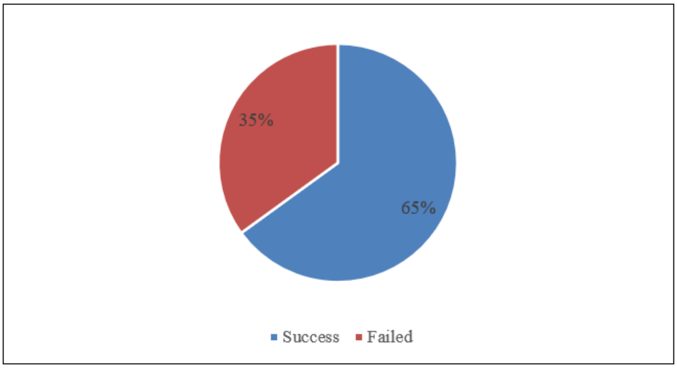
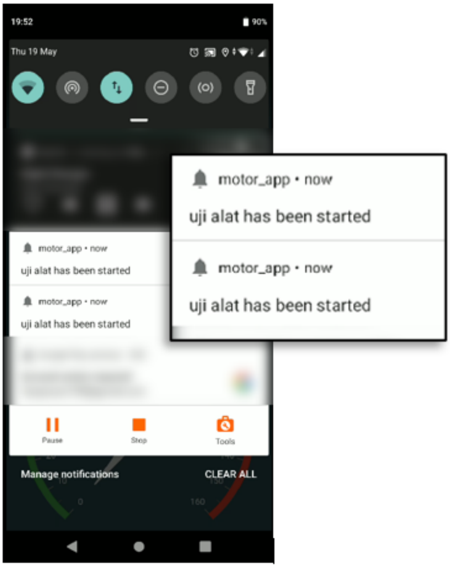


Figure 10. Percentage of downlink signal received.

Figure 10 shows the reliability and performance of the device to receive downlink signal. It suggests that while the system is mostly effective, there is still a notable failure rate of 35%. During the field test, this problem always occurs if the downlink signal is sent around the time when the device transmits uplink signals. If the uplink and downlink signals occur simultaneously it will cause interference which disrupts the process of receiving the downlink signal.

The vehicle that successfully receives the downlink signal containing information "3" will enter the parking mode and turn on the parking status on the application. If a vehicle that is in a parking status detects a speed and vibration that exceeds the limit, a warning notification will be sent by the device to the server and received via the MOTRAV application. Based on the test results, mobile phones that have the MOTRAV application and have been integrated with the device will receive a warning notification. the alert notification is written in the format "[Device name] has been started". Since the device name during the test is "uji alat", the notification form is shown in Figure 11.

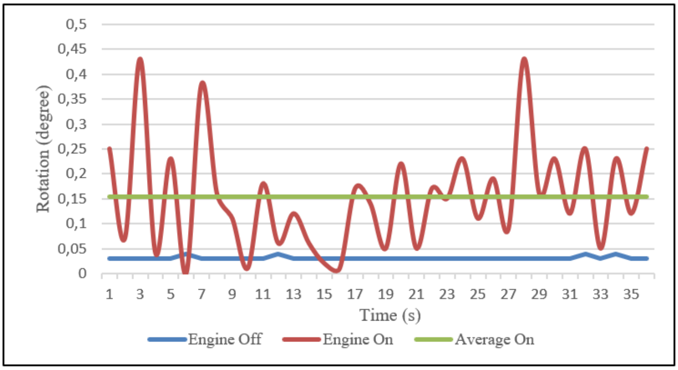


motor_app • now
uji alat has been started

motor_app • now
uji alat has been started

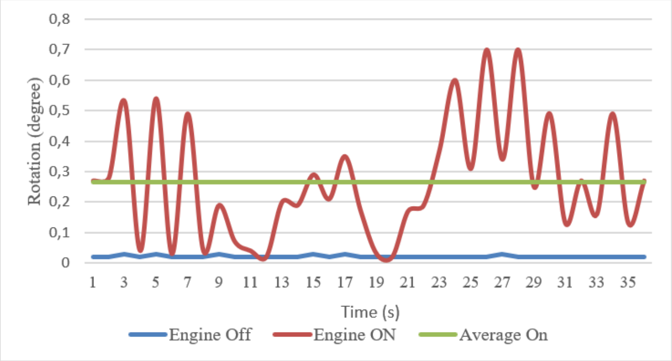
Figure 11. Warning notification on mobile phone.

In order to detect vibrations, the MPU6050 sensor module is used to calibrate the rotational values obtained from the motorcycle engine's vibrations when it is running. Calibration involves measuring the absolute rotation magnitude along the x and y axes of the MPU6050 sensor during motorcycle startup. This absolute rotation data is essential for calculating the average rotation, which serves as a reference for measuring vibrations.



(a)

Based on Figure 12, the absolute rotation on the x-axis is at an average value of



(b)

Figure 12. Absolute rotation on (a) X-Axis and (b) Y-Axis.

0.15, while the absolute rotation value on the y-axis is at 0.26. From these results, a rotation measured by the MPU6050 module will be calculated as a vibration must meet the Equation (1):

$$\text{vibration} = (\bar{x} + 10\%\ \text{error} \ * \bar{x}) \,\|\, (\bar{y} + 10\%\ \text{error} \ * \bar{y}) \tag{1}$$

Where $(\bar{x})$ is the average rotation detected on the x-axis of the MPU6050 sensor while $(\bar{y})$ is the average rotation detected on the y-axis of the MPU6050 sensor. In addition, to distinguish the vibrations caused by the engine from external vibrations, it is necessary to collect data to measure the number of vibrations that occur when the engine is running. The data was taken for 20 cycles with each cycle time of 5 seconds. The number of vibrations in each cycle can be seen in Figure 13.

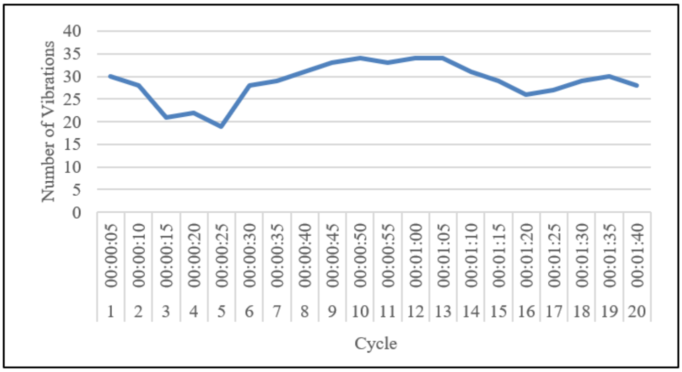
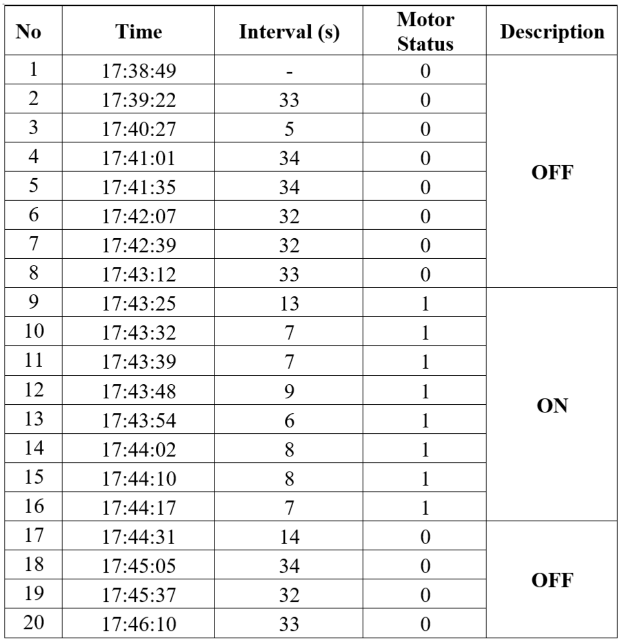


Figure 13. Number of vibrations on each cycle.

In each data collection cycle, as depicted in Figure 13, an average of 28.8 vibrations is obtained. Based on these findings, the indicator signaling that the engine is running requires a minimum of 28 vibrations to be detected within the vehicle. Once this threshold is met, the motorcycle transitions to an ‘ON’ state, which is reflected in the MOTRAV application. During the ‘ON’ state, the system accelerates the transmission of uplink signals compared to when the motor is in the ‘OFF’ state.

Table 1 illustrates the difference in transmission intervals between the two engine conditions during evaluation. Specifically, when the engine is off (indicated by motor status 0), the uplink signal is transmitted at intervals exceeding 30 seconds. Conversely, in the ‘ON’ condition, the transmission interval is less than 10 seconds.

Table 1. Uplink interval difference when engine is ON and OFF.



No	Time	Interval (s)	Motor Status	Description
1	17:38:49	-	0	**OFF**
2	17:39:22	33	0	
3	17:40:27	5	0	
4	17:41:01	34	0	
5	17:41:35	34	0	
6	17:42:07	32	0	
7	17:42:39	32	0	
8	17:43:12	33	0	
9	17:43:25	13	1	**ON**
10	17:43:32	7	1	
11	17:43:39	7	1	
12	17:43:48	9	1	
13	17:43:54	6	1	
14	17:44:02	8	1	
15	17:44:10	8	1	
16	17:44:17	7	1	
17	17:44:31	14	0	**OFF**
18	17:45:05	34	0	
19	17:45:37	32	0	
20	17:46:10	33	0	

The data results presented in Table 1 align with the programmed commands. However, errors may arise due to device malfunctions, as evidenced by the third row. Additionally, the system can encounter errors when it detects rapid changes in motor status within a very short timeframe. In such cases, the system promptly sends an uplink signal before the motor status actually changes. Instances of this type of error are visible in rows 9 and 17 of Table 1.

5. Conclusion

The designed system is successfully used to monitor the location and speed of vehicles via MOTRAV application. The location and speed shown has an interval of less than 10 seconds when the vehicle is in use and can adaptively change to more than 30 seconds when the vehicle is not in use to reduce power usage. Those intervals can be adjusted as needed to reduce power usage even further. The system can also receive instructions in the form of downlink signals with a success percentage of 65%. The 35% failure rate out of 20 trials is due to interference of the uplink signal with the downlink signal where LoRa cannot send and receive signals concurrently. Vehicles that have been integrated with the system can have their engines turned off via the MOTRAV application if the device successfully receives the instruction signal. Vehicle safety can also be enhanced with "parking mode", where in this mode if the vehicle engine is detected to be started and the vehicle is moving at a speed of more than 5.5 km/h, the vehicle owner will receive a warning notification through the MOTRAV application.

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