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Design of an Early Warning System at Train Crossings Based on Long-Range Vibration Sensors Embedded with an Internet of Things (IoT) Microcontroller

R. Gaguk Pratama Yudha [1], Novi Vitria[2], R. Akbar Nur Apriyanto [3], Wahyu Pribadi[4], Bi Asngali[5], R. Oktav Yama Hendra[6], Ikhsan Rizki Ramadhan[7], Ridwan Mashuri[8]
[1,2,3,4,5,6,7,8]Department of Engineering, State Polytechnic of Madiun, Madiun, East Java, Indonesia

Abstract**—***Railway transportation, as one of the primary modes of transport for both passengers and freight, inherently prioritizes safety, comfort, and security throughout its operation. The implementation of an Early Warning System (EWS) at railway crossings has proven to be an effective approach in reducing the high incidence of accidents, which are often attributed to human error and unsafe actions. This study aims to design a device capable of monitoring train arrivals via a smartphone-based application. The system output includes the calculation of average vibration values to determine the vibration range of different objects, along with real-time notifications of approaching trains. The experimental results indicate that the average vibration levels recorded for hybrid trains range from 0.95 m/s² to 4.00 m/s², inspection trains range from 0.31 m/s² to 0.40 m/s², and automobiles range from 0.09 m/s² to 0.10 m/s². In conclusion, the proposed system enhances safety at railway crossings by providing accurate and timely early warnings, thereby improving situational awareness for both road users and crossing operators.*

Keywords**—***Vibration, Early Warning System, Long Range, Internet of Things.*

I. INTRODUCTION

Trains are a land transportation mode that is predominantly used for long-distance travel between cities and provinces. Therefore, railway operators are obliged to prioritize passenger safety in accordance with Law No. 23 of 2007 on Railways, Article 133 [1]. However, most train accidents occur due to negligence by railway crossing officers or road users who forcefully cross the tracks [2]. This situation is worsened by the absence of an implemented Early Warning System (EWS) on railway tracks.

The Regulation of the Minister of Transportation No. 24 of 2015 concerning Railway Safety Standards requires that level crossings be equipped with signs, markings, traffic signal devices, crossing gates, and crossing guards employed by railway infrastructure operators [3]. Many accidents at railway crossings are caused by the absence of crossing gates or failure of the gates to operate when needed [4].

An Early Warning System, or early detection system, can reduce the number of accidents, which has become a major issue today, and has already been widely applied at railway crossings. In 2018, accident rates at railway crossings increased where no Early Warning System was in place. The implementation of an Early Warning System on railway tracks, particularly at locations far from railway crossings, also requires sensors capable of detecting incoming trains. Vibration sensors can significantly help minimize such accidents. However, using cables over long distances would be more costly, and signal network installation for communication is less effective compared to wireless technology. Therefore, Long Range (LoRa) technology is considered more efficient for long-distance communication.

LoRa is a wireless communication system commonly used in the Internet of Things (IoT) [5]. However, LoRa technology only enables communication between microcontrollers for sending and receiving data. Therefore, for real-time monitoring of train arrivals, railway crossing operators need technology that connects directly to smartphones.

Based on these problems, the researchers designed an “Early Warning System Design for Train Crossings Based on Vibration Sensors - Long Range Embedded Microcontroller Internet of Things (IoT)”. This device utilizes an accelerometer sensor, relay, lights, buzzer, and an ESP32 microcontroller. By employing IoT technology, the collected data is directly connected to a smartphone. When the sensor detects vibrations generated by an approaching train, it will send a notification to ensure that railway crossing operators and road users remain alert and avoid accidents.

II. METHODOLOGY

The method used in this research is design and experimental. The design method is a systematic process in planning and developing a new system into an integrated unit. In this research, several stages are required to facilitate the design process, as illustrated in the flowchart below.

1. Literature Review

The method used in designing train monitoring using vibration sensors involves collecting data from several sources, including journals, articles, previous thesis reports, and other sources.

2. Tool Design

Tool design is the initial step before developing a train monitoring system. This method is used to design an Internet of Things (IoT) system. "Early Warning System Design for Train Crossings Based on Vibration Sensors - Long-Range Embedded Microcontroller" generally requires several stages.

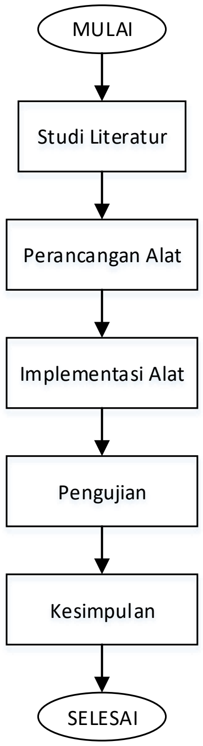

Figure 2. 1 Research Stages

3. *Implementation*

The development process of software for monitoring vibration acceleration measurements using sensors is carried out by programming on the Arduino IDE available on the device; Once the design is complete, validation and revisions are necessary. Error indicators are present in the device's software and hardware if the system is not connected and readable. This stage ensures the device operates as expected; In the implementation of the transfer system, the process of retrieving and processing data from hardware is carried out through a LoRa signal network connection with other connected LoRa signals.

4. *Testing*

Testing is performed to ensure the system is operating as expected. Before testing, it's a good idea to test each component. If the system isn't detected or isn't displaying output, retesting will be performed. The purpose of this testing is to determine the device's design results and analyze errors and deficiencies.

5. *Conclusion*

Conclusions are drawn based on the results obtained from testing that the system is running according to its function.

2.1 Research Design

2.1.1 Transmitter

Figure 2.2 shows the figure of the using Transmitter for I2C communication.

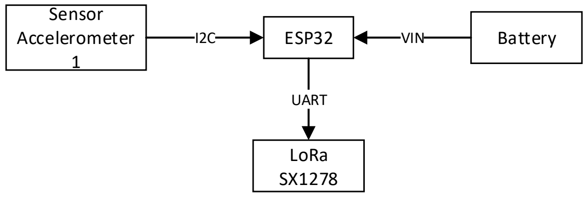

Figure 2. 2 Transmitter Block Diagram

Figure 2.2 This system uses I2C communication to send and receive data from the MPU6050 accelerometer sensor to the ESP32 via the SCL and SDA pins. UART is the ESP32's communication protocol on the RX/TX pins, which LoRa uses to send and receive data between devices.

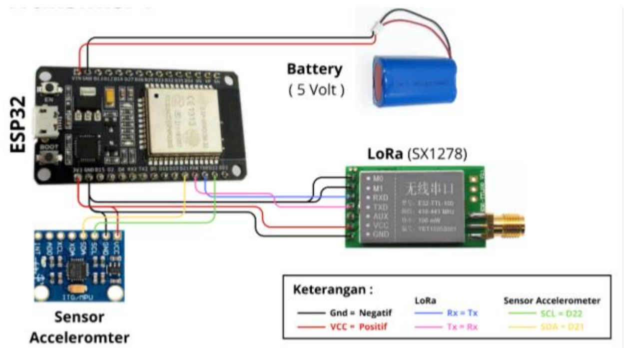

Figure 2. 3 Transmitter Wiring Schematic

The data sending system (transmitter) uses components such as the ESP32 microcontroller as a microcontroller used to regulate operations and provide power to the sensor and manage LoRa communications, the accelerometer 1 sensor acts as a detector of trains from the south or north which can activate the Early Warning System, the battery as a source of 5 volts, and the LoRa SX1278 as communication between the transmitter and receiver.

2.1.2 Receiver

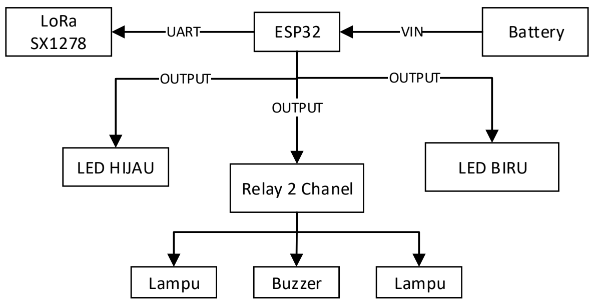

Figure 2. 4 Receiver Block Diagram

This system uses I2C communication to send and receive data from the MPU6050 accelerometer sensor to the ESP32 via the SCL and SDA pins. UART is the ESP32's

R. Gaguk Pratama Yudha, Novi Vitria, R. Akbar Nur Apriyanto, Wahyu Pribadi4, Bi Asngali, R. Oktav Yama Hendra, Ikhsan Rizki Ramadhan, and Ridwan Mashuri, "Design of an Early Warning System at Train Crossings Based on Long-Range Vibration Sensors Embedded with an Internet of Things (IoT) Microcontroller," *International Research Journal of Advanced Engineering and Science*, Volume 10, Issue 4, pp. 60-64, 2025.

communication protocol on the RX/TX pins, which LoRa uses to send and receive data between devices. There are also several outputs, including LEDs, buzzers, and lights.

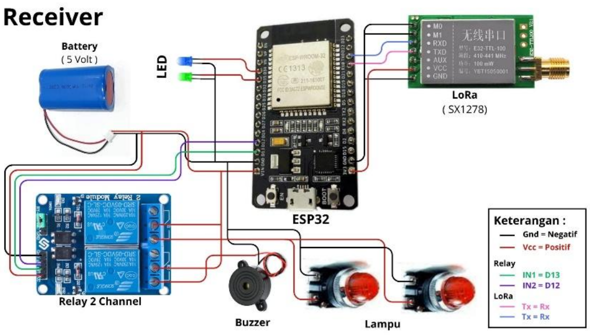

Figure 2. 5 Receiver Wiring Schematic

The data receiver system uses components such as an ESP32 microcontroller, battery, LoRa SX1278, two-channel relay, lights, buzzer, and LEDs. Each component has a specific function. The ESP32 serves as the brain of the system. The power source is a 5-volt battery, and the LoRa SX1278 is used for communication between the transmitter and receiver. Additionally, the receiver has outputs, as shown in the image above, including an LED, a light, and a buzzer. The LED serves as an output indicator that tracks the train's direction. Two lights are present because the train barrier logic operates when the barrier is open and closed.

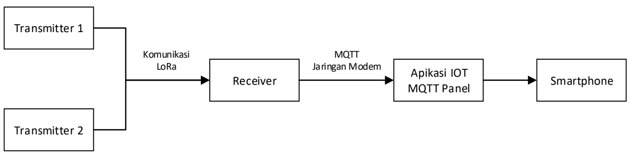

Figure 2. 6 Overall System Block Diagram

Based on the system's operating principle, the data obtained by both transmissions is sent to the receiver as output from both transmissions. The data obtained by the receiver is then received by the smartphone via the Internet of Things (IoT), using the smartphone's hotspot network, which is read through the IoT MQTT Panel application.

Figure 2. 7 Equipment Placement

The transmitter and receiver were installed on the Madiun State Polytechnic railway test track. The receiver was placed in the Madiun State Polytechnic Station Laboratory. The transmitter was placed on the tack marked as shown in Figure 2.7.

2.2 System flowchart

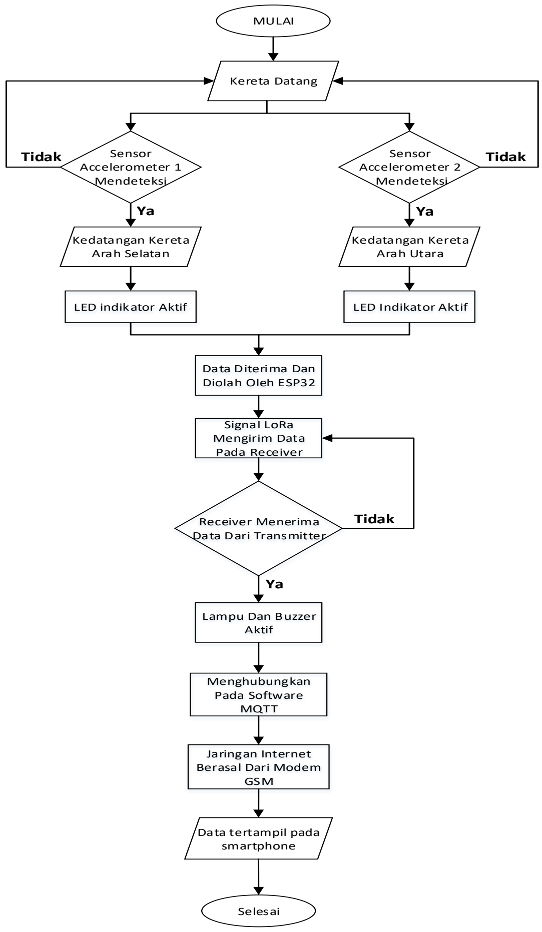

Figure 2. 8 System Flowchart Early Warning

In this flowchart explanation, there are two conditions when the train arrives because this tool is used when the train comes from the south or from the north. In one of these conditions, there may be two accelerometer sensors, namely accelerometer sensor 1, and accelerometer sensor 2. If accelerometer sensor 1 detects a train coming from the south, then the LED indicator will light up to tell us that the train is coming from the south. If accelerometer sensor 2 detects that the train is coming from the north, the LED indicator will light up to show that the train is coming from the north. After the data is received and processed by the ESP32, the LoRa signal will be sent or transferred to the receiver via inter-LoRa communication. This indicates whether the receiver has received data from the sensor or not. If it does, the receiver will resend or repair inter-LoRa communication. If it does, then the actuator will be active such as a buzzer, a light. If the data has been sent to the recipient, the next process connects the recipient to mqtt via the internet network from the smartphone hotspot, and if it is connected, the data detected and processed by the receiver can be monitored and displayed on our smartphone and the process is complete.

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III. RESULTS AND ANALYSIS

The results of the hardware system design for a vibration measuring device using the MPU6050 accelerometer sensor based on IoT (Internet of Things). The MPU6050 accelerometer sensor will act as the main sensor that detects and measures acceleration on three axes (x, y, and z) with a high level of precision.

Figure 3. 1 Research Tools Hardware

This can be seen from the design, which aims to be resistant to sunlight so that the components don't overheat during data collection, allowing them to function effectively.

The software development process requires several crucial steps. First, the ESP32 is installed in the Arduino IDE so that the microcontroller can be programmed. The next step is writing the program code using the Arduino programming language, which includes initializing and configuring the MPU6050 accelerometer sensor via the I2C interface connected to the ESP32. Calibration of the MPU6050 accelerometer sensor is crucial during the programming phase. This is achieved by adding offset coding to compensate for the sensor's offset value. Offset is the value that appears on the sensor output when the sensor is stationary or without actual acceleration. Adding offset coding aims to eliminate or minimize the effect of this offset on the measurement. When designing the monitoring software for the IoT MQTT Panel on the dashboard, several outputs are displayed.

3.1 Testing the MPU6050 Accelerometer Sensor

Testing of a vibration measuring system using the MPU6050 accelerometer sensor on the Madiun State Polytechnic Hybrid Train was conducted to evaluate the device's performance in detecting, measuring, and monitoring vibrations in the vehicle. To validate the data, data was collected using the Physics Toolbox Accelerometer application running on a smartphone.

Figure 3. 2 Application for Sensor Validation

The measurement data was then collected and organized in the tables below. These tables contain comprehensive summaries of the sample data successfully recorded from both accelerometer sensors and smartphone data.

TABLE 3.1 Sensor Validation 1

Sensor Accelerometer 1

X	Y	Z	HP X	HP Y	HP Z	%Error		
						X	Y	Z
-0,00	0,01	1,00	-0,001	0,011	1,002	0,00	1,10	1,00
-0,00	-0,00	1,00	-0,002	-0,004	1,00	0,00	0,00	1,00
0,01	-0,00	0,99	0,011	-0,003	0,999	1,10	0,00	0,99
0,00	-0,00	0,99	0,003	-0,004	0,964	0,00	0,00	0,96
0,00	-0,00	1,00	0,005	-0,004	1,001	0,00	0,00	1,00
-0,00	-0,00	1,00	-0,003	-0,005	1,001	0,00	0,00	1,00
Rata-Rata Presentase *Error*						0,18	0,18	0,99

Table 3.2 Sensor Validation 2

Sensor Accelerometer 2

X	Y	Z	HP X	HP Y	HP Z	%Error		
						X	Y	Z
-0,02	-0,01	1,01	-0,023	-0,015	1,015	2,30	1,50	1,01
-0,03	-0,00	1,00	-0,032	-0,008	1,001	3,20	0,00	1,00
-0,02	-0,00	1,00	-0,024	-0,003	1,007	2,40	0,00	1,00
-0,03	-0,00	1,00	-0,035	-0,008	1,005	3,50	0,00	1,00
-0,02	-0,00	1,00	-0,025	-0,002	1,002	2,50	0,00	1,00
-0,03	-0,00	1,00	-0,037	-0,009	1,003	3,70	0,00	1,00
Rata-Rata Presentase *Error*						2,93	0,25	1,00

The data obtained from the error percentage is good, it can be said to be good because it does not exceed 5% so that the sensor can be used for data collection effectively.

3.2 Long Range (LoRa) Testing

TABLE 3.3 LoRa Testing

Kondisi	Jarak Jangkauan	Rata-Rata Delay (ms)
Tanpa Halangan	200m	383,125
	400m	397,125
	600m	397,125
	800m	401,25
	1000m	679,375
Adanya Halangan	20m	301,25
	40m	446,125
	60m	709,125

The data obtained shows that distance significantly affects transmission delay. Furthermore, LoRa also has limitations when used in areas with many tall buildings or other obstacles, which can reduce the effective communication distance between devices. Thus, in an unobstructed environment, LoRa is unable to maintain good performance over distances exceeding 1 km. Therefore, distance, antenna height, and testing location significantly affect communication between sender and receiver.

3.3 Analysis of MPU6050 Accelerometer Sensor Readings

TABLE 3.3 Vibration Range

No.	Jenis Objek	Range Getaran (m/s^2)	Keterangan
1.	Kereta *Hybrid* PNM	0,95 - 1,08	Lintasan Lurus
		3,11 - 4,00	Lintasan Belok
2.	Kereta Inspeksi	0,31 -0,40	Lintasan Lurus
		0,32 - 0,38	Lintasan Belok
3.	Mobil	0,09 - 0,10	Melintasi Rel

Based on Table 3.3, it is shown that the accelerometer sensor can detect various objects, resulting in different vibration ranges. For the PNM hybrid train running on a straight track, the vibration range is between 0.95 m/s² and 1.08 m/s². When turning, the vibration increases to between 3.11 m/s² and 4.00 m/s². This difference indicates that turning conditions generate noise caused by friction between the wheels and the rail surface.

Meanwhile, the inspection train produces vibrations in the range of 0.31 m/s² to 0.40 m/s², and when turning, between 0.32 m/s² and 0.38 m/s². The significant difference between the inspection train and the PNM hybrid train is due to weight and size.

On the other hand, the vibrations generated by cars show a range of 0.09 m/s² to 0.10 m/s². This indicates that vibrations on the rail caused by passing cars are influenced by the structure and material of the road crossing. The structure and material of the crossing, such as concrete or asphalt, can affect how vibrations from the rail are transmitted to the surrounding environment. Denser or stiffer road crossings may absorb vibrations better than others.

3.4 Long Range Communication Analysis (LoRa)

Transmitter 1	*Receiver*	Keterangan
		Arah Utara

Figure 3. 3 Long-Range Communication in the North

Based on how a system works, LoRa communication can function properly. This is demonstrated by the way the sensor detects an object, the LED indicator on the transmitter lights up, and the receiver responds by activating the incoming direction indicator LED and activating the buzzer.

Transmitter 2	*Receiver*	Keterangan
		Arah Selatan

Figure 3.4 Long-Range Communication in the Southbound Direction

LoRa communication on the transmitter sends accurate data when detecting objects such as trains or other objects. This was proven through thorough system testing. When the sensor detects an object, the LED indicator on the transmitter lights up. This response is then relayed to the receiver, which activates the incoming direction LED and buzzer. This process ensures that every object detection is responded to quickly and clearly. Furthermore, the system has demonstrated consistency in data transmission, ensuring reliability in all operations.

3.5 Internet of Things (IoT) Analysis

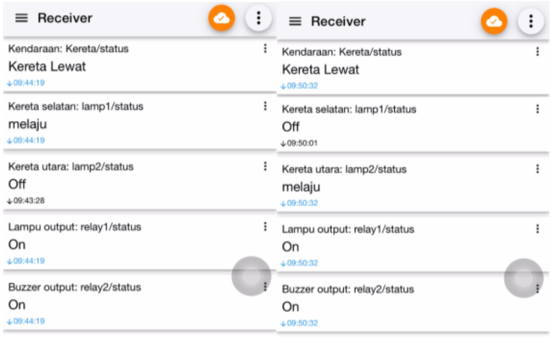

Figure 3.5 Monitoring on IoT Mqtt Panel

These notifications ensure that employees are always alert to incoming trains, improving safety and efficiency. The system can detect trains coming from the south or north, allowing for real-time monitoring of each train's arrival. These notifications allow employees to take immediate action, reducing the risk of human error and ensuring timely operation of the barriers to avoid accidents.

IV. Conclusion

Based on the research results, it can be concluded that the MPU6050 accelerometer sensor is capable of detecting vibrations, thus determining the range of several objects such as trains and cars. Then, software was designed to display vibration values and notifications to facilitate remote data monitoring. The vibration values obtained from each object vary due to several factors such as size, weight, and the type of rail surface passed over. LoRa communication can be affected by distance, antenna height, and also the testing location.

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