Improved Safety and Communication for Railway Track Maintenance Workers Using IoT-Enabled Alert System

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Abstract: *Railway stations frequently face safety concerns, particularly at track and platform edges, especially during peak working hours when crowds increase, Lack of proper training on safety protocols and equipment. The close proximity to trains poses risks for railway workers. To mitigate these hazards and enhance safety at railway platforms, a targeted improvement method has been identified. Our research paper suggests using an Internet of Things (IoT) device to improve communication and safety for track maintenance workers. It deals with the regular accidents brought on by poor communication between station masters and laborers. By quickly notifying supervisors and tracking personnel when it detects vibrations on the track, the suggested gadget reduces the possibility of accidents. The design, implementation, testing, and efficiency of the device in enhancing worker safety and communication on the track are all covered in depth in this report. This paper offers important new perspectives on how to apply IoT ideas to improve workplace safety and communication in risky situations. India has a vast railway network, and maintaining the tracks there presents significant safety risks for workers. This research provides a viable solution applicable to Indian railway systems by addressing the problem of inadequate communication and safety in track repair. Putting the suggested IoT gadget into use might significantly lower accident rates and increase worker safety in India's railway industry. This method successfully achieved its objectives, resulting in the development of a railway worker's safety device. This device raises safety awareness and has the potential to reduce accidents among Railway Track Maintenance Workers.*

Keywords: *Arduino, Alerting System, Radio Frequency, Internet of Things, Microcontroller*

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Nomenclature

Abbreviation	Expansion
OLED	Organic Light light-emitting diode
Li-ion	Lithium-ion
SPI	Serial Peripheral Interface
IoT	Internet of Things

1 Introduction

In India, the rail network is one of the primary modes of transportation, and its scope continues to grow with the increasing demand for both passenger and freight movement [1]. Ensuring the safety of railway track maintenance workers is a critical challenge that has not been fully addressed by existing solutions. While previous efforts have focused primarily on warning systems for train drivers or passengers, the safety of workers on the tracks remains a pressing concern. Workers often operate close to active tracks. A lack of awareness or miscommunication about train schedules can lead to collisions. Low light conditions or adverse weather can reduce visibility, making it difficult for workers to see approaching trains or hazards.

In recent years, advancements in technology, particularly the IoT, have opened new avenues for enhancing safety and communication in various industries. Leveraging real-time data, automated alerts, and seamless communication channels reduces the risks associated with track maintenance operations.

The integration of IoT technology not only enhances situational awareness but also fosters a proactive safety culture among workers.

Our proposed IoT-enabled Railway Alert System offers a novel and innovative approach to this problem by providing real-time alerts to track maintenance workers about approaching trains. This is particularly important in scenarios where traditional communication methods, such as walkie-talkies, may be unreliable due to environmental factors or signal interference. The system employs vibration sensors to detect the movement of trains and uses wireless communication technologies to transmit alerts directly to workers in real time. This solution not only fills a critical gap in current railway safety systems but also enhances worker safety by addressing the unique challenges faced by track maintenance crews. The system's ability to provide real-time alerts represents a significant improvement over existing safety measures, making it a valuable contribution to railway safety innovation.

This paper is organized as follows. Section 2 explains the Literature review. Section 3 detailed the methodology. Section 4 portrays the Experimental results. Section 5 discusses the discussion of result. Section 6 mentions the advantages and disadvantages of the proposed method. Finally, section 7 concludes the paper along with the future scope.

2 Literature Review

Indian Railways is one of the largest railway networks in the world and it relies on various forms of communication for its operations. Here are some of the types of communication used by Indian Railways:

A. **Verbal communication:** This is essential for train announcements, ticketing, onboard information, customer service, and coordination among staff. It is used to inform passengers about train arrivals, departures, delays, and cancellations, and provide them with ticket prices, availability, and class options. Staff members use it to offer important information, safety instructions, and customer service, as well as coordinate operations such as train movement, platform allocation, and maintenance schedules [2].

B. **Written communication:** This plays a vital role in Indian Railways, serving as a means of official correspondence, record-keeping, and providing critical information to passengers. It is used for memos, circulars, notices, reports, train schedules, and timetables. Signboards and displays are used at railway stations and on-board trains to convey essential information, including station names, platform numbers, and train timings. Passengers are required to provide written details during the ticketing process, especially for long-distance or reserved travel. Additionally, safety instructions are communicated through written communication, printed on tickets, displayed on signboards, and communicated through posters [21].

C. **Electronic communication:** This has become an indispensable part of Indian Railways, transforming its operations and improving the passenger experience [8]. The online ticketing services offered through the official website and mobile application have revolutionized the ticketing process, enabling passengers to book tickets, check availability, and make payments electronically without visiting a railway station. The passenger information system, powered by electronic displays at railway stations and on-board trains, provides real-time information about train schedules, delays, cancellations, and other relevant details. E-mail and messaging services have enabled Indian Railways to communicate with passengers and staff members efficiently, providing them with up-to-date information about train schedules, delays, and cancellations. The use of GPS and tracking systems has enhanced the safety and security of passengers, enabled the real-time monitoring of train movement, and shared information through electronic displays and other communication channels. Indian Railways has also adopted social media platforms like Twitter and Facebook to communicate with passengers, providing them with the latest information about train schedules, delays, cancellations, and other relevant details [22].

D. **Visual communication:** This is a vital part of Indian Railways, providing important information to passengers and staff who may face difficulties with written or verbal communication. Maps and diagrams are displayed at railway stations and onboard trains to provide information about train routes, station locations, and other relevant details. Signage is used to display information about station names, platform numbers, and other relevant information. Visual communication is also used to provide safety instructions to passengers through posters, signage, and other visual aids. Electronic display screens are used to provide real-time information about train schedules, delays, and other relevant information, which can be displayed at railway stations and on-board trains. Additionally, visual communication is used for branding and marketing purposes, utilizing logos, graphics, and other visual elements to promote the Indian Railways brand and services [3].

E. **Emergency communication:** This is crucial to ensure the safety of passengers and staff members in Indian Railways. Passengers can activate the emergency brake or alarm to alert the train driver and other staff members in case of an emergency. Emergency response teams equipped with communication equipment are deployed to deal with emergencies. The public address system is used to make announcements and provide instructions to passengers during emergencies. Indian Railways has established an emergency communication protocol to ensure effective and efficient communication during emergencies.

F. **Track maintenance worker communication:** In India, track maintenance workers have several methods to receive notifications of approaching trains to ensure their safety while working on or near the tracks. These include:

- **Walkie-talkies**: This is the most common method of communication between track maintenance workers and train drivers. Walkie-talkies allow workers to stay in constant contact with the driver and be alerted immediately of any approaching trains.
- **Radio communication:** Indian Railways also uses radio communication to communicate with track maintenance workers. This is especially useful in areas where walkie-talkie communication may not be reliable, such as in tunnels or remote areas.
- **Flagmen:** Flagmen are used to warn track maintenance workers of approaching trains. Flagmen are typically stationed at a safe distance from the tracks and use flags or other signals to alert workers of oncoming trains.
- **Trackside alarms:** Trackside alarms are devices that are installed along the tracks to alert track maintenance workers of approaching trains. These alarms can be triggered by the presence of a train or by the manual activation of a switch.

Indian Railways is committed to the safety of its passengers and staff members, and it uses a variety of communication methods to ensure that everyone is safe and informed. They may station workers as lookouts at a distance from the work site, who are trained to visually identify and signal the approach of trains. Workers may also use whistles to signal to each other and to train engineers that they are working on the tracks [9]. Railway signals installed at various points along the tracks provide warning to workers of approaching trains. These signals are often accompanied by audio warnings that workers in the vicinity can hear. Workers may use wireless sets to communicate with each other and with train dispatchers, who can alert them to approaching trains. Additionally, workers may use flagging equipment to indicate to train engineers that workers are present on the tracks. Some workers may use personal alert devices that vibrate, sound an alarm, or emit a flashing light when a train is approaching [11].

2.1 Literature Gap

Prior research has mostly concentrated on enhancing communication between station masters and passengers, ignoring the necessity of improved safety precautions and communication for railway employees [10]. The communication in the walkie-talkies can be disrupted by electromagnetic interference from railway signals, overhead lines, or other electronic equipment, leading to missed or unclear messages. The trackside alarms may trigger unnecessarily due to environmental factors, equipment malfunctions, or human error, causing confusion and leading to alarm fatigue. Adverse weather conditions (fog, rain, snow) and nighttime operations can significantly reduce the visibility of flags, making communication ineffective. Through the resolution of the shortcomings of current technologies, such as CCTV and walkie-talkies, the Internet of Things gadget seeks to dramatically increase worker safety for railway track maintenance personnel. By providing several essential characteristics, the IoT gadget lowers the chance of mishaps and railway worker injuries. The device can give on-spot alerts and is less affected by other technologies. The suggested Internet of Things gadget seeks to close this gap by detecting vibrations and other signals from passing trains using a variety of sensors. The data is subsequently wirelessly sent to a central server or control room, facilitating real-time communication and giving pertinent staff precise information on any threats. The suggested IoT gadget affects worker safety by giving precise and timely notice of impending trains.

3. Methodology

The proposed device consists of a sensor that detects vibrations, a microcontroller that processes the data, and a wireless communication module that transmits alerts to a supervisor and workers via their smartphones or other mobile devices. The device was designed, implemented, and tested to improve safety and communication for track maintenance workers. The prototype was tested in a controlled environment to simulate vibrations caused by a train passing by the track. Results showed that the device accurately detected vibrations and sent alerts to the appropriate parties, allowing for preventive action to be taken to avoid accidents. Fig. 1 shows the Arduino transmitter interface.

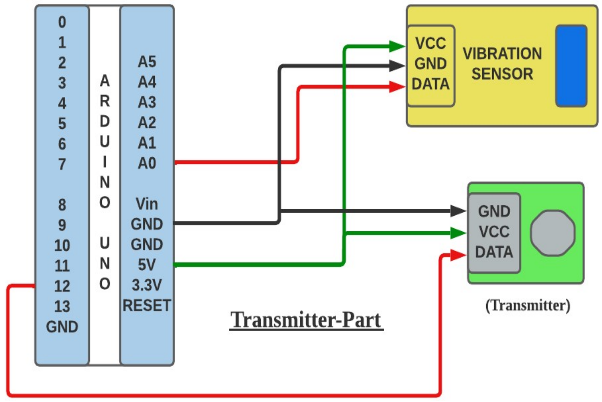

Fig 1. Arduino-Transmitter Interfacing

The Arduino Uno is the brain of the system. It controls and coordinates the various components of the system. In this setup, the Arduino Uno provides power to both the vibration sensor and the transmitter while ensuring a common ground connection. The vibration sensor detects any train movement or vibrations on the tracks. The detected vibrations send an analog signal to one of the Arduino's analog input pins. The Arduino processes this data according to its programmed logic, such as determining the intensity of the vibration or setting conditions. The RX and TX module sends alerts to the maintenance workers when the vibration sensor detects a train. Once the data is processed, the Arduino sends the information to the transmitter via a connected data pin. The transmitter then wirelessly sends this data to a remote device or receiver, enabling wireless monitoring or further processing of the vibration readings. The OLED display shows the status of the system, such as whether it is armed and ready or if it has detected a train. The buzzer alerts the maintenance workers of any potential hazards, such as an approaching train. The 18650 Li-ion battery powers the system.

3.1 Component Description

The system is built using the following components:

- **Arduino Uno:** The Arduino Uno is a microcontroller board used for building electronic projects. In the context of the IOT-enabled Railway Alert System, the Arduino Uno is responsible for controlling and coordinating the various components of the system (Fig. 2).
- **Vibration sensor:** A vibration sensor, also known as an accelerometer, is a device used to detect vibration or motion. In the context of the IOT-enabled Railway Alert System, the vibration sensor is used to detect any train movement or vibrations on the tracks (Fig. 3).
- **RX and TX modules:** The RX-TX module is a wireless communication module used to transmit and receive data wirelessly between two devices. In the IOT-enabled Railway Alert System context, the RX-TX module sends alerts to the maintenance workers (Fig. 4).
- **OLED display:** An OLED display is a type of display technology that uses organic materials to emit light when an electric current is passed through it. In the context of the IOT-enabled Railway Alert System, the OLED display is used to show the status of the system (Fig.5).
- **Buzzer:** The buzzer is an electronic component that produces a loud, audible sound when an electric current is passed through it. In the context of the IOT-enabled Railway Alert System, the buzzer is used to alert the maintenance workers of any potential hazards (Fig. 6).
- **18650 Li-ion battery:** The Li-ion battery is a rechargeable battery that uses lithium ions to store and release energy. The system is powered by an 18650 Li-ion battery, making it easy to install and use (Fig. 7).

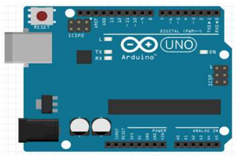

Fig 2. Arduino UNO

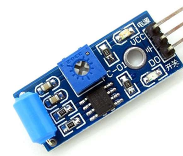

Fig 3. Vibration Sensor

Fig 4. Receiver and Transmitter module

Fig 5. OLED Display

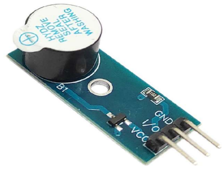

Fig 6. Buzzer

Fig 7. 18650 Li-ion battery

3.2 Transmission Module

The device has two parts i.e., Transmitter-part and Receiver-part. The Transmitter-part of the device is responsible for transmitting data from the vibration sensor to the receiver module wirelessly (Fig.8). It consists of two main components, namely the vibration sensor and the transmitter module. The vibration sensor is responsible for detecting and measuring the vibrations and converting them into electrical signals. These electrical signals are then transmitted wirelessly using the transmitter module (Arduino Uno), which uses a variety of wireless communication protocols, such as Radio Frequency (Fig.8). The transmitter part plays a critical role in ensuring that the vibration data is transmitted accurately and efficiently to the receiver module [5]. The receiver is powered by the Arduino and communicates the received data through a connected digital pin.

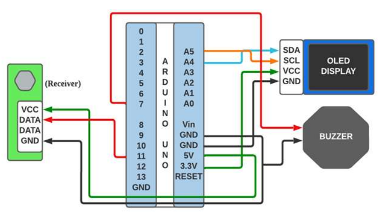

Fig 8. Arduino-Receiver Interfacing

3.3 Receiver Module

In the receiver module, the buzzer and OLED display module are connected with Arduino-UNO (Fig.8). Arduino Uno acts as the central microcontroller that processes the data received from the receiver. The Arduino reads the data coming from the receiver and uses that data to control other components like the OLED display and the buzzer. OLED Display is used for displaying the received data visually and the buzzer provides an auditory alert based on the data received. For instance, if the received data triggers a threshold or event, the Arduino activates the buzzer to notify the user. This setup allows for real-time monitoring and feedback, combining both visual and auditory outputs to indicate system status or alerts.

3.4 Vibration-Buzzer Process

We have used two libraries: "RH_ASK.h" and "SPI.h". "RH_ASK.h" is the RadioHead library for RF communication, while "SPI.h" is a library that enables communication with devices that support the SPI protocol. In the "setup ()" function, serial communication is initiated at 9600 baud, and the RF driver is initialized using "driver.init()". If the initialization fails, the serial monitor displays an "init failed" message. The vibration sensor's data pin is connected to A0. In the "loop()" function, the analog value of the vibration sensor is read using "analogRead()" and printed to the serial monitor with "Serial.println()". The strength of the vibration is determined by comparing the sensor value, and if it is greater than 1000 but less than or equal to 5000, the vibration intensity (represented as V in Table 1) is moderate, and the message "1" is sent using "driver.send()". The "driver.waitPacketSent()" function is used to wait for the message to be sent, and a 1000-millisecond delay is added to allow time for the message to be conveyed. The message "1" is then received by the serial monitor. If the sensor reading is greater than 5000, the vibration is strong, and the message "2" is sent using the same process as before. After a 1000 millisecond delay, the message "2" is printed to the serial monitor. The code allows a device's transmitter to wirelessly read data from a vibration sensor and send it using an RF module and the "RadioHead" library.

In the "setup()" function, the RF driver is initialized, and the OLED display is initialized with the I2C address 0x3C. The OLED display is then cleared, the text size is set to 1, and the text color is set to white. In the "loop()" function, the display is cleared, and the text size is set to 2.8. A "Working" message is then displayed on the OLED display. The digital output pin 7 is set to low, and the buffer length and buffer data are declared. If the RF driver receives data, the data is printed to the serial monitor, and the received message is converted to a string. If the received message is "1", the "Train is Near" message is then displayed on the OLED display, and the buzzer is activated five times with a one-second delay between each activation (Table 1). If the received message is "2", an "Alert" message is then displayed on the OLED display, and the buzzer is activated two times with a five-second delay between each activation (Fig.10). The code allows the RF driver to receive messages, and depending on the message, appropriate action is taken, such as displaying a message on the OLED display and activating the buzzer.

***Table 1.* Vibration-Buzzer Alert Log**

Message ID	Vibration	Message	Beep Delay	Buzzer Alert
1	1000<V<5000	Train is Near	1 Second	5 Times
2	V>5000	Alert	5 Seconds	2 Times
##	V<1000	All Clear	OFF	0

4. Experimental Result

In the transmission module, when the vibration is received from the sensor If the value is between 1000 and 5000 are over then the OLED display shows either "Train is Near" or "Alert," which is represented in Fig. 9.

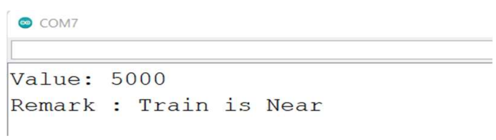

***Fig 9.* Vibration sensed by sensor**

The vibration sensor is connected to A0 and its analog value is read in the "loop()" function. If the value is between 1000 and 5000, it sends the message "1" indicating moderate vibration. That is represented in Fig 10.

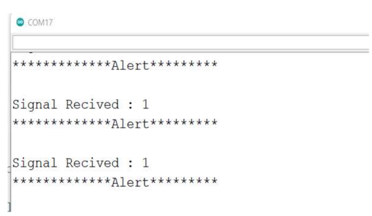

***Fig 10.* Massage received by Receiver**

Apart from that the IoT device is designed to improve railway worker safety by providing real-time hazard detection, which is crucial for preventing accidents. It delivers rapid communication, sending alarm signals within 10 to 15 milliseconds, ensuring workers receive immediate alerts. The device enhances worker safety by notifying them of potential dangers, like approaching trains, and is reliable across various weather conditions, maintaining consistent performance. Its implementation is expected to significantly reduce accident rates by addressing communication gaps. Additionally, the device's user-friendly design ensures that workers can easily understand and respond to alerts, even in high-pressure situations.

5. Discussion

The implementation of the IoT-enabled alert system significantly enhanced the safety of railway track maintenance workers by providing real-time communication and hazard detection. The study's findings revealed a reduction in near-miss incidents and an improvement in the response time to emergencies compared to traditional manual methods. These results align with previous research that emphasized the effectiveness of real-time communication in reducing risks for trackside workers.

Moreover, the IoT system's ability to detect incoming trains and communicate alerts through wearable devices contributed to a safer work environment, as workers were better prepared to evacuate the track area promptly. This capability was particularly useful during night shifts or in areas with limited visibility, where human perception is often compromised. The study thus validates the role of IoT technology in enhancing situational awareness and reducing human error in critical safety operations.

One of the key strengths of the IoT-enabled system was its scalability and ease of integration into existing railway infrastructure. The findings indicated that the system can be adapted to various track conditions and maintenance schedules, offering a flexible solution for different railway operators. However, challenges such as initial setup costs and the need for periodic calibration of sensors were identified as potential barriers to widespread adoption. Addressing these issues through cost-benefit analysis and government support could facilitate more extensive implementation.

This study also contributes to the ongoing discussion on digital transformation in the railway industry by demonstrating that IoT solutions can bridge the gap between safety and operational efficiency. The improved communication between workers and central control units not only reduced safety risks but also optimized track maintenance schedules. These improvements can lead to reduced downtime and increased overall productivity, which are critical for the operational success of railway companies.

Future research could explore the integration of advanced AI-based predictive models with the IoT alert system to forecast potential risks and automate safety measures further. Additionally, studying the long-term impact of such systems on worker satisfaction and mental well-being could provide deeper insights into the broader implications of adopting IoT-based safety technologies in the railway sector.

6. Advantages and Disadvantages

Advantages

- Workers can take instant safety precautions thanks to its early warning system's capacity to detect vibrations and other signs from passing trains.
- Wireless data transfer to a central server or control room guarantees that pertinent staff members have instant access to the information, enabling them to make deft judgments in real time.
- The IoT gadget is a workable and affordable option to raise worker safety in the railway sector since it is simple to incorporate into current communication networks.

Disadvantages

- The system relies heavily on technology, which may pose challenges in areas with poor network coverage or technological infrastructure. If the wireless communication fails due to signal interference or environmental factors.
- The initial costs associated with implementing the system, maintenance, and upkeep lead to additional operational costs and resource allocation.
- The system is specifically designed for railway track maintenance workers, which may limit its applicability in other areas of railway operations or different industries. This specificity could restrict the broader adoption of the technology.

7. Conclusion

In conclusion, this research suggests an IoT gadget that is intended to increase safety and communication among Indian railway employees. The gadget fills the current vacuum in the literature by addressing efficient communication methods in this particular situation. Evaluating the suggested IoT device's performance in terms of its capacity to identify and provide real-time information about possible hazards to railway personnel is the main goal of the study. This assessment looks at the device's overall effect on worker safety as well as its accuracy in identifying these threats and its dependability in various weather situations. The IoT gadget used in this study has demonstrated that it has achieved its goals of boosting safety and communication among Indian railway workers. The transmitter part of the gadget may deliver alarm signals in 10 to 15 milliseconds. Within 5–10 milliseconds of receiving the data, the receiver component turns on the buzzer and starts beeping. This quick reaction time and quick communication show that there is no communication barrier between the laborers and the station master, enabling the prompt and effective transfer of important information. This gadget efficiently meets the demand for real-time communication and risk detection by utilizing Internet of Things technology, hence improving track maintenance workers' safety.

8 Future Scope

The use of cloud services can be investigated to increase the effectiveness of the suggested approach. The system's performance and speed can be enhanced by utilizing 5G technology [26]. These developments improve the system's speed and dependability, enabling real-time applications that require quicker data transfer rates and reduced latency. The system's capabilities may be increased by switching from an Arduino to an ESP8266 microcontroller, which enables internet access and Wi-Fi functionality.

The team intends to look at the viability of integrating cloud services like AWS or Microsoft Azure to make use of their processing and storage power and assess how well they can boost system performance [24]. When using cloud services, the team will also assess the system's security, scalability, and stability. The suggested model can provide higher data transfer rates and reduced latency, which is essential for real-time applications, by using CV2X or 5G technology to increase the system's speed and performance [23]. The team hopes to improve the system's effectiveness and contribute to the creation of successful traffic safety systems by investigating these developments. Due to its low cost and Wi-Fi connection, the ESP8266 microcontroller is the perfect component for tying Internet of Things (IoT) devices to the Internet. The ESP8266 can detect mechanical vibration or shock in the surroundings and transfer this data to the cloud when used in combination with a vibration sensor (Fig. 11).

The signal pin of the vibration sensor must be linked to a digital input pin on the ESP8266 to connect it to the vibration sensor. The ESP8266 will process and send the data to the cloud after receiving a signal from the vibration sensor in response to a vibration or shock. The ESP8266 may be set with the proper credentials, such as the Wi-Fi network name and password and the cloud server address, to send data to the cloud via a variety of protocols, such as MQTT or HTTP [6]. Once set up, the ESP8266 will periodically gather information from the vibration sensor and send it to the cloud.

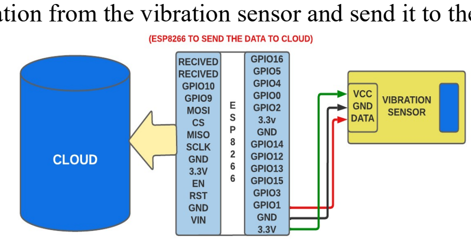

Fig 11. ESP8266 connected to Vibration Sensor

On the other hand, the second ESP8266 is connected to an OLED display and a buzzer and is programmed to receive data from the cloud [27]. If the data indicates that the measured vibration is above a certain threshold (in this case, 5000), the ESP8266 will activate the buzzer and display an "Alert" message on the OLED display (Fig.12).

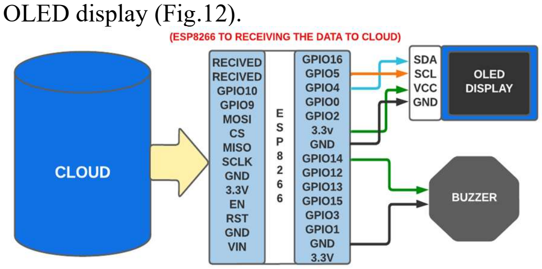

Fig 12. ESP8266 connected to OLED and Buzzer

In this scenario, the two ESP8266s are being used to create a simple vibration detection and alert system. The first ESP8266 collects vibration data from a sensor and sends it to the cloud using a protocol such as MQTT or HTTP [18]. In addition to being subscribed to a particular topic or channel where the vibration data is being published, the second ESP8266 is set up to receive data from the cloud [19]. The second ESP8266 compares the vibration amplitude to a preset threshold value of 5000 when it gets the vibration data. When the amplitude exceeds this limit, a buzzer sounds and an OLED display shows the word "Alert" [20]. The ESP8266 sends a signal to a buzzer's digital output pin, activating the buzzer and making a loud noise. The ESP8266 sends a sequence of commands to initialize the display, clean the screen, and then write the message using the proper commands to show the message on the OLED display [7]. This system can be expanded upon to include additional sensors or alerts, or to send data to more complex cloud services for further processing and analysis.

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