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Long range-based smart vehicle safety and control system

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ABSTRACT

The increasing demand for intelligent transportation systems has led to the development of advanced vehicle safety solutions. This paper presents an automotive vehicle control safety system based on long range (LoRa) sensor technology for reliable, LoRa, and low-power communication. The proposed system integrates multiple sensors to monitor critical parameters such as obstacle distance, vehicle condition, and environmental factors. Using LoRa communication, real-time data is transmitted between vehicles or to a monitoring unit to support timely decision-making and accident prevention. The system ensures secure and energy-efficient data transmission while maintaining extended coverage. Experimental analysis demonstrates that the proposed LoRa-based safety framework enhances vehicle control, improves situational awareness, and contributes to safer and smarter transportation systems.

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1. INTRODUCTION

The advancement of internet of things (IoT) and low-power networks has enabled smart monitoring solutions across various industries, including automotive applications. Vehicle-to-vehicle (V2V) communication allows cars to exchange real-time information such as position, speed, and emergency alerts, improving road safety and reducing accidents. This project simulates V2V communication using two mobile robots connected through a long range (LoRa) network. The leading robot is equipped with sensors to measure environmental conditions, driver health parameters, gas levels, and obstacle distances. The follower robot measures its distance from the leading robot and adjusts its speed accordingly based on the received data. Additionally, the experiment evaluates the impact of LoRa modulation parameters, particularly the spreading factor, on received signal strength indicator (RSSI) at different distances and conditions. The goal is to determine the most suitable spreading factor for reliable communication in various environments [1].

Smart cities are a key part of modern economic and technological development. One major challenge in smart city management is air pollution, caused by harmful gases such as PM2.5, CO, NO_2, and O_3. Although government monitoring stations provide real-time air quality index (AQI) data, they are spaced far apart, limiting coverage. To improve monitoring, this study proposes a vehicle monitoring system (VMS) equipped with air quality sensors, global positioning system (GPS), temperature/humidity sensors, and on-board diagnostics II (OBD-II). By installing the system in vehicles, air pollution data can be collected across wider areas while driving. The system uses long range wide area network (LoRaWAN) technology, which offers LoRa, low-power communication and supports IoT connectivity. This makes the VMS suitable for smart city applications and future intelligent transportation systems [2].

Artificial intelligence (AI) is transforming the automotive industry by enabling autonomous decision-making systems such as obstacle detection and route planning. To improve safety, vehicles must share data through the internet of vehicles (IoVs). This paper proposes a low-power wide-area communication system that enables secure, bidirectional message exchange between vehicles, helping identify high-risk areas and enhance road safety [3].

The number of autonomous vehicles on the road is increasing rapidly, making reliable vehicle-to-everything (V2X) communication essential for safe and efficient operation. V2X enables vehicles to communicate not only with other vehicles but also with road infrastructure, pedestrians, and networks, playing a key role in the development of smart cities and self-driving cars. It includes four main types: V2V, which helps prevent collisions and reduce traffic delays; vehicle-to-infrastructure (V2I), which supports communication with traffic signals and roadside units for better traffic management; vehicle-to-pedestrian (V2P), which improves pedestrian safety using wireless technologies like smartphones; and vehicle-to-network (V2N), which connects vehicles to servers and data centers for broader services. Together, these systems enhance road safety, traffic efficiency, and intelligent transportation [4].

The automotive industry is undergoing a major transformation driven by digitization, connectivity, and automation. Modern vehicles are no longer just mechanical machines; they are intelligent systems connected through the IoV. This rapid growth is reflected in the expanding IoV market, which is expected to grow significantly in the coming years. IoV consists of in-vehicle networks, inter-vehicle communication, and vehicle-to-cloud connectivity, enabling features like autonomous driving, predictive maintenance, and real-time updates. However, this connectivity also increases cybersecurity risks. Modern vehicles contain dozens of electronic control units (ECUs) connected through networks like controller area network (CAN) and automotive Ethernet. If one unit is compromised, attackers could potentially access safety-critical systems such as braking or steering. Even systems like tire pressure monitoring systems (TPMS), which seem simple, can become security vulnerabilities if their wireless data is not encrypted. To address this issue, this work proposes a secure TPMS communication framework for IoV. The system uses a Raspberry Pi and LoRa transceivers with AES-128 encryption and authentication to protect tire pressure data from tampering or eavesdropping. Real-time encrypted data is tested in both physical experiments and large-scale MATLAB simulations, comparing 5G, LoRaWAN, and LoRa peer-to-peer networks. The study demonstrates that combining low-power communication, encryption, and physical access control creates a scalable and secure solution for connected and autonomous vehicles. By strengthening even small subsystems like TPMS, overall V2V communication security in smart IoV environments can be significantly improved [5].

Batteries have become a vital part of our daily lives, especially with the rise of electric vehicles and renewable energy systems. As we rely on them more, it is important to keep track of their health to ensure they work safely, efficiently, and for a longer time. In electric vehicles, battery problems like overheating or overcharging can not only reduce performance but also create serious safety risks. That's why a reliable battery monitoring system is so important. Many current monitoring systems are costly, complex, and have limited communication range, making them difficult to use in remote or budget-sensitive applications [6]. Major companies like Tesla and Bayerische Motoren Werke (BMW), along with research organizations such as Indonesian National Research and Innovation Agency (BRIN), are developing smart, battery-powered autonomous vehicles that support renewable energy and reduce fossil fuel use. A key part of these vehicles is communication technology. LoRa is especially important because it can send data over long distances using very little power. By adjusting settings like spreading factor and bandwidth, LoRa can balance speed and reliability. In addition, technologies like V2V, V2X, and fifth-generation (5G) are being explored to improve real-time communication, safety features, and navigation. Overall, modern intelligent vehicles combine advanced battery systems with efficient communication technologies to create safer and more connected transportation [7].

Measuring comfort levels inside vehicles—especially military vehicles—is essential for both safety and usability. Military vehicles are built with heavy steel armor and weapons to withstand harsh terrains, but they must also provide a safe and reasonably comfortable environment for drivers and passengers. Before deployment, these vehicles go through extensive testing. This includes not only checking their strength and durability but also evaluating internal conditions such as noise, temperature, humidity, air pressure, and altitude. Traditionally, experts perform these tests manually. However, results can vary depending on the evaluator's experience, leading to inconsistencies [8]. In today's technology-driven world, electronic and microcontroller-based systems are widely used in many industries, including shipping. Because shipping operations often require constant monitoring, automatic control systems are essential to improve efficiency and reduce human workload. One important example is the autopilot system for boats. This system uses GPS to guide the boat automatically toward a predetermined destination. It works by comparing the boat's real-time position with the programmed destination. If the boat has not yet reached the target, it continues moving; once it arrives, it stops. Autopilot systems are commonly used in vehicles such as airplanes,

helicopters, and boats. They combine navigation systems with control algorithms to keep the vehicle stable and on course, even when facing disturbances like wind, waves, or engine imbalance. These systems are also useful in research and development for testing new control methods, sensors, and microprocessors. For communication and monitoring, LoRa technology is often used. Originally developed by Cycle in France and later acquired by Semtech in 2012, LoRa is a low-power wireless communication technology capable of transmitting data over distances of more than 10 kilometers. Although its data rate is relatively low, it is reliable and energy-efficient [9].

Natural disasters such as fires and earthquakes can cause serious damage, especially in low-income or vulnerable communities. To reduce these risks, scientists and engineers are developing smarter detection systems that can identify warning signs early and help people respond more quickly. Today, advanced sensing technologies like microelectromechanical systems (MEMS) devices, seismographs, geophones, GPS trackers, and accelerometers are used to monitor environmental changes and detect potential disasters. Many research teams are combining modern sensors with intelligent algorithms and communication systems to create faster and more reliable emergency warning systems. Disasters can be natural such as earthquakes and pandemics or human-made, like environmental pollution or resource shortages. Addressing these challenges requires collaboration across many fields, including electronics, communication systems, materials science, AI, and medicine. By working together, these disciplines help build innovative systems that can better protect lives [10].

2. CONTROL SCHEME

Figure 1 shows the light monitoring and display system, which uses a light-dependent resistor (LDR) to detect light intensity. The Arduino reads the light level. The information is shown on a liquid crystal display (LCD). The data is also sent wirelessly via LoRa to other system sections.

Obstacle detection and motor control. It uses an infrared (IR) sensor to detect obstacles or objects near the vehicle. The Arduino processes the sensor signal. It controls a relay, which turns the direct current (DC) motor ON or OFF. Status information is displayed on an LCD. LoRa allows sharing this information with other controllers [11]–[15].

Fuel level, temperature, and alert system. It uses sensors to monitor fuel level, temperature, and light level (LDR). The Arduino displays readings on an LCD. A buzzer gives alerts if there is danger (for example, low fuel or high temperature). LoRa sends this safety data to other system units. This system uses multiple Arduino controllers connected through LoRa to monitor light, obstacles, fuel level, and temperature, display the information, and automatically control vehicle functions to improve safety.

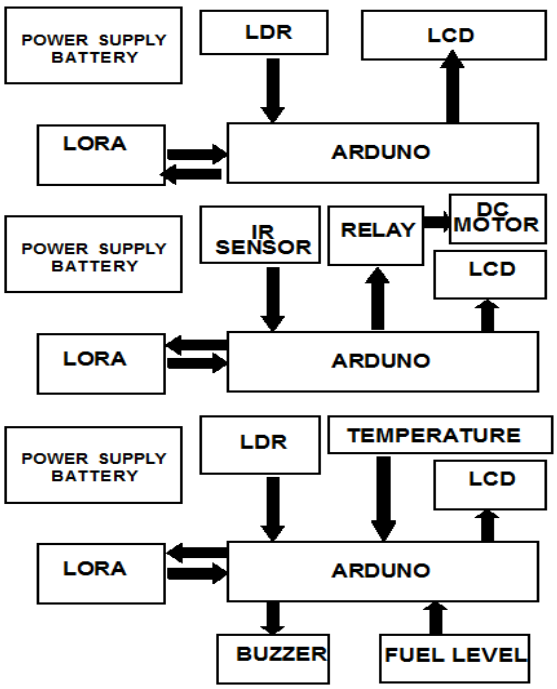


Figure 1. Light monitoring and display

3. WORKING PRINCIPLE

The fuel sensor continuously monitors the amount of fuel present in the vehicle's fuel tank and generates an analog signal proportional to the fuel level. This signal is received by the Arduino microcontroller, which processes and converts it into a meaningful and readable value. The processed fuel level information is then displayed on the LCD screen, allowing the user to view the current fuel status directly on the vehicle. At the same time, the Arduino transmits the fuel level data to the LoRa communication module. The LoRa module sends this information wirelessly through the antenna to a remote receiving unit over a long distance. This enables continuous and real-time remote monitoring of the vehicle's fuel level. The system operates automatically and ensures reliable communication, helping improve vehicle monitoring, safety, and management efficiency. The system parameters, including battery voltage, operating voltage, current consumption, and communication frequency, are summarized in Table 1. Figure 2 shows that the Arduino microcontroller acts as the main control unit of the vehicle system. It is connected to a fuel sensor, which continuously measures the amount of fuel available in the vehicle tank. The fuel sensor detects the fuel level and sends an electrical signal to the Arduino. The Arduino then processes this signal and converts it into readable fuel level data. The processed fuel level information is displayed on the LCD screen**,** allowing the user or driver to easily monitor the current fuel status in real time. This helps in avoiding unexpected fuel shortages and ensures better vehicle management. The system also includes a LoRa module connected to an antenna, which enables LoRa wireless communication [5], [16]**–**[19].

Table 1. System parameters

Parameter	Value	Description
Battery voltage (per cell)	3.5–4.2 V	Nominal ~3.7 V
Arduino operating voltage	5 V	Regulated power supply
LoRa operating voltage	3.3 V	Must be regulated
Arduino current	40–50 mA	Normal operation
LoRa TX current	120–140 mA	Transmission peak
LoRa RX current	10–15 mA	Receiving mode
Frequency	433/868/915 MHz	Region dependent

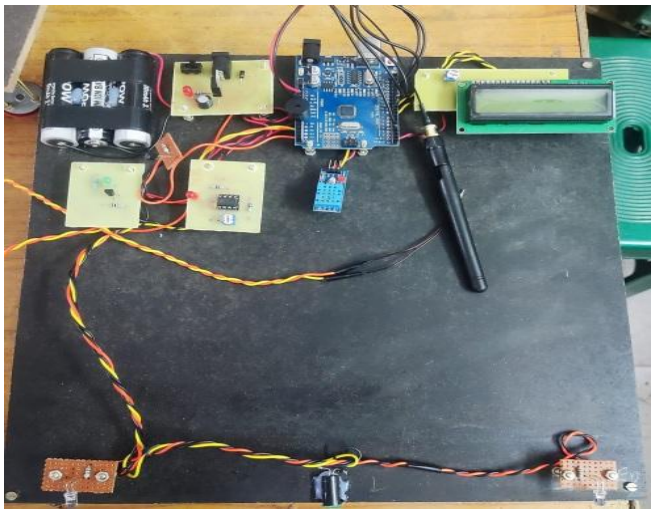


Figure 2. Smart fuel sensing vehicle prototype using LoRa

Figure 3 shows prototype vehicle is a smart vehicle prototype that uses an LDR sensor and LoRa module to automatically control vehicle lights and enable wireless monitoring. The Arduino microcontroller acts as the main controller, connecting the LDR sensor, LoRa module with antenna, LCD, and vehicle lights. The LDR sensor continuously checks the surrounding light conditions. When the environment is bright, the system keeps the vehicle lights OFF to save energy. When it becomes dark, such as at night or in tunnels, the system automatically turns the lights ON to improve visibility and safety. This allows the vehicle to switch between light and dark modes automatically without driver involvement. At the same time, the LoRa module and antenna transmit the vehicle's light status and system information wirelessly over a long distance,

enabling remote monitoring. The LCD display shows the current light condition and system status in real time.

Figure 4 shows is a smart vehicle prototype that uses a DC motor for wheel movement and an IR sensor to detect obstacles. The Arduino microcontroller acts as the brain of the system, controlling the motor, sensor, LoRa module, relay, and LCD display. The DC motor rotates the wheel to move the vehicle. When the path is clear, the motor keeps running normally. If the IR sensor detects an obstacle in front of the vehicle, it sends a signal to the Arduino, which immediately turns OFF the motor through a relay. This prevents collisions and improves safety. The system also includes a LoRa module with an antenna to send vehicle status information wirelessly over long distances, allowing remote monitoring. The LCD display shows real-time updates such as motor status and obstacle detection.

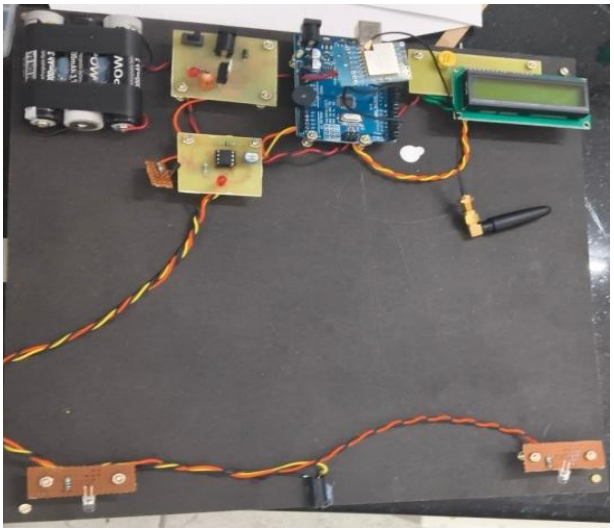


Figure 3. Automatic light control system for vehicle using LDR sensor

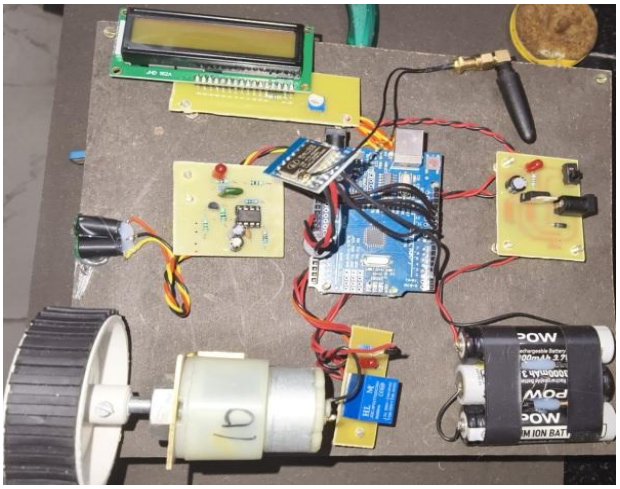


Figure 4. LoRa-enabled vehicle with IR sensor for obstacle detection

4. CONCLUSION

This paper presented a LoRa-based smart vehicle safety and control system designed to enhance road safety through reliable, LoRa, and low-power wireless communication. By integrating multiple sensors for monitoring obstacle distance, vehicle condition, and environmental parameters, the proposed system enables continuous real-time data acquisition and transmission. The use of LoRa technology ensures extended communication coverage with minimal energy consumption, making the system suitable for both urban and remote transportation environments. Experimental results demonstrate that the proposed

framework effectively improves situational awareness and supports timely decision-making for accident prevention. The secure and energy-efficient data transmission capability further strengthens the reliability of the system for intelligent transportation applications. Overall, the developed LoRa-based safety system contributes to smarter vehicle control, enhanced driver assistance, and improved road safety.

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AUTHOR CONTRIBUTIONS STATEMENT

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Kaidari Sai Teja	✓		✓	✓						✓	✓		✓	✓
Korra Harilal			✓		✓		✓			✓		✓		✓
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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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