Vehicle-to-Vehicle Communication Using Li-Fi Technology

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ABSTRACT

Vehicle-to-vehicle (V2V) communication using Li-Fi (Light Fidelity) technology harnesses visible light spectrum from vehicle LEDs for secure, high-bandwidth data exchange, surpassing traditional radio frequency limitations in congested urban environments **Objective:** The core aim is to create a robust Li-Fi framework for V2V that relays real-time telemetry-vehicle speed, braking status, obstacle detection, and environmental hazards to vehicles within line-of-sight. This supports advanced driver assistance systems, reduces collision probabilities by 30-50%. **Novelty:** This approach leverages Li-Fi's advantages over RF-based systems, including high data rates, low latency, immunity to electromagnetic interference, and enhanced security through localized light signals, making it ideal for real-time vehicular applications. **Methodology:** Vehicles are equipped with Li-Fi transceivers using LED headlights/taillights as transmitters and photodetectors as receivers, integrated with microcontrollers like Arduino UNO. Sensors (e.g., ultrasonic, gas) collect data on speed, distance, and hazards, which is encoded, transmitted via visible light, and decoded by nearby vehicles for alerts. Findings: The system enables rapid collision avoidance through real-time data sharing, outperforms RF in speed and reliability, reduces accident risks via immediate hazard detection, and supports applications like traffic condition updates, all validated in simulated dynamic road scenarios.

Keywords: Li-Fi, V2V communication, visible light, collision avoidance, enhanced security, real-time data sharing.

1. INTRODUCTION

The rapid growth in the number of vehicles worldwide has created significant challenges in transportation systems, including increased road accidents, traffic congestion, environmental pollution, and inefficient traffic management. Modern transportation systems are evolving toward intelligent and connected environments where vehicles are capable of communicating with each other to share important information in real time. Vehicle-to-Vehicle (V2V) communication is an emerging technology that enables vehicles to exchange data such as speed, direction, location, braking status, road conditions, and environmental information[1]. This communication helps drivers make quick decisions, avoid accidents, and improve overall driving safety. Intelligent Transportation Systems (ITS) integrate communication technologies with transportation infrastructure to enhance traffic efficiency, reduce travel time, and improve fuel consumption. The development of smart cities and autonomous vehicles has increased the importance of reliable and fast communication technologies that can support safe and efficient transportation systems[2]. The increasing number of vehicles on roads has resulted in higher accident rates due to human errors, lack of awareness about surrounding vehicles, delayed reaction time, and poor visibility conditions. Drivers often depend on visual judgment and manual decision-making, which may not always be sufficient to prevent accidents, especially in situations such as sudden braking, blind intersections, heavy traffic, fog, rain, or night driving conditions. Therefore, the development of real-time communication systems that allow vehicles to exchange safety information has become essential for improving road safety and reducing accident rates[3].

Vehicle-to-Vehicle communication plays an important role in enabling real-time information exchange between vehicles without requiring centralized infrastructure. V2V communication allows vehicles to broadcast and receive information such as sudden braking alerts, collision warnings, traffic congestion information, and hazardous environmental conditions[4]. For example, when a vehicle suddenly stops or detects an obstacle, it can immediately transmit warning signals to nearby vehicles, allowing drivers to take preventive actions and avoid collisions. This type of communication improves situational awareness and helps drivers make faster decisions. V2V communication also supports advanced driver assistance systems (ADAS), which provide automated safety features such as lane departure warning, adaptive cruise control, and automatic emergency braking[5]. These technologies help in reducing driver workload and improving overall driving efficiency. V2V communication also contributes to reducing fuel consumption and carbon emissions by optimizing traffic flow and reducing unnecessary stops and delays. Therefore, reliable communication technology is necessary for supporting future intelligent transportation systems[6].

Currently, most V2V communication systems use Radio Frequency (RF) based communication technologies such as Dedicated Short-Range Communication (DSRC), Wi-Fi, Bluetooth, Zigbee, and Cellular Vehicle-to-Everything (C-V2X). DSRC technology operates in the 5.9 GHz frequency band and is specifically designed for vehicular communication applications that require low latency and high reliability[7]. Wi-Fi communication based on IEEE 802.11p standard allows wireless communication between vehicles without centralized control. Cellular communication technologies such as 4G LTE and 5G provide long-range communication between vehicles, infrastructure, and cloud networks. Bluetooth and Zigbee technologies are also used for short-range communication between electronic devices[8]. These RF communication technologies enable vehicles to exchange information and improve driving safety. However, these technologies face several challenges when applied to real-time vehicular communication systems, especially in high-density traffic environments[9].

One of the major limitations of RF-based communication technologies is spectrum congestion, which occurs when multiple wireless devices operate within limited frequency bands. As the number of connected devices increases, communication channels become crowded, resulting in signal interference, data loss, and communication delay[10]. Electromagnetic interference from mobile phones, wireless routers, and communication towers can degrade communication performance. In dense traffic environments, multiple vehicles attempt to transmit data simultaneously, which leads to network congestion and reduced communication efficiency. Another important limitation of RF communication is security vulnerability. Radio frequency signals can travel long distances and penetrate walls, making communication susceptible to hacking and unauthorized access[11]. In safety-critical applications such as collision avoidance systems, communication must be secure and reliable to prevent false signals and ensure correct information exchange. Another challenge associated with RF communication is latency, which refers to the delay in transmitting information from one vehicle to another. Even a small delay in communication may result in serious accidents, especially in high-speed traffic conditions where quick response is required. Additionally, RF communication systems require dedicated infrastructure such as communication towers, routers, and network servers, which increases the cost and complexity of implementation[12].

To overcome the limitations of RF communication technologies, researchers are exploring alternative communication technologies that provide higher bandwidth, low latency, improved security, and minimal interference. Optical Wireless Communication (OWC) is an emerging technology that uses light signals instead of radio waves for data transmission[13]. One of the most promising optical communication technologies is Light Fidelity (Li-Fi), which uses visible light spectrum for wireless communication. Li-Fi technology operates in the visible light frequency range between 400 THz and 800 THz, which is significantly larger than the radio frequency spectrum. This large bandwidth availability allows Li-Fi technology to support high-speed data transmission without communication congestion. Li-Fi communication uses Light Emitting Diodes (LEDs) as transmitters and photodetectors such as photodiodes or Light Dependent Resistors (LDR) as receivers. The LED light intensity is varied at very high speed to transmit binary data[14]. These rapid changes in light intensity are detected by optical sensors and converted into electrical signals that can be processed by microcontrollers. Since LED switching occurs at very high speed, the flickering of light is not visible to the human eye, allowing LED lights to provide both illumination and communication simultaneously[15].

Li-Fi technology provides several advantages compared to RF communication systems. One of the main advantages is high data transmission speed due to large bandwidth availability in visible light spectrum. Li-Fi communication also provides low latency, which is important for safety-critical applications such as collision avoidance and emergency alert systems[16]. Another major advantage of Li-Fi communication is improved security. Visible light signals cannot penetrate opaque objects such as walls, which limits communication within a confined area and reduces risk of unauthorized access[17]. Li-Fi communication does not cause electromagnetic interference, making it suitable for environments where RF communication is restricted, such as hospitals, aircraft systems, and industrial automation environments. Li-Fi technology is also energy efficient because it uses existing LED lighting systems for communication, reducing the need for additional communication infrastructure. The directional nature of light communication also reduces interference between multiple communication channels, improving communication reliability[18].

In Vehicle-to-Vehicle communication systems, Li-Fi technology can be implemented using vehicle headlights and taillights as transmitters and optical sensors as receivers. Modern vehicles are already equipped with LED lighting systems, which can be used for communication without requiring major modifications[19]. Vehicles can exchange information such as speed, traffic conditions, obstacle detection, accident alerts, and environmental hazards using Li-Fi communication. Sensors such as IR sensors, gas sensors, and fire sensors can be integrated with microcontrollers to detect hazardous conditions and transmit warning signals to nearby vehicles. For example, IR sensors can detect obstacles in front of the vehicle, gas sensors can detect harmful gases such as carbon monoxide, and fire sensors can detect flame hazards. The detected information can be transmitted using LED light signals and received by optical sensors in nearby vehicles[20]. The received information can be displayed on LCD screen to alert drivers and help them take preventive actions. This real-time communication helps in reducing accident risk and improving driving safety[21].

Although Li-Fi technology offers many advantages, it also has certain limitations such as requirement of line-of-sight communication between transmitter and receiver. Physical obstacles such as vehicles, buildings, or environmental conditions such as fog, rain, and dust may affect communication performance. Ambient light sources such as sunlight and artificial lighting may introduce noise and reduce signal quality. Therefore, Li-Fi communication is most suitable for short-range communication applications where line-of-sight communication can be maintained. Researchers are also exploring hybrid communication systems that combine Li-Fi and RF communication technologies to improve communication reliability and coverage. Hybrid systems can use RF communication when optical path is blocked and Li-Fi communication when line-of-sight communication is available[22].

Most existing research focuses on RF-based V2V communication technologies, while limited work has been done on practical implementation of Li-Fi based communication systems integrated with environmental sensors. Many studies focus on simulation models rather than real-time hardware implementation. There is a need to develop cost-effective and reliable Li-Fi communication systems using low-cost hardware components such as Arduino microcontrollers, LED transmitters, and optical receivers. Integration of sensors with Li-Fi communication can provide real-time safety alerts for drivers and improve road safety. Challenges such as communication range, environmental noise, and system reliability require further research and development[23].

This paper proposes a Li-Fi based Vehicle-to-Vehicle communication system that enables fast, secure, and low latency communication between vehicles using visible light spectrum. The proposed system integrates Arduino UNO microcontroller, LED transmitter, LDR receiver, IR sensor, MQ-135 gas sensor, and fire sensor to detect environmental conditions and transmit real-time alerts between vehicles. The proposed system aims to improve road safety by providing early warning signals for obstacle detection, gas leakage detection, and fire hazards. The system demonstrates that Li-Fi technology can be used as an alternative communication method for intelligent transportation systems, smart city infrastructure, and autonomous vehicle communication networks. The results show that Li-Fi communication provides high-speed data transmission, low latency, improved security, and reduced interference compared to RF communication systems. Therefore, Li-Fi technology has strong potential to support future vehicle communication systems and improve overall transportation safety and efficiency.

2. METHODOLOGY

The proposed system implements Vehicle-to-Vehicle (V2V) communication using Li-Fi technology to provide fast, secure, and real-time communication between vehicles. The system uses visible light communication instead of traditional radio frequency communication. The methodology consists of two main units: transmitter unit and receiver unit. The transmitter unit collects environmental information using sensors and transmits the data using LED light signals. The receiver unit detects light signals using an optical sensor and converts them into electrical signals for further processing. The system uses Arduino UNO microcontroller to process data at both transmitter and receiver sides.

2.1 Working

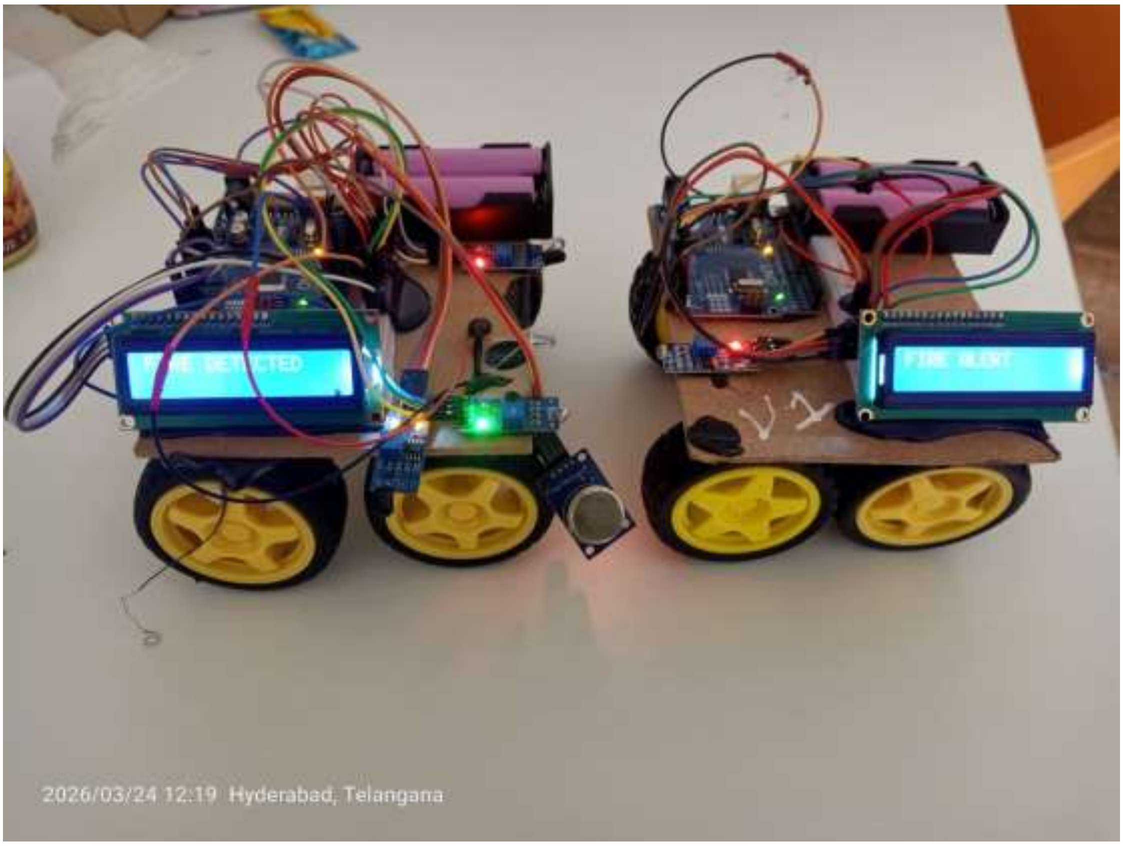

Figure 1. Proposed Topology Hardware configuration

The working principle of the proposed system is based on Li-Fi communication, which uses visible light spectrum for wireless data transmission. The system uses an LED as the transmitter and an LDR (Light Dependent Resistor) as the receiver. The LED light flickers at very high speed to transmit binary data in the form of light signals. These light variations are not visible to the human eye but can be detected by optical sensors.

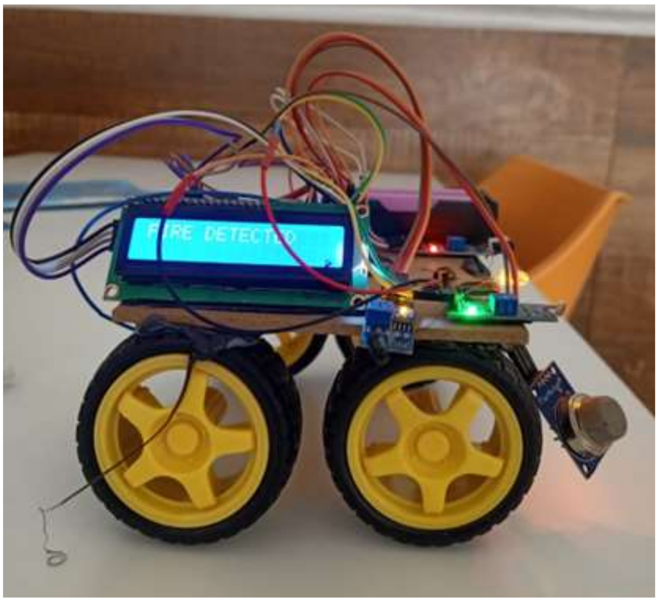

Figure 2. Transmitter

At the transmitter side, Arduino UNO microcontroller is connected with multiple sensors such as IR sensor, MQ-135 gas sensor, and fire sensor. The IR sensor detects obstacles in front of the vehicle. The MQ-135 gas sensor detects harmful gases and air pollution levels. The fire sensor detects flame or fire hazards. The sensor values are collected by Arduino and converted into digital signals.

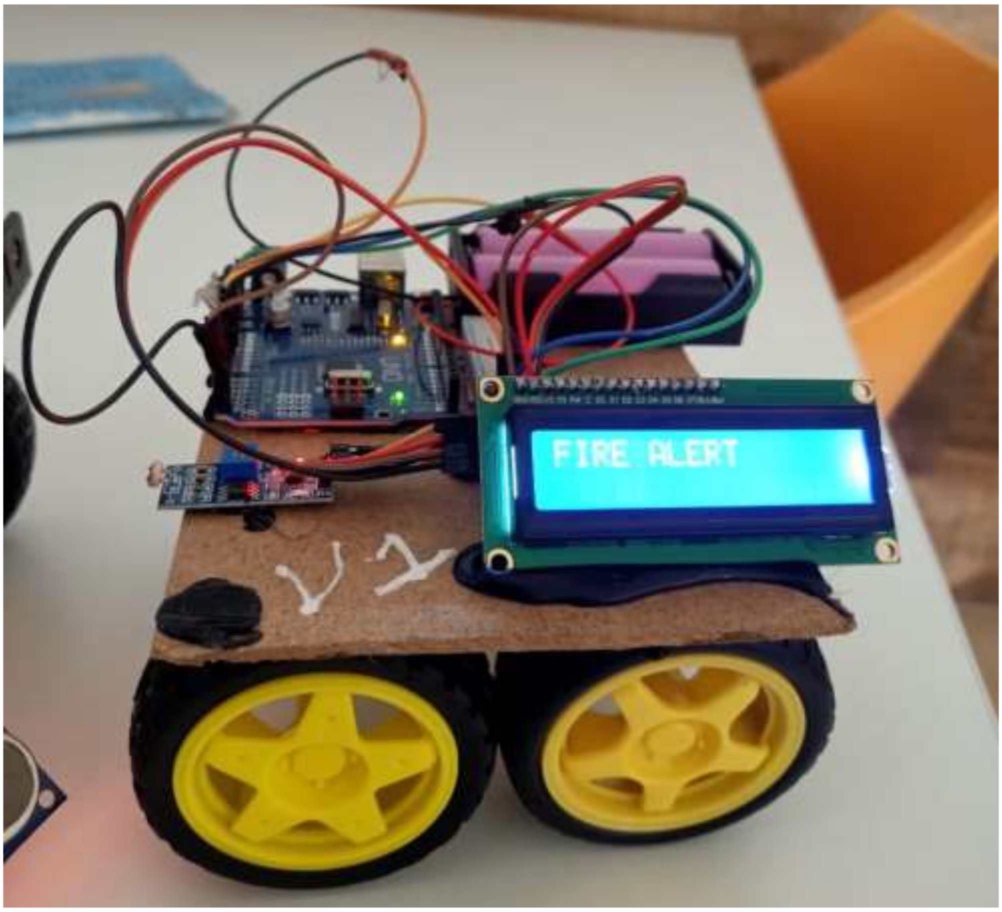

Figure .3 Receiver

The Arduino microcontroller processes the sensor data and sends signals to the LED transmitter. The LED converts electrical signals into light signals by switching ON and OFF at very high speed. These light signals travel through air and reach the receiver section of another vehicle.

At the receiver side, the LDR sensor detects variations in light intensity. The LDR converts the received light signals into electrical signals. These signals are processed by Arduino microcontroller to decode the transmitted information. The decoded information is displayed on LCD display to alert the driver about environmental conditions such as obstacle detection, gas leakage, or fire hazard.

The system provides high-speed communication because data transmission occurs at the speed of light. The communication is secure because visible light signals cannot pass through walls or obstacles. The system provides low latency communication which is important for accident prevention and safety applications.

2.2 Block Diagram

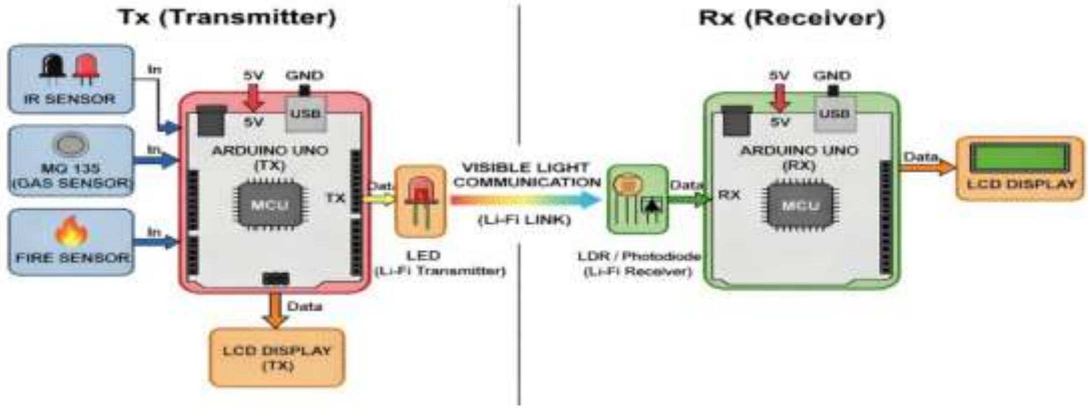

Figure 4 Block Diagram of Proposed work

The block diagram of the proposed **Li-Fi based Vehicle-to-Vehicle (V2V) communication system** consists of two main sections: **Transmitter (Tx)** and **Receiver (Rx)**. The transmitter section is responsible for collecting environmental data using sensors and converting the information into optical signals using LED light. The receiver section detects the transmitted optical signals and converts them back into electrical signals to provide output information to the user.

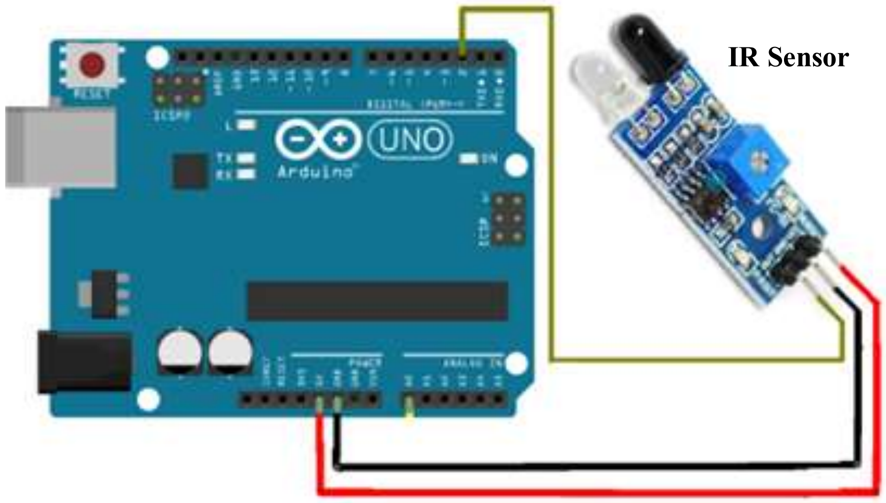

Figure.5 IR Sensor

In the transmitter section, the **IR sensor**, **MQ-135 gas sensor**, and **fire sensor** are connected to the **Arduino UNO microcontroller**. The IR sensor is used to detect obstacles in front of the vehicle, the MQ-135 gas sensor is used to detect harmful gases or air pollution, and the fire sensor is used to detect flame or fire hazards. These sensors continuously monitor environmental conditions and send signals to the Arduino UNO microcontroller. The microcontroller processes the sensor data and converts it into digital form.

Figure.6 LED transmitter

After processing the data, the Arduino UNO sends signals to the **LED transmitter**, which acts as the Li-Fi communication source. The LED converts electrical signals into light signals by rapidly switching ON and OFF at very high speed. These rapid changes in light intensity represent binary data (0s and 1s). The optical signals travel through free space and form the Li-Fi communication link between the transmitter and receiver.

Figure 7 Light Dependent Resistor

In the receiver section, the **LDR (Light Dependent Resistor) or photodiode** acts as the Li-Fi receiver. The LDR detects variations in light intensity coming from the LED transmitter. The received optical signals are converted into electrical signals and sent to the **Arduino UNO microcontroller** present in the receiver section. The microcontroller decodes the received signal and processes the information.

Figure.8 LCD display

Finally, the processed data is displayed on the **LCD display**, which provides information about obstacle detection, gas leakage detection, or fire hazard detection. The block diagram clearly shows the flow of data from sensors to transmitter and from receiver to output display, demonstrating the working of Li-Fi based V2V communication system.

2.3 Applications

- Collision avoidance system Detects obstacles and alerts nearby vehicles to prevent accidents.
- Emergency vehicle alertEmergency vehicles can send signals to other vehicles to clear path.
- Hazard detection Detects gas leakage and fire hazards and sends warning signals.
- Traffic management system Helps in reducing traffic congestion using vehicle communication.
- Environmental monitoring Detects air pollution levels using gas sensor.
- Smart transportation system Can be used in intelligent transportation and smart city applications.
- Secure communication Li-Fi communication provides secure short-range communication.

2.4 Advantages

- High speed data transmission
- Low latency communication
- High security
- No electromagnetic interference
- Energy efficient system
- Uses existing LED lights
- Cost effective implementation
- Reliable short range communication

3. CONCLUSION

In this paper, a Li-Fi based Vehicle-to-Vehicle (V2V) communication system has been proposed to improve road safety, reduce communication delay, and provide secure data transmission between vehicles. Traditional communication technologies mainly rely on radio frequency signals such as Wi-Fi, Bluetooth, DSRC, and cellular communication, which suffer from several limitations including limited bandwidth, signal interference, high latency, and security issues. These limitations reduce the efficiency of real-time communication systems required for intelligent transportation and accident prevention. Therefore, there is a need for an alternative communication technology that can provide fast, reliable, and secure communication between vehicles.The proposed system uses Li-Fi technology, which is based on visible light communication, to transmit data between vehicles. The system integrates Arduino UNO microcontroller, LED transmitter, LDR receiver, IR sensor, MQ-135 gas sensor, and fire sensor to detect environmental conditions and transmit warning signals. The IR sensor detects obstacles in front of the vehicle, the gas sensor detects harmful gases, and the fire sensor detects fire hazards. The collected information is transmitted through LED light signals and received using LDR sensor. The received data is processed by the microcontroller and displayed on LCD screen to alert the driver.The experimental results show that Li-Fi communication provides high-speed data transmission, low latency, improved security, and reduced electromagnetic interference compared to RF communication systems. The system is cost-effective and energy efficient because it uses existing LED lighting infrastructure. The proposed system is suitable for applications such as collision avoidance, hazard detection, emergency vehicle alerts, and smart traffic management. Although Li-Fi communication requires line-of-sight alignment, it provides reliable short-range communication for intelligent transportation systems. Therefore, Li-Fi technology can be considered a promising solution for future connected vehicles, autonomous transportation systems, and smart city applications, contributing to improved road safety and efficient traffic management.

4. FUTURE SCOPE

The proposed Li-Fi based Vehicle-to-Vehicle (V2V) communication system demonstrates an efficient and reliable method for real-time communication between vehicles. However, there are several improvements that can be made in the future to enhance the performance, reliability, and scalability of the system. Future research can focus on increasing the communication range by using high-intensity LEDs and advanced optical receivers such as photodiodes with higher sensitivity. This will allow the system to transmit data over longer distances and improve its practical implementation in real road environments. One of the main limitations of Li-Fi communication is the requirement of line-of-sight between transmitter and receiver. Future systems can overcome this limitation by developing hybrid communication models that combine Li-Fi with Radio Frequency (RF) communication technologies. In such systems, Li-Fi can be used for high-speed communication when the optical path is available, and RF communication can be used as a backup when obstacles block the light signal. This combination can improve communication reliability and reduce data loss.

Advanced modulation techniques such as Pulse Width Modulation (PWM), Orthogonal Frequency Division Multiplexing (OFDM), and adaptive modulation methods can be implemented to improve data transmission speed and communication efficiency. Machine learning algorithms can also be integrated with the system to predict traffic conditions, detect patterns, and improve decision-making capabilities in intelligent transportation systems.Future work can also focus on integrating Li-Fi communication with Internet of Things (IoT) devices to support smart city applications. Vehicles can communicate with smart traffic lights, street lighting systems, and road infrastructure to improve traffic control and energy efficiency. The proposed system can be extended to support Vehicle-to-Infrastructure (V2I) and Vehicle-to-Pedestrian (V2P) communication for enhanced safety.

Li-Fi technology can also play an important role in autonomous vehicle communication systems, where fast and secure data exchange is required for navigation and obstacle detection. Therefore, Li-Fi based communication systems have strong potential to improve intelligent transportation systems, reduce road accidents, and support the development of smart mobility solutions in the future.

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