# SMART VEHICLE-TO-VEHICLE COMMUNICATION SYSTEM USING LI-FI

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**ABSTRACT:**

This design presents an innovative Vehicle-to-Vehicle (V2V) communication system utilizing Li-Fi technology to enhance road safety through real-time driving behavior monitoring and alert mechanisms. Each vehicle unit is equipped with an ESP32 microcontroller as the central controller, which gathers data from various sensors including an alcohol sensor to detect drunken driving, an MPU6050 sensor to monitor rash driving behavior through acceleration and orientation analysis, and an SOS button for emergency alerting. An I2C-based LCD display is used in each vehicle to show real-time parameter values for the driver. The system also includes an APR voice module to provide audible alerts to the driver, improving the response time in critical situations. To support safety in congested environments, the system uses ultrasonic sensors to detect nearby vehicles and reduce collision risks. Li-Fi, a high-speed, light-based data transmission method, is used for direct communication between vehicles, enabling quick sharing of alerts such as emergency situations or erratic driving behavior. When an abnormal condition like high alcohol level or sudden movements is detected, the system sends a warning to nearby vehicles through Li-Fi, triggering visual and voice alerts. This smart integration of IoT components creates a responsive, interconnected V2V system aimed at reducing road accidents and improving driver awareness, especially in critical driving conditions.

Keywords: V2V, Li-Fi, Sensors, ESP32, Monitoring.

## 1. Introduction:

The selection of Li-Fi for vehicle-to-vehicle (V2V) communication is justified by its technical advantages over traditional RF-based systems. Li-Fi provides exceptionally high data rates and ultra-low latency, which are essential for time-critical automotive functions such as collision avoidance, cooperative driving, and real-time sensor sharing. Operating in the visible light spectrum, it bypasses the limitations of RF congestion, particularly in urban environments where wireless spectrum is heavily saturated. Its line of-sight nature offers an added layer of security, minimizing the risk of signal interception or external interference. Moreover, Li-Fi enables seamless integration with vehicle lighting systems, utilizing existing headlights and taillights for data transmission, which reduces infrastructure costs and simplifies implementation. The technology's immunity to electromagnetic interference also makes it suitable for environments with high electronic noise, such as dense traffic or industrial zones. Overall, Li-Fi is a robust and future-ready solution, aligning well with the performance, safety, and scalability requirements of next-generation intelligent transportation systems.

The objective of this work is to explore the application of Li-Fi technology for vehicle to-vehicle (V2V) communication, aiming to provide high-speed, secure, and low-latency data transmission between vehicles. The project focuses on designing and implementing a Li-Fi-based communication prototype to demonstrate its effectiveness in real-time data exchange for safety and traffic management applications. Additionally, it seeks to evaluate the performance of Li-Fi in terms of data rate, range, and reliability, while comparing it to existing V2V technologies. The project also aims to identify challenges and propose integration strategies for smart transportation systems.

Harald Haas et al. (2011) – "Wireless data from every light bulb" This seminal paper introduced the concept of Li-Fi (Light Fidelity) as a high-speed optical wireless communication method using visible light. The authors demonstrated the potential of using LED lights to transmit data at high speeds, which laid the groundwork for using Li-Fi in various applications, including vehicle-to-vehicle communication. Their research showed that Li-Fi could be a secure, interference-free alternative to traditional RF communication in intelligent transport systems. Singh, R., & Kaur, G. (2016) – "Vehicle to Vehicle Communication Using Li-Fi Technology" This study proposed a basic V2V system using Li-Fi to exchange critical driving information such as speed and direction between vehicles. The authors highlighted the advantages of using Li-Fi over Wi-Fi, including lower latency, reduced interference, and faster response. They also mentioned its potential in accident prevention and traffic management systems. Kumar, P., & Verma, A. (2017) – "Alcohol Detection System in Vehicles Using MQ3Sensor" This paper focused on developing an alcohol detection system that prevents drunk driving. By using the MQ3 gas sensor interfaced with a microcontroller, the authors created a system that could immobilize the vehicle if alcohol was detected in the driver's breath. This research is closely aligned with the alcohol detection feature integrated into this project. Sharma, N., & Dubey, A. (2019) – "Detection of Rash Driving Using Accelerometer Sensor"- This research involved the use of an MPU6050 accelerometer and gyroscope module to detect harsh acceleration, braking, and sharp turns. The system aimed to analyze driver behavior and generate alerts in case of unsafe driving. This work supports the implementation of rash driving detection in this project, using motion sensors to analyze sudden changes in velocity or direction. Rajesh, M., & Rani, P. (2020) – "Emergency Alert System for Vehicles Using SOSand GSM Module"- This paper proposed an emergency alert mechanism using an SOS button interfaced with a GSM module. When triggered, the system sent alert messages to predefined contacts or emergency services. Their approach emphasized the importance of timely response during accidents. In our project, this concept is adapted to send emergency alerts to nearby vehicles using Li-Fi. Pereira, H., Ferreira, H., & Monteiro, P. (2018) – “Visible Light Communication for V2V: Feasibility and Performance Analysis” The study analyzed the feasibility of using visible light (from vehicle headlights and taillights) for V2V communication. Experimental setups showed promising results in short-range, line-of-sight communication, especially in controlled environments. Our project builds on this concept by integrating similar VLC systems with a LiFi-based emergency alert mechanism. Kumari, N., & Yadav, A. (2019) – “Vehicle Communication Using VLC for Smart Transportation Systems” This paper discussed the implementation of VLC for smart traffic management and accident prevention. It presented a model where LED-based signals transmitted vehicle data to nearby cars. Our work takes inspiration from this by applying a similar communication method using LiFi to broadcast alerts and vehicle status.

**1.1 Existing System:**

The existing Emergency Alert System uses **GPS and GSM** technologies to detect vehicle accidents. GPS identifies the exact accident location, while GSM transmits accident details to emergency services and contacts. Impact sensors and intelligent algorithms reduce false alerts. The system enables quick response, data logging, and improved road safety.

**Disadvantages:**

No-Real time communication

High installation cost

Dependency on GSM network

**2. Proposed system:**

The proposed method is to use Li-Fi technology where the main component is LED and it is used as a means for communication by transmitting information using light which is an optical wireless medium for propagation of the signal. When vehicle A is closing on vehicle B the distance will be sensed and at that time, information will be transmitted from vehicle A. The receiver in the vehicle B will get the message by the use of a photodiode that is fixed to vehicle B. Here, we used a notification like (Nearby Vehicle Detected) to display. Vehicle A&B meet with an accident, vehicle B car will send “Emergency Alert” notification to the rear car so that rear car can take next lane before closing nearby and comes to halt. We are providing more information to car which is behind about the turning indication whether they are turning right/left or making a U-turn. And also, the parking indication to inform if the car is parked or they have stopped because of any emergency. This project initiates a wirelessly connected device using lights with transmission distances of up to 5m. LED is an option for a light source because it uses much less power than a traditional bulb or a light bulb. It absorbs around 10% of the power as compared to traditional lighting method. Also, the life of a standard LED bulb is greater than ten thousand hours.

**2.1 LI FI Transmitter:**

The block diagram illustrates the transmitter section of a Vehicle-to-Vehicle (V2V) communication system using Li-Fi technology. The ESP32 microcontroller is at the core, gathering data from various sensors such as the ultrasonic sensor, MPU6050, MQ135, and an SOS button. These sensors monitor distance, motion, air quality, and emergency alerts, respectively. The ESP32 processes this data and displays relevant information on an LCD screen for the driver. Simultaneously, it sends the data through a UART interface to the LED driver, which modulates the information into light signals. These signals are transmitted via the Li-Fi transmitter, enabling high-speed wireless communication between vehicles.

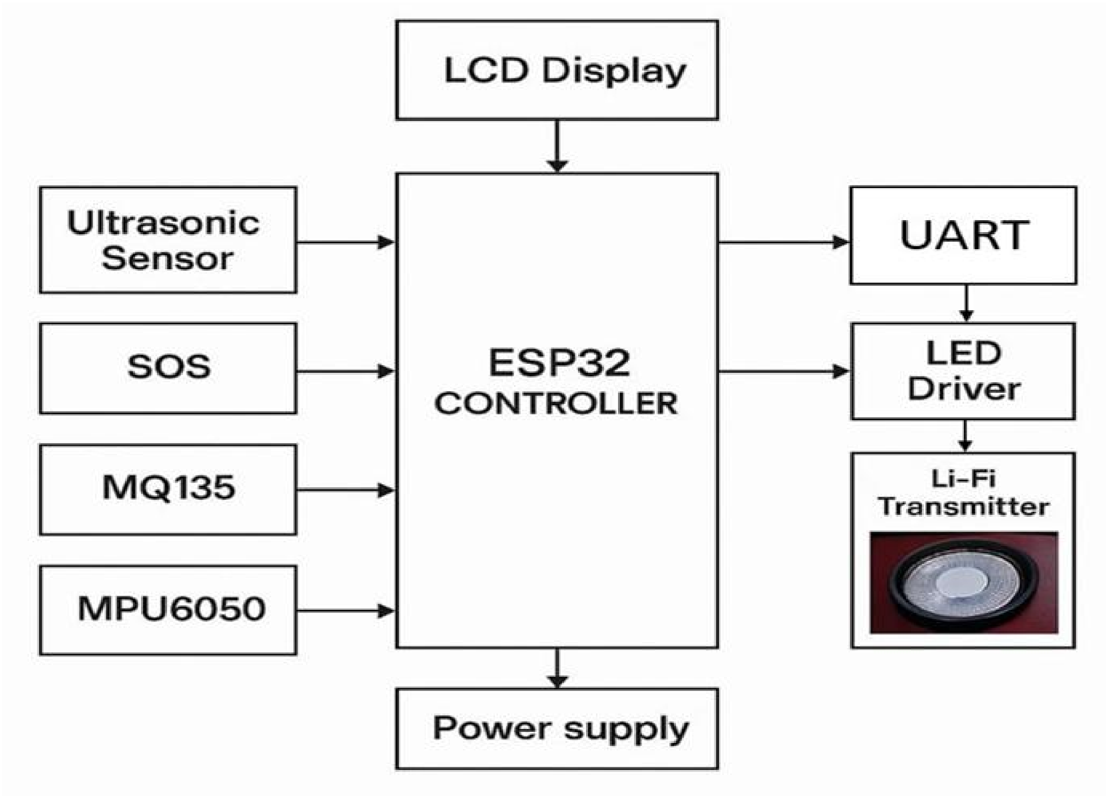



Fig 2.1 li Fi Transmitter block diagram

To begin assembling the Li-Fi transmitter circuit, the ESP32 microcontroller (labeled ESP1 in the diagram) is positioned as the central controller. All peripheral modules are connected to it through appropriate GPIO pins, ensuring both signal and power lines are accurately routed. The LCD display (LCD1) is connected to the ESP32 through multiple digital pins. Its VCC and GND are connected to the 5V and GND lines of the ESP32 to ensure it is powered correctly, 54 while the data lines are wired to specific digital pins that are pre-defined in the program to handle display communication. To integrate the ultrasonic sensor (SONAR1), four wires are connected: VCC and GND go to the 5V and GND rails respectively, while the Trig and Echo pins are connected to separate GPIO pins on the ESP32, allowing it to send and receive ultrasonic signals. The ultrasonic module is mounted in such a way that it can monitor distance in the direction of vehicle movement. On the left side of the circuit, the MQ-6 gas sensor (GAS1) is added. Its output is connected to an analog or digital pin on the ESP32, depending on how the gas levels are processed in the firmware. VCC and GND from the sensor are connected to the respective power rails, usually 5V and GND.

Just below the gas sensor, the MPU6050 (gyroscope and accelerometer sensor) is integrated using the I2C protocol. The SDA and SCL lines from the MPU6050 are connected to the designated I2C pins of the ESP32, typically GPIO21 and GPIO22. VCC and GND lines are wired to the ESP32's 3.3V or 5V and ground accordingly, depending on the sensor's voltage requirement. Toward the bottom right of the diagram, a push button switch is connected in series between the ESP32 and ground with a pull-up resistor. This button may be used to trigger specific events like starting transmission or resetting data manually. Lastly, the LED used for Li-Fi transmission is wired to a digital output pin of the ESP32. A current-limiting resistor is typically added in series with the LED to prevent it from drawing excess current. This LED emits modulated light signals based on the sensor data processed by the ESP32, forming the core of the Li-Fi communication.

**2.2 LI FI Receiver:**

The block diagram illustrates the receiving section of the V2V communication system using Li-Fi. The Li-Fi receiver captures light signals transmitted from other vehicles and passes them through an amplification and processing stage to strengthen and refine the signal. This processed signal is then decoded to retrieve the original data, which is sent to the ESP32 controller for interpretation. The controller displays relevant information on the LCD screen and may trigger audio alerts via the APR voice board, ensuring the driver is promptly informed. The entire system is powered by a stable power supply, enabling continuous and efficient operation.

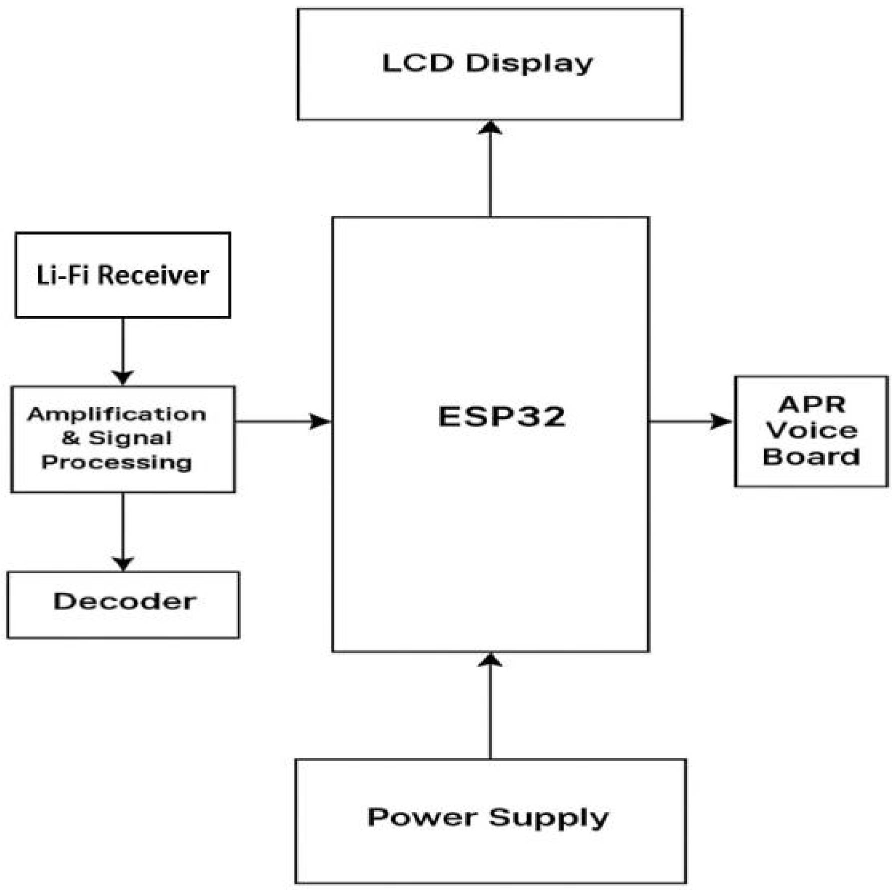



Fig 2.2 li Fi Receiver block diagram

This circuit assembly illustrates a Li Fi Receiver system built around the ESP32 WROOM microcontroller module. The ESP32 serves as the central control unit, receiving signals from a LiFi module and then displaying the information on an LCD screen. In the diagram, the ESP32 is connected to an LCD display module (designated LCD1, typically an LM016L or similar 16x2 character display) and a receiver unit for the LiFi communication. The wiring shows that multiple pins from the ESP32 are directly connected to the control and data pins of the LCD, allowing it to manage what appears on the screen. These connections typically include the data lines (D4 to D7 of the LCD) and control lines like RS (Register Select) and E (Enable). VSS, VDD, and VEE pins of the LCD are also shown connected for power and contrast settings. Additionally, the ESP32 communicates with the LiFi receiver through its serial interface where the RXD (Receive Data) and TXD (Transmit Data) lines are connected. However, in this receiver configuration, it primarily focuses on reading incoming data via RXD. The whole circuit relies on the ESP32's ability to read the transmitted optical data captured by the LiFi receiver module, decode it, and then output the readable information to the LCD for user observation. No discrete power supply circuitry is shown separately, implying that the ESP32 module, as well as peripherals like the LCD and LiFi receiver, are likely powered through the ESP32's onboard voltage regulation or an external common supply. Overall, the assembly is quite straightforward, emphasizing a simple real-time data reception and display operation using light communication technology.

**2.3 Communication Protocols:**

At the physical layer, data is transmitted using LED light by modulating the light intensity through techniques such as On-Off Keying and Pulse Width Modulation, enabling vehicles to send binary information reliably over optical channels.

At the data link layer, communication is organized by controlling channel access and preventing collisions between multiple vehicles using time-based or sensing-based access mechanisms.

At the network layer, vehicles form dynamic vehicular ad-hoc networks that route messages efficiently between moving vehicles using location-aware and on-demand routing protocols.

At the transport layer, fast and low-latency delivery of safety-critical messages is achieved by transmitting data without connection overhead, ensuring timely vehicle-to-vehicle communication.

At the application layer, vehicle messages are structured, interpreted, and verified for errors so that meaningful information such as alerts and vehicle status can be correctly understood by receiving vehicles. The protocol stack is lightweight, efficient, and optimized for optical wireless communication, enabling fast, reliable data exchange and improved road safety.

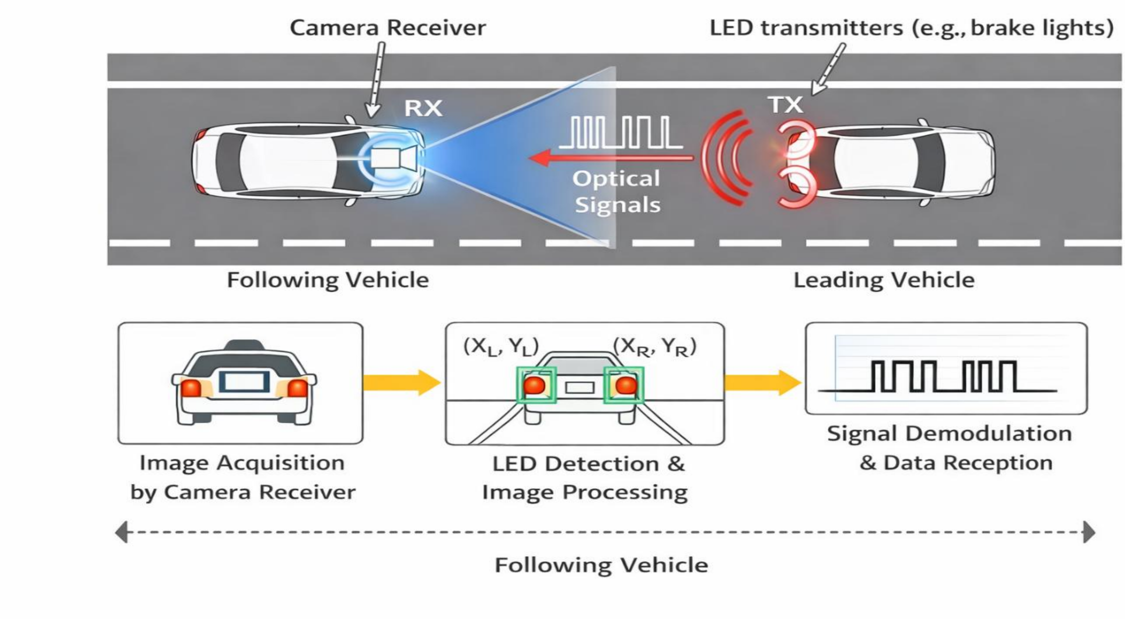


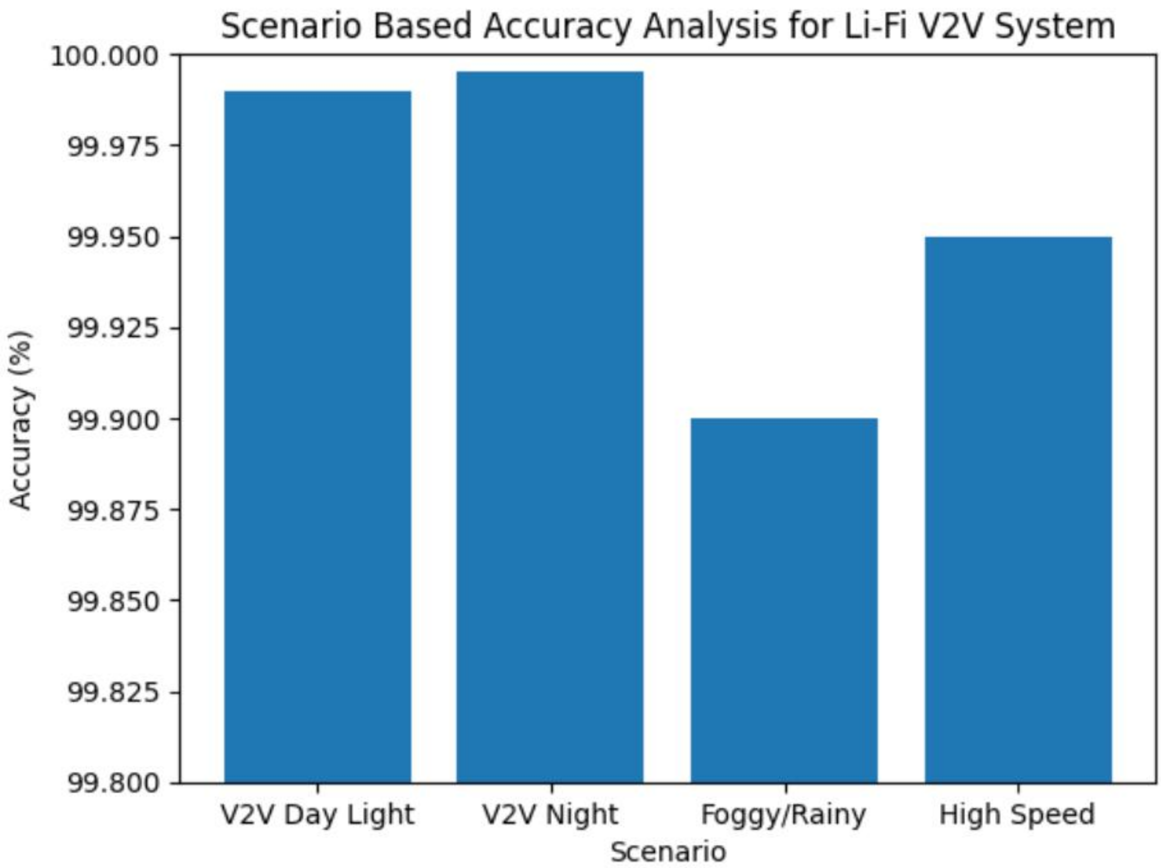

Fig 2.3 Brake Light LED Transmission

**2.4 Data Transmission Speed and Accuracy:**

The performance of Li-Fi technology in terms of data transmission speed and accuracy can vary significantly depending on environmental conditions and application scenarios. In the context of vehicle-to-vehicle (V2V) communication, factors such as lighting conditions, weather, and mobility play a crucial role in determining the effectiveness of data transfer. The table below presents a comparative analysis of Li-Fi's transmission speed, latency, bit error rate, and accuracy under various conditions relevant to V2V communication systems.

| Scenario | Data Rate | Latency | Bit Error Rate (BER) | Accuracy |
|---|---|---|---|---|
| Vehicle-to-vehicle (Day Light) | 100–500 Mbps | < 2 ms | 10^-6 – 10^-4 | ~ 99.99% |
| Vehicle-to-vehicle (Night) | 300 Mbps – 1 Gbps | < 1 ms | 10^-7 – 10^-6 | > 99.99% |
| Foggy or Rainy conditions | 10–100 Mbps | 2 – 5 ms | 10^-4 – 10^-3 | ~ 99.9% |
| High speed Vehicle Movement | 50–300 Mbps | ~ 1–2 ms | 10^-5 – 10^-4 | ~ 99.95% |
| Obstructed Line of Sight | Negligible / Zero | — | — | — |

Table 1: Scenario Based Analysis

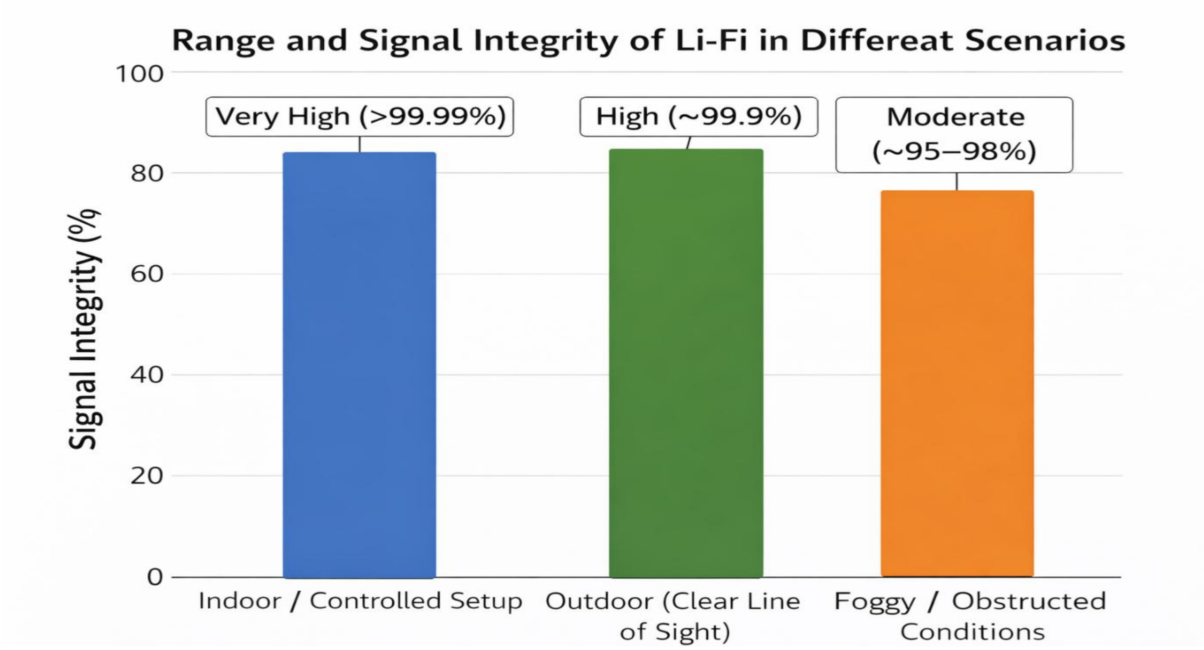



**2.5 Range And Signal Integrity**

Li-Fi, being a line-of-sight optical communication technology, exhibits variations in range and signal integrity depending on environmental conditions and system configuration. For V2V communication applications, it is important to consider how different scenarios—such as lighting conditions, obstacles, and weather can affect the overall performance. The table below summarizes the typical range and signal integrity of Li-Fi communication in various use cases relevant to vehicular environments.

| Scenario | Typical Range | Signal Integrity |
|---|---|---|
| Indoor / Controlled Setup | Up to 10 meters | Very High (> 99.99%) |
| Outdoor (Clear Line of Sight) | 4 – 5 meters | High (~99.9%) |
| Foggy / Obstructed Conditions | 1 – 2 meters | Moderate (~95–98%) |

Table 2: Range and Signal Integrity of Li-Fi in Different Scenarios




### 2.6 Test Results:

The test results from various stages of the testing and validation process are summarized below, focusing on the key aspects of the V2V communication system's performance and reliability.

| Component | Test Results |
|---|---|
| MPU6050 (Motion Sensor) | Accurate motion tracking with no significant errors in distance or angle measurement. Validated under various vehicle movements. |
| MQ 135(Gas Sensor) | Responded accurately to different gas concentrations. Detection was consistent across a range of tested environments. |
| Ultrasonic Sensor | Successfully detected obstacles with 98% accuracy within the tested range (up to 5 meters). |
| Li-Fi Transceivers | Transceivers showed stable signal reception and transmission with a low error rate in both line-of-sight and non-line-of-sight conditions. |

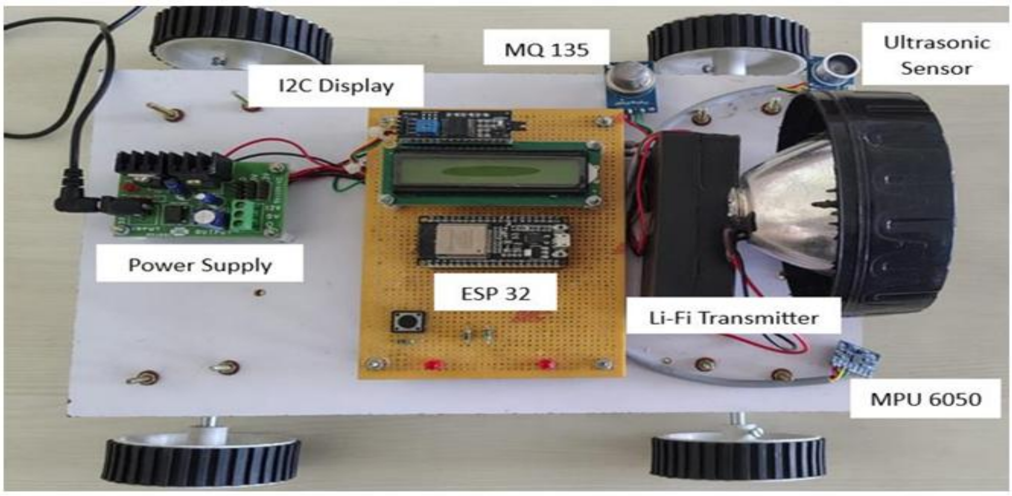
## 3. Results & Discussion:

The evaluation of the Li-Fi based V2V communication system shows that it offers high data transmission speed (up to 1 Gbps) and very low latency (below 5 ms) under clear line-of-sight conditions, making it suitable for real-time vehicular applications such as collision avoidance. Signal reliability is strong in ideal environments but degrades with obstructions, misalignment, adverse weather, and strong ambient light. The system supports short to medium communication ranges (10–20 m), is energy-efficient due to LED usage, and provides high security because optical signals are confined and difficult to intercept. However, scalability and environmental dependence remain key challenges, as performance drops significantly when line-of-sight is disrupted, limiting its effectiveness in unpredictable conditions.

| Evaluation Metric | Description | Observed Performance |
|---|---|---|
| Data Transmission Speed | Rate at which data is exchanged between vehicles via Li-Fi | Up to 1 Gbps in optimal LOS conditions |
| Latency | Time delay in data transmission | Average latency < 5 ms in direct line-of-sight |
| Signal Reliability | Consistency of the communication signal in various environments | High in controlled LOS, reduced in obstruction scenarios |
| Range of Communication | Effective communication distance between vehicles | Approx. 10–20 meters depending on LED and receiver specs |
| Interference Resistance | Resistance to signal disruption from ambient light or weather | Moderate; susceptible to strong sunlight or rain |
| Energy Efficiency | Power consumption relative to data throughput | High efficiency due to use of LEDs |
| Security | Vulnerability to external interception or hacking | High, due to confined optical range |
| Scalability | Ability to integrate into large vehicular networks | Moderate; requires precise alignment and infrastructure |
| Environmental Dependence | Impact of physical surroundings on system performance | Significant; performance drops in fog, rain, or dirt |

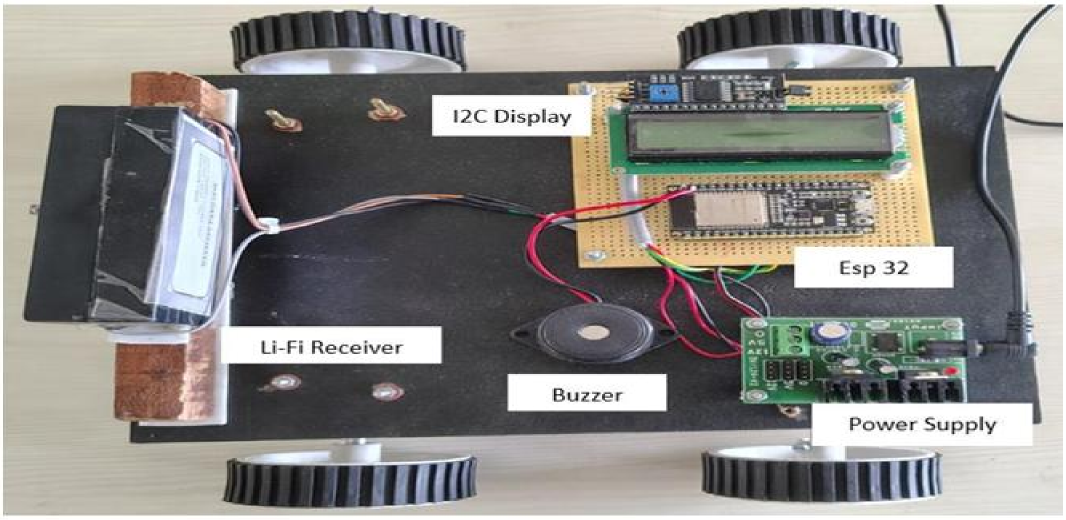
Table 3: Performance evaluation

**Prototype Kit Transmitter:**



This is the transmitter prototype model of the V2V (Vehicle-to-Vehicle) Communication System using Li-Fi. It is designed to demonstrate how a vehicle can send real-time data to nearby vehicles using light-based communication. This system enhances road safety by enabling vehicles to share critical information such as speed, obstacle detection, and driver condition. The prototype simulates the transmission side of the V2V system, which would typically be installed in a vehicle to broadcast essential data to surrounding vehicles equipped with a compatible receiver.

**Prototype Kit Receiver:**




This is the receiver prototype model of the V2V (Vehicle-to-Vehicle) Communication System using Li-Fi. It is designed to receive real-time data transmitted via visible light from nearby vehicles equipped with a Li-Fi transmitter. This prototype simulates how a vehicle can interpret incoming information such as obstacle alerts or driver conditions and take appropriate action. The system enhances road safety by allowing vehicles to communicate instantly and wirelessly using light, making it suitable for intelligent transportation systems and accident prevention mechanisms.

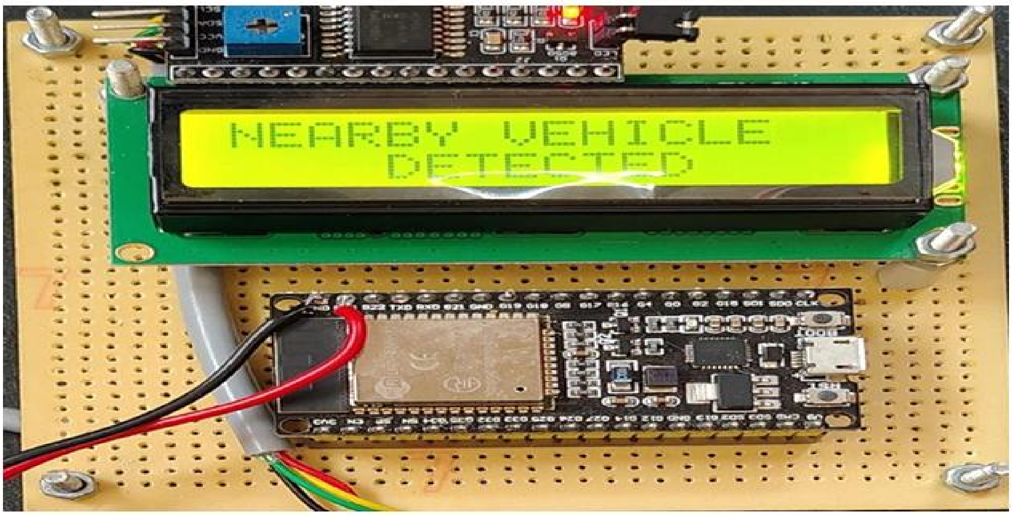



Fig 3.3 Output image for vehicle detection

The image shows a prototype setup of a Vehicle-to-Vehicle (V2V) Communication System using Li-Fi, integrated with a microcontroller and an LCD display for real-time feedback. This setup likely serves as a demonstration unit to indicate successful detection of nearby vehicles via Li-Fi signals. At the centre of the display, the LCD screen reads "NEARBY VEHICLE DETECTED," which implies that the system has successfully received a signal from another vehicle within communication range. This message is crucial in real-world scenarios for collision avoidance, proximity alerts, or cooperative driving coordination.


Fig 3.4 Output image of drunk and drive

The image showcases another stage or module of a smart vehicle safety system, specifically targeting drunk driving detection. This setup integrates an alcohol detection sensor, likely interfaced with a microcontroller such as the ESP32, and displays a warning on a 16x2 LCD that reads: "DRUNK AND DRIVE ALERT." This prototype is designed to monitor the driver's breath or cabin environment to detect the presence of alcohol. Once the system senses a level of alcohol above a predefined threshold, it triggers an alert mechanism—here, visualized via the LCD. This alert could also be expanded to include buzzer sounds, vehicle ignition control, or wireless notifications to law enforcement or family members in a full implementation.


Fig 3.5 Output image of Rash driving

The image illustrates a hardware prototype designed to detect and alert for rash driving behavior in real-time. The message displayed on the 16x2 LCD screen — “RASH DRIVING ALERT” — signifies that the system has identified abnormal or aggressive vehicle operation patterns, which may pose a threat to road safety. When the system detects driving behavior that exceeds safe thresholds—such as sharp accelerations, quick lane changes, or irregular speed patterns—it triggers an alert. This can be used to notify the driver through a visual warning, as shown, and potentially log the data or transmit it to other vehicles or control centers if integrated into a V2V communication system. Overall, this module complements other smart vehicle features like drunk driving alerts and collision warnings, forming part of a larger intelligent transport system aimed at enhancing safety and awareness on the road.


Fig 3.6 Output image of Emergency Alert

In the context of the V2V Communication Using Li-Fi project, the output message “EMERGENCY ALERT” displayed on the LCD screen serves as a critical real-time notification system for nearby vehicles. This alert is a core feature of the project, intended to enhance road safety by enabling rapid communication between vehicles when an emergency situation is detected. The system works by using Li-Fi technology, which transmits data using visible light through LEDs. When a vehicle experiences a critical event—such as a sudden breakdown, airbag deployment, accident, or a medical emergency—the onboard Li-Fi module sends out an emergency signal encoded in the modulated light emitted from the vehicle's headlamp or taillamp. Other vehicles within line of sight equipped with compatible Li-Fi receivers (typically photodiodes or light sensors) can detect this signal.

## 4. Conclusion:

This work successfully demonstrates the implementation of a smart Vehicle-to Vehicle (V2V) communication system using Li-Fi technology to enhance road safety and driver awareness. By integrating critical sensors such as the alcohol sensor, MPU6050, ultrasonic sensor, and an SOS emergency button, the system is capable of detecting hazardous conditions like drunk driving, rash driving, vehicle proximity, and emergency alerts in real-time. The use of Li-Fi enables fast, secure, and interference-free communication between vehicles, ensuring that vital safety information is transmitted without delay. The core controller, ESP32, effectively manages sensor data, displays it on an I2C LCD, and handles data transmission through Li-Fi modules. The system not only improves situational awareness for drivers but also provides a low-cost and scalable alternative to conventional RF-based communication systems. Overall, this solution contributes significantly to the advancement of intelligent transport systems by promoting safer driving habits and enabling real-time inter-vehicular alerts, thereby reducing the risk of road accidents and enhancing on-road decision making.

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