Vehicle To Vehicle Communication Using Li-Fi Technology

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***Abstract*—This research presents a robust and cost-effective implementation of Vehicle-to-Vehicle (V2V) communication utilizing Light Fidelity (Li-Fi) technology, aimed at enhancing road safety and reducing the latency associated with traditional Radio Frequency (RF) systems. As traffic density increases, the demand for high-speed, interference-free communication becomes critical. Unlike conventional Wi-Fi or Bluetooth, Li-Fi uses the Visible Light Spectrum (VLC) to transmit data, offering higher security and immunity to electromagnetic interference.**

The proposed system is built upon the Arduino Uno microcontroller, which acts as the central processing unit for data modulation and demodulation. For the transmitter module, high-intensity LEDs are used to flicker at speeds imperceptible to the human eye, representing binary data. This light signal carries critical vehicular information, such as speed, braking status, or obstacle detection. On the receiver side, a Light Dependent Resistor (LDR) or photodiode captures the varying light intensities and converts them back into electrical signals for the Arduino to process.

To simulate real-world vehicular movement, the project integrates DC motors controlled by an L298N Motor Driver, allowing the prototype to respond physically to received data (e.g., automatic braking when a "stop" signal is received from the lead vehicle). Real-time status updates and received messages are displayed on a 16x2 LCD interface, providing immediate feedback on the communication link's integrity. Experimental results demonstrate that the system successfully transmits data over short distances with minimal error rates, proving its viability for "platooning" and collision avoidance applications. This Li-Fi-based approach provides a sustainable solution for Intelligent Transportation Systems (ITS) by leveraging existing vehicle lighting infrastructures, ensuring a future of safer, interconnected, and autonomous mobility.

***Index Terms*—Li-Fi Technology, Arduino Uno, Vehicle-to-Vehicle Communication, Intelligent Transportation Systems, Visible Light Communication (VLC), Road Safety.**

I. INTRODUCTION

The rapid escalation in the number of vehicles on the road has led to a significant increase in traffic congestion and road accidents, posing a major challenge to global transportation safety. Conventional Intelligent Transportation Systems (ITS) primarily rely on Radio Frequency (RF) based communication, such as Dedicated Short-Range Communications (DSRC) and Wi-Fi. However, the RF spectrum is becoming increasingly congested, leading to issues like electromagnetic interference, limited bandwidth, and latency. To address these limitations, Visible Light Communication (VLC), popularly known as Li-Fi (Light Fidelity), has emerged as a revolutionary alternative for Vehicle-to-Vehicle (V2V) communication. Li-Fi utilizes the unlicensed visible light spectrum, offering high-speed data transmission, enhanced security, and immunity to electromagnetic interference.

In a V2V ecosystem, vehicles need to exchange real-time data regarding speed, braking status, and distance to prevent collisions. This project proposes a robust Li-Fi-based V2V communication system implemented using an Arduino Uno as the central processing unit. The system leverages high-intensity LEDs as the transmitter to broadcast data through light pulses and a Light Dependent Resistor (LDR) or photodiode as the receiver to capture these signals. By integrating DC Motors and a Motor Driver (L293D), the system simulates a mobile vehicular environment where automated responses, such as emergency braking or speed synchronization, can be triggered based on the received data. A 16x2 LCD is incorporated to provide a real-time visual interface, displaying critical parameters like the distance between vehicles and received alert messages.

The core principle of this technology lies in the rapid switching of LEDs, which is imperceptible to the human eye but can be easily decoded by the receiver. When the lead vehicle detects an obstacle or applies brakes, the Arduino encodes this information into binary data, which is then transmitted via the LED headlights. The following vehicle's LDR detects the variations in light intensity and sends the signal back to its respective Arduino Uno for processing. This creates a low-latency communication link that is significantly faster than human reaction time. Furthermore, Li-Fi is highly cost-effective as it utilizes existing LED infrastructure and does not require expensive frequency licensing.

This research focuses on the practical implementation of Li-Fi for short-range V2V scenarios, emphasizing its efficiency in preventing rear-end collisions. Unlike RF signals that can penetrate walls and be intercepted, Li-Fi is confined to the line-of-sight (LOS), which inherently provides a more secure communication channel between vehicles. The integration of Arduino and sensory components provides a scalable and modular framework for testing V2V logic. As we move toward the era of autonomous driving and smart cities, adopting VLC-based systems will play a pivotal role in creating a safer, more coordinated, and interference-free vehicular network. This paper details the hardware architecture, the software logic for data modulation, and the performance analysis of the Li-Fi system under various environmental conditions.

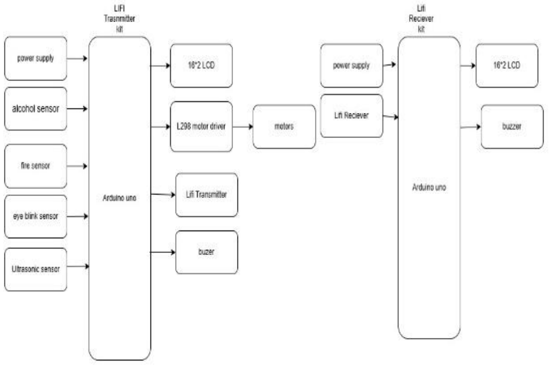

Figure 1 : Block Diagram

II. LITERATURE SURVEY

The evolution of Intelligent Transportation Systems (ITS) has necessitated the development of robust, high-speed, and interference-free communication protocols to enhance road safety and traffic efficiency. Traditional Vehicle-to-Vehicle (V2V) communication has predominantly relied on Radio Frequency (RF) technologies, such as Dedicated Short-Range Communications (DSRC) and Wi-Fi. However, as the number of vehicles on the road increases, the RF spectrum faces significant congestion, leading to latency issues and electromagnetic interference. To mitigate these challenges, Light Fidelity (Li-Fi) technology has emerged as a promising alternative. Li-Fi utilizes the Visible Light Communication (VLC) spectrum, offering a bandwidth that is substantially larger than the RF spectrum. By leveraging the existing LED lighting infrastructure of vehicles—such as headlights and taillights—Li-Fi provides a cost-effective and secure medium for data transmission. Researchers have demonstrated that Li-Fi can achieve high data rates while remaining immune to electromagnetic interference, making it ideal for the dense electronic environments found in modern automotive systems.

Recent studies have focused on the implementation of Li-Fi using accessible hardware components like the Arduino Uno microcontroller. The Arduino serves as the central processing unit, managing the modulation of data into light signals and the subsequent demodulation at the receiver end. In a typical V2V setup, information such as vehicle speed, braking status, or obstacle detection is converted into digital signals. These signals drive an LED transmitter through a switching circuit. On the receiving vehicle, a Light Dependent Resistor (LDR) or a photodiode captures the varying intensity of the light, converting it back into electrical signals for the Arduino to process. To simulate real-world vehicular movement, integration with DC motors and motor drivers (such as the L298N) is essential. These components allow for the physical movement of prototype vehicles, enabling the testing of communication stability during motion and varying distances.

Data visualization is another critical aspect explored in contemporary literature. The use of Liquid Crystal Displays (LCD) in V2V prototypes allows for real-time monitoring of transmitted data, providing immediate feedback to the driver or system tester. For instance, if a leading vehicle detects an obstacle using ultrasonic sensors and transmits a "STOP" signal via Li-Fi, the following vehicle’s LCD can display the warning while the motor driver simultaneously disengages the DC motors to prevent a collision. This hardware-in-the-loop approach demonstrates the practical viability of Li-Fi for safety-critical applications. Scholars have noted that while LDRs are cost-effective for basic prototyping, they have slower response times compared to photodiodes; however, for low-speed urban transit simulations using Arduino, they remain a staple in academic research due to their simplicity and ease of integration.

Despite its advantages, Li-Fi technology faces environmental constraints such as atmospheric turbulence, sunlight interference, and "line-of-sight" requirements. Extensive research is currently being conducted on signal processing algorithms to filter out ambient light noise and improve the signal-to-noise ratio (SNR) in outdoor conditions. Comparative analyses between Li-Fi and RF systems often highlight that while Li-Fi does not penetrate walls or opaque objects, this "limitation" actually enhances security by preventing signal leakage and hacking from external sources. In the context of vehicle safety, the directional nature of light ensures that communication is localized between relevant vehicles, reducing the risk of data collisions. As the automotive industry moves toward autonomous driving, the integration of Li-Fi as a redundant communication layer alongside RF is widely regarded by the scientific community as a necessary step for achieving high-reliability V2V networks.

ARDUINO UNO:

The Arduino Uno is a widely utilized open-source microcontroller board based on the ATmega328P, serving as the industry standard for prototyping and academic engineering projects. It features 14 digital input/output pins, of which 6 can provide Pulse Width Modulation (PWM) output for controlling devices like DC motors and servos. Additionally, the board includes 6 analog inputs that allow it to read data from various sensors, such as ultrasonic, fire, or moisture sensors. Operating at a clock speed of 16 MHz, the Uno provides a balance between processing power and energy efficiency, making it ideal for battery-operated or solar-powered systems. The board is easily programmable via the Arduino IDE using a simplified version of C++, which abstracts complex register-level programming into user-friendly functions. It includes a USB connection for power and code uploading, a power jack for external batteries, an ICSP header, and a dedicated reset button. One of its greatest strengths is its compatibility with a vast ecosystem of "shields"—expansion boards that plug directly into the Uno to add capabilities like Wi-Fi, Ethernet, or motor driving. Its robust design is particularly forgiving for beginners, as it can withstand minor wiring errors that might damage more sensitive microcontrollers. In a multipurpose agricultural robot, the Uno acts as the "brain," coordinating signals between the motor driver, the water pump, and the LCD status display. Because it operates at 5V, it integrates seamlessly with standard electronic components and modules. Furthermore, its extensive community support ensures that troubleshooting and finding library files for new sensors is highly efficient. Ultimately, the Arduino Uno remains a cornerstone of the maker movement due to its reliability, affordability, and versatility in hardware-software integration.

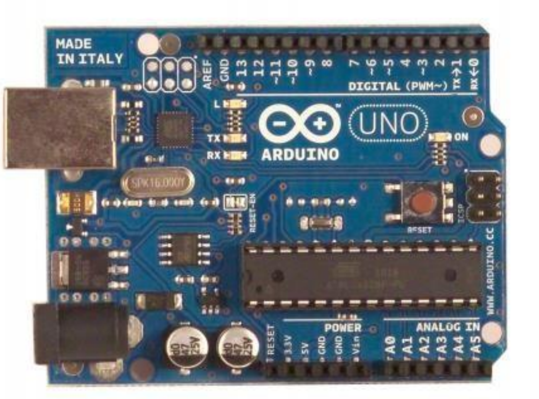

Figure 2: Arduino UNO

DC MOTOR:

A DC motor is an electromechanical device that converts direct current electrical energy into mechanical energy through the interaction of magnetic fields. It operates primarily on the principle of Lorentz Force, which states that a current-carrying conductor placed within a magnetic field experiences a physical force. The core components include the stator, which provides a stationary magnetic field, and the rotor (or armature), which rotates when energized. To maintain continuous rotation in one direction, a commutator and brushes are used to periodically reverse the direction of current flow within the armature coils. In robotic applications, such as your agriculture robot, these motors are prized for their high starting torque and ease of speed control. Speed is typically managed using Pulse Width Modulation (PWM), which varies the average voltage supplied to the motor. For bidirectional control, they are often paired with an H-bridge motor driver like the L293D or L298N. DC motors are categorized into brushed and brushless types, with brushed versions being more common in simple Arduino projects due to their lower cost and straightforward wiring. Their efficiency and compact size make them ideal for driving wheels, operating pumps, or powering mechanical arms in automation. Because they can draw significant current, they usually require an external power source—like a solar-charged battery—rather than drawing power directly from a microcontroller's pins. Overall, the DC motor remains the backbone of portable robotics due to its reliability and predictable performance.

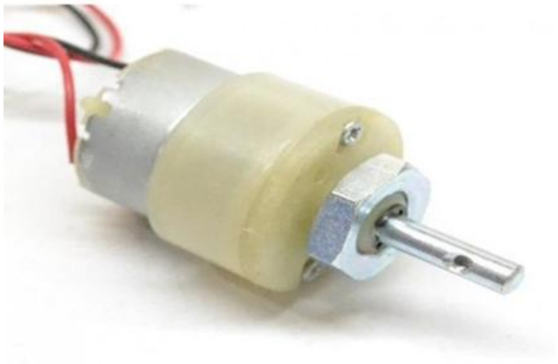

Figure 3: DC Motor

MOTOR DRIVER:

A motor driver acts as the essential interface between a low-power microcontroller, like an Arduino, and high-power DC motors that require significant current. While the Arduino provides the logic and control signals, its GPIO pins cannot supply the amperage needed to physically turn a motor's shaft without risking permanent hardware damage. The motor driver solves this by drawing power directly from an external battery source and switching it to the motors based on the microcontroller's low-voltage commands. Most drivers, such as the L293D or L298N, utilize an H-Bridge circuit configuration, which allows the user to change the direction of current flow and thus reverse the motor's rotation. They also facilitate speed control through Pulse Width Modulation (PWM), effectively "chopping" the voltage to regulate how fast the robot moves. Beyond simple movement, these drivers include protective features like back-EMF diodes to prevent voltage spikes from destroying sensitive electronics. In a multipurpose agriculture robot, the motor driver is responsible for handling the heavy torque required for plowing or navigating uneven terrain. It essentially translates the "brain's" binary decisions into the "muscle's" physical force. Without this component, the robot would remain stationary as the control logic would have no way to drive the mechanical actuators. By isolating the control and power circuits, the motor driver ensures system stability and operational longevity.

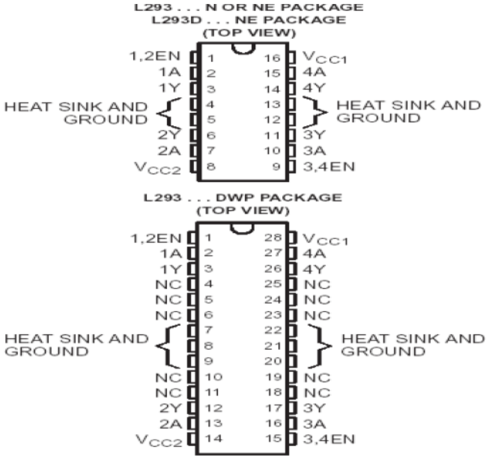

Figure 4: Pin diagram of Motor Driver

LCD:

A Liquid Crystal Display (LCD) is an electronic display module that utilizes the light-modulating properties of liquid crystals combined with polarizers to produce images or text. Unlike LEDs, which emit light directly, an LCD requires a backlight or reflector to produce visible output, making it highly energy-efficient for portable devices. In embedded systems, the 16x2 alphanumeric LCD is the most common variety, capable of displaying 16 characters per line across two separate rows. These modules typically operate using the Hitachi HD44780 controller, which handles the complex timing required to render ASCII characters. When integrated with an Arduino Uno, the LCD is often connected via a parallel interface using 4-bit or 8-bit modes, or through an I2C adapter to save digital pins. The display consists of a matrix of pixels where the orientation of liquid crystals is manipulated by an electric field to block or pass light. A potentiometer is usually connected to the "V0" pin to manually adjust the contrast levels of the characters against the background. In the context of a Vehicle-to-Vehicle (V2V) communication project, the LCD serves as the primary user interface to visualize real-time data. It can display critical alerts, such as "Vehicle Detected" or "Emergency Brake Applied," translated from the Li-Fi signals received by the LDR. The durability and low power consumption of LCDs make them ideal for automotive prototypes where battery life is a concern. Furthermore, the ability to display custom characters allows developers to create icons for signal strength or directional arrows. Modern LCDs also feature a controllable backlight, which can be toggled via code to indicate system status or save power during idle periods. Ultimately, the LCD provides a bridge between the raw sensor data of the microcontroller and the human operator, ensuring that the internal logic of the Li-Fi system is transparent and actionable.

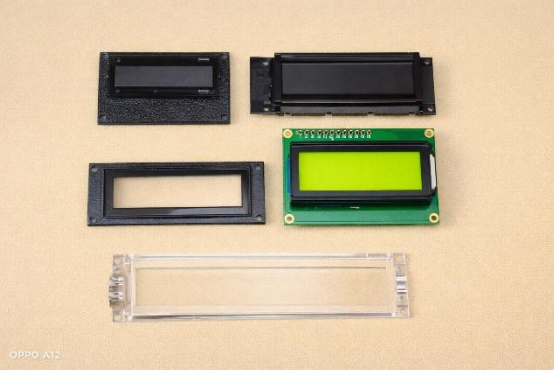

Figure 5: LCD

LED:

An LED (Light Emitting Diode) is a semiconductor light source that emits light when an electric current flows through it. Unlike traditional incandescent bulbs that rely on a heated filament, LEDs produce light through a process called electroluminescence. In this process, electrons in the semiconductor recombine with electron holes, releasing energy in the form of photons. The color of the light is determined by the energy band gap of the materials used in the semiconductor, ranging from infrared to ultraviolet. LEDs are polar components, meaning they only allow current to flow in one direction; they consist of an anode (positive) and a cathode (negative). One of their most significant advantages is high energy efficiency, as they convert a higher percentage of power into light rather than heat. They are incredibly durable and have a long operational lifespan, often lasting tens of thousands of hours. Because of their small size, they can be easily integrated into complex circuit boards or used for high-resolution displays. In communication projects like Li-Fi, LEDs act as high-speed transmitters by flickering at rates imperceptible to the human eye. They also require a current-limiting resistor to prevent damage from excessive voltage. Their fast switching time makes them ideal for digital signaling and automotive lighting. Today, LEDs have largely replaced older lighting technologies in homes, streetlights, and industrial applications. As a solid-state technology, they are also more environmentally friendly, containing no mercury or toxic gases.

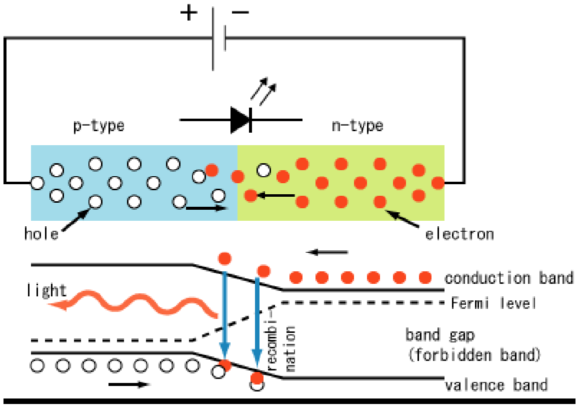

Figure 6: LED

LDR:

A Light Dependent Resistor (LDR), also known as a photoresistor or cadmium sulfide (CdS) cell, is a passive electronic component whose resistance decreases significantly as the intensity of incident light increases. In total darkness, an LDR typically exhibits a very high resistance, often reaching several megaohms (M Omega), effectively acting as an open circuit in many low-power applications. However, when exposed to bright light, the resistance drops dramatically to just a few hundred ohms (Omega). This characteristic is due to the photoconductivity of the semiconductor material, where photons provide enough energy to jump electrons into the conduction band. Because of this variable resistance, they are frequently used in voltage divider circuits to provide an analog signal to microcontrollers like the Arduino Uno. In vehicle-to-vehicle communication, they serve as the receiver by detecting the rapid flickering of an LED "transmitter" that represents binary data. They are favored in prototyping because they are inexpensive, robust, and very simple to integrate into sensor modules. However, LDRs have a relatively slow response time compared to photodiodes, making them better suited for low-speed data transmission or simple light-sensing tasks. They are commonly found in street lights, alarm systems, and light intensity meters. The physical construction usually involves a zig-zag track of photosensitive material on a ceramic substrate, which maximizes the surface area for light contact. Despite newer technologies, the LDR remains a fundamental tool for engineers studying the intersection of light and electronics.

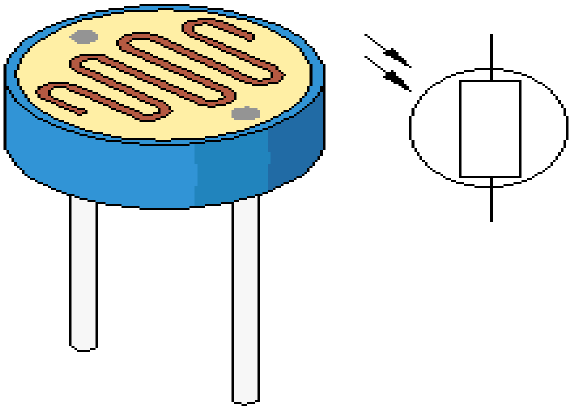

Figure 7: LDR

III. CONCLUSION

The development and implementation of the Vehicle-to-Vehicle (V2V) Communication System using Li-Fi Technology demonstrate a viable, high-speed, and interference-free alternative to traditional Radio Frequency (RF) based systems. By leveraging the Arduino Uno as the central processing unit, this project successfully integrated optical wireless communication into a mobile automotive prototype. The transmitter side utilized high-intensity LEDs to pulse data at frequencies imperceptible to the human eye, representing a cost-effective and energy-efficient method for data propagation. On the receiver end, the Light Dependent Resistor (LDR), calibrated for precision, effectively captured these optical signals, translating light intensity variations back into digital logic. The integration of the L298N Motor Driver and DC motors allowed for real-time hardware responses based on the transmitted data, simulating critical safety maneuvers such as automated braking or speed synchronization when a leading vehicle communicates a hazard. The system's status and the specific data packets received were displayed instantaneously on the 16x2 LCD, providing a clear interface for monitoring communication health and signal integrity. From a research perspective, this project confirms that Li-Fi can significantly reduce latency in short-range vehicular environments, which is paramount for preventing collisions in high-density traffic. While RF systems often suffer from electromagnetic interference and bandwidth congestion, this optical approach operates in the unregulated visible light spectrum, offering enhanced security since the signal is confined to the line-of-sight.

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