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Development of a Li-Fi Enabled Inter-Vehicle Data Transmission System

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Abstract
Nowadays the road accidents are increasing in a drastic amount. It reinforces the importance of efficient and real time communication between vehicles to improve road safety. The usual vehicle-to-vehicle communication systems are mostly dependent on radio frequency (RF) technologies like Wi-Fi, Bluetooth and cellular networks, which have the restrictions such as electromagnetic interference, bandwidth saturation, and security issues. These restrictions reduce their potential for safety-critical applications that require rapid actions. By acknowledging these issues, this proposed project has been developed by aiming to develop a Li-Fi (Light Fidelity) based vehicle-to-vehicle communication system that utilizes visible light for data transfer. In the proposed system, the headlights and rear lamps of vehicles, which are equipped with high-bright LEDs, are used as transmitters, and photodiodes placed on the receiving vehicle are used as receivers. Safety messages such as sudden braking notifications, speed changes, and obstacle notifications are converted into digital signals and transmitted through high-speed LED modulation, which is invisible to the human eye. The receiving vehicle decodes the received information using a microcontroller to produce warning notifications and automatically triggers braking and speed reduction as needed. The proposed Li-Fi communication system has advantages such as low latency, high data transfer rate, improved security, and resistance to RF interference.

Keywords: *Li-Fi, Vehicle-to-Vehicle Communication, Visible Light Communication, Automatic Braking, Road Safety, Intelligent Transportation System.*

1. Introduction

Most existing V2V communication systems rely on radio frequency (RF) based technologies such as Wi-Fi, Bluetooth, ZigBee, and cellular networks, which suffer from inherent limitations including electromagnetic interference, limited bandwidth, network congestion, latency, and security vulnerabilities. These limitations reduce the reliability of RF-based systems in time-critical safety applications where immediate response is essential to prevent collisions. Li-Fi (Light Fidelity) is an emerging wireless communication technology that uses visible light śinstead of radio waves for data transmission, offering advantages such as high data rates, low latency, enhanced security, and immunity to RF interference. With the widespread adoption of LED technology in modern vehicle headlights and tail lamps, Li-Fi presents a practical and efficient solution for short-range, line-of-sight vehicle-to-vehicle communication. By modulating the intensity of LED light at high speeds imperceptible to the human eye, data can be transmitted securely and reliably between moving vehicles. This paper proposed a design and implementation of a Li-Fi based vehicle-to-vehicle communication system aimed at improving road safety by enabling real-time transmission of critical information such as sudden braking alerts and obstacle warnings, as well as incorporating automatic. However, most of the existing V2V communication systems are based on radio frequency (RF) technologies such as Wi-Fi, Bluetooth, ZigBee, and cellular networks, which have limitations such as electromagnetic interference, bandwidth, congestion, latency, and security issues. These factors make the RF-based systems less reliable in time-critical safety communications, where immediate action is required to avoid accidents. Li-Fi (Light Fidelity) is a new wireless communication technology that uses visible light instead of radio waves to transmit data. Li-Fi technology has advantages such as high data rate, low latency, improved security, and resistance to RF interference. With the increasing use of LED technology in modern vehicle headlights and taillights, Li-Fi technology provides a feasible and efficient solution for short-range, line-of-sight communication between vehicles. By varying the intensity of the LED light at speeds that are not perceptible to the human eye, secure and reliable communication can be achieved between moving vehicles.

2. Related Works

There have been several researches works conducted in the field of vehicle safety and vehicle-to-vehicle communication to minimize road accidents and optimize traffic flow. Initial research works on V2V communication were mainly based on radio frequency (RF) technologies such as Dedicated Short-Range Communication (DSRC), Wi-Fi, Bluetooth, and cellular networks to support the transfer of safety messages such as collision warnings and braking notifications. These research studies demonstrated the feasibility of cooperative vehicle communication; however, they also underscored the difficulties associated with spectrum saturation, electromagnetic interference, heightened latency, and security risks, particularly in congested traffic situations and urban environments. In order to address these limitations, researchers have suggested advanced RF-based technologies that incorporate adaptive routing protocols, congestion management, and encryption algorithms. However, these solutions have added complexity to the system and heightened processing demands. Recently, Visible Light Communication (VLC), commonly referred to as Li-Fi, has been established as a new wireless communication method that utilizes the existing LED lighting for data transfer. Numerous research studies have been undertaken to investigate the use of Li-Fi for indoor wireless communication, intelligent lighting systems, and short-range data transfer, which demonstrated outstanding data transfer rates, minimal latency, and resistance to RF interference. In the context of vehicular communication, numerous studies have been suggested for the deployment of Li-Fi based vehicle-to-vehicle (V2V) communication systems. These systems utilize LED headlights and tail lamp transmitters, along with photodiode or image sensor receivers, to facilitate line-of-sight communication. These studies emphasize the benefits of Li-Fi technology in terms of directional transmission, improved security, and minimized interference; however, most of the existing works are restricted to simulation analysis or simply focus on data transfer without incorporating active safety features.
Moreover, some of the proposed systems do not support real-time decision-making functions such as automatic braking and speed control. Hence, there is a need for an effective Li-Fi based V2V communication system that not only supports reliable real-time data transfer but also incorporates automated safety reactions for improved accident prevention in intelligent transportation systems. Various recent studies have explored the use of hybrid communication systems that combine RF communication with sensor fusion algorithms for improved robustness; however, these systems are also prone to latency and congestion problems in dense traffic scenarios. Li-Fi based vehicular communication has also been explored as a complementary or alternative technology due to its line-of-sight nature, spatial reuse capabilities, and immunity to RF interference.

3. Proposed Methodology

The proposed methodology for Vehicle to Vehicle (V2V) data transfer using Li-Fi technology is intended to provide faster, secure, and reliable data transfer between vehicles using visible light technology. Li-Fi is a short-range wireless communication technology using light emitting diodes (LEDs) for data transfer using visible light technology. The proposed system provides vehicles with the ability to communicate with each other using light emitted from their head lights, brake lights, or LEDs fitted on vehicles. The idea behind this proposed system is to provide vehicles with Li-Fi transmitter and receiver modules to facilitate simultaneous data transfer and reception between vehicles. The transmitter part of this system is composed of high brightness LEDs and microcontroller units, while the receiver part is composed of photodiodes and light sensors to

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receive light signals and convert them into electrical signals. The microcontroller is used to collect data from various sensor devices fitted on vehicles, including speed sensor devices, brake status sensor devices, and direction sensor devices.

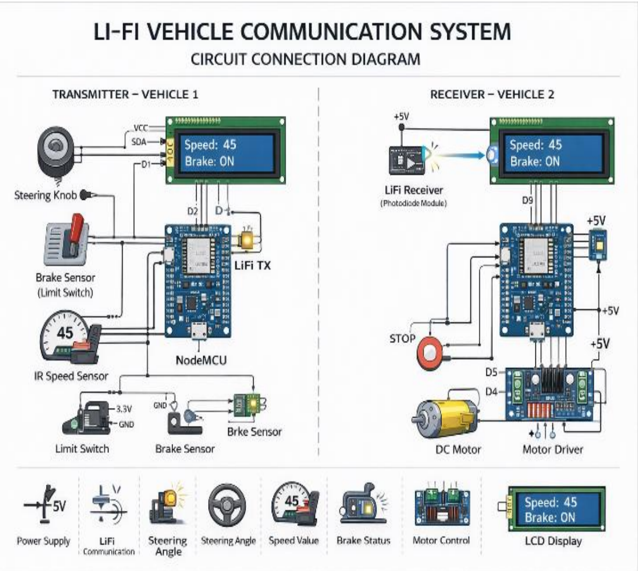

Figure 1 **Li-Fi Vehicle communication System**

The light signals received on the Receiver end are received by the photodiode and then converted into electrical signals. Since the electrical signals obtained from the photodiode are weak, an amplifier circuit is used to increase the strength of the signals before they are fed to the microcontroller for further processing. The microcontroller processes the signals and then converts them into useful information, such as the speed information, braking information, and traffic information, which can be displayed on a display unit located inside the vehicle or used to generate signals to the driver to enhance road safety is shown in Figure 1 Li-Fi Vehicle communication System. This is because, it will be in operation all the time, thus enabling the vehicles to communicate information regarding their status and environment in real time. For example, in case a vehicle stops suddenly, information regarding this incident will be communicated to the following vehicles in real time using Li-Fi technology, thus enabling them to take precautions to prevent accidents. Vehicles will also communicate information regarding lane changing, traffic, and emergency vehicles, among others. The process of implementing this methodology involves creating hardware and software components. They were classified into two types they are: The hardware components include the microcontroller, LED transmitter, photodiode receiver, amplifier circuit, sensor, and power supply unit, while the software components include the programming of the microcontroller for data acquisition, encoding, transmission, reception, and decoding. The entire process of communication takes place through several steps, such as data acquisition, data encoding, light modulation, transmission of data, reception of data, amplification of data, data decoding, and finally displaying the data. One of the major advantages of this proposed Li-Fi-based V2V communication system is that it can attain very high data transmission speed compared to other traditional wireless communication systems. This Li-Fi communication system has the advantage of being very secure, as light cannot pass through solid objects such as walls, thereby ensuring high security. This Li-Fi communication system does not cause electromagnetic interference, which is another major advantage of this Li-Fi communication system, as it can be implemented even in situations where RF communication is restricted. The use of LED lights is also an advantage of this Li-Fi communication system, as it is an energy-efficient system.

3.1. Transmitter Side

The transmitter section is a vital part of a vehicle-to-vehicle (V2V) communication system that uses Li-Fi (Light Fidelity). In this system, data transmits using visible light instead of traditional radio frequency signals. The transmitter turns digital information from a vehicle into high-speed light signals using LEDs. These light signals are picked up by a vehicle that has a photodetector receiver. This vehicle uses Visible Light Communication (VLC) technology, Speed, braking status, traffic warnings, and accident alerts can be shared by vehicles without any delay or security issues. The transmitter module is made up of several components that are mostly microcontroller, LED light source, driver circuit, and data encoder, and power supply unit. Vehicle information is collected from sensors or onboard systems in the data generation stage of the process. The information that can be accessed includes vehicle speed, distance, brake activation, direction signals, and emergency

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alerts. The collected data is processed and prepared for transmission by a microcontroller, such as an Arduino Uno or ESP32. It is shown in the Figure 2 Transmitter End. The data is processed in the microcontroller to create a digital binary sequence that is composed of 1s and 0s. A modulation technique that is effective for optical communication is used by the system to encode these binary signals. One common technique in Li-Fi systems is On-Off Keying (OOK). The LED light is turned ON to represent a binary '1' and then turned OFF to represent a binary '0' in this approach. In microseconds, the switching takes place at extremely high speeds that exceed the human eye's ability to perceive.

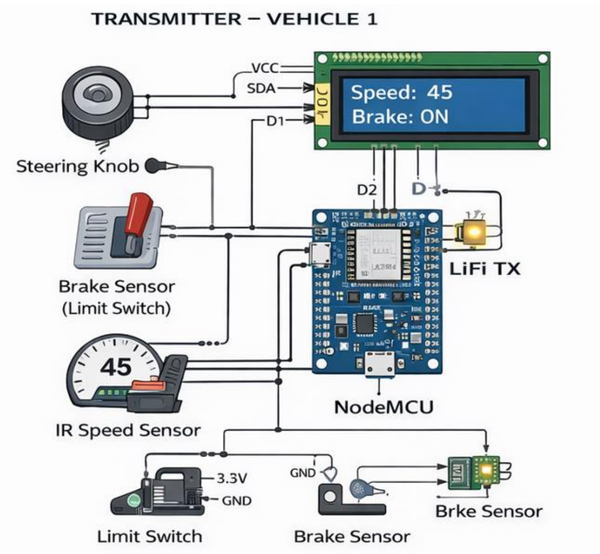

Figure 2 Transmitter End

The transmitter is anchored by the data encoding and signal conditioning stage. To ensure a proper time between the sending and receiving vehicles, the data can be formatted or packetized before transmission. To enhance communication reliability, it is possible to include error detection methods such as parity bits or checksums. The receiver's ability to decode transmitted information is ensured by this step, even when there's noise or environmental factors such as sunlight or street lighting. All parts of the transmitter system are supplied with the necessary electrical power by the power supply unit. The vehicle's battery system usually operates at 12V to provide power to the transmitter in vehicle applications. For a steady operation and to prevent fluctuations that could impact signal transmission, it is vital to have good power management. To increase reliability and extend the transmission range in real V2V applications, it is possible to use multiple LED arrays as well as the transmitter. The following vehicle gets this signal and can activate a driver alert system or an automatic braking feature.

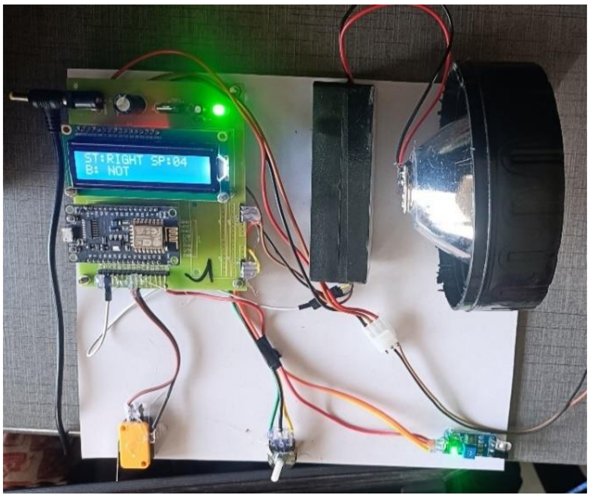

Figure 3 Transmitter End

The Li-Fi transmitter system has the advantage of being highly secure and causing minimal interference. Visible light signals do not penetrate walls and remain within the line of sight, unlike radio frequency communication technologies like Wi-Fi or cellular networks. Enhancing communication security and reducing the chances of outside interference are both benefits of this. Additionally, the visible light spectrum's large bandwidth allows for faster data transmission than traditional RF systems. To put it briefly, LEDs are used to convert vehicle data into high-speed optical signals in a vehicle-to-vehicle Li-Fi communication system's transmitter. A microcontroller is included, as well as LED driver circuit, high-brightness LEDs, an engraving system, and a power supply. The transmitter facilitates efficient and reliable communication between vehicles by rapidly changing the LED light intensity using digital data. This technology is essential for improving road safety by enabling real-time information sharing, which assists in preventing accidents and enhancing intelligent driving.

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3.2. Receiver End

The Li-Fi vehicle-to-vehicle communication system is dependent on the receiver module for its function. Electrical data is converted into monitoring and control by detecting the optical signal transmitted from the leading vehicle. The visible light channel is used by the light signal from the LED of the transmitting vehicle (Vehicle-1) to be detected by a photodiode sensor installed in the receiving vehicle (Vehicle-2). Variations in light intensity are converted into electrical current signals by the photodiode, which acts as an optical detector. Through the Li-Fi communication channel, these signals transport the encoded information. Due to the photodiode's typically weak electrical signal, it must undergo a signal conditioning process to adjust the current signal into a voltage level fit for digital processing. The Node MCU ESP8266, the main processing component of the receiver system, is the source of transmitted signals to the control unit. The Node MCU is constantly checking the incoming signal and decoding the optical data based on the communication logic programmed. Real-time Li-Fi communication applications are made possible by the Node MCU ESP8266's small size, low power consumption, and adequate processing ability. Figure 3 Shows Transmitter End.

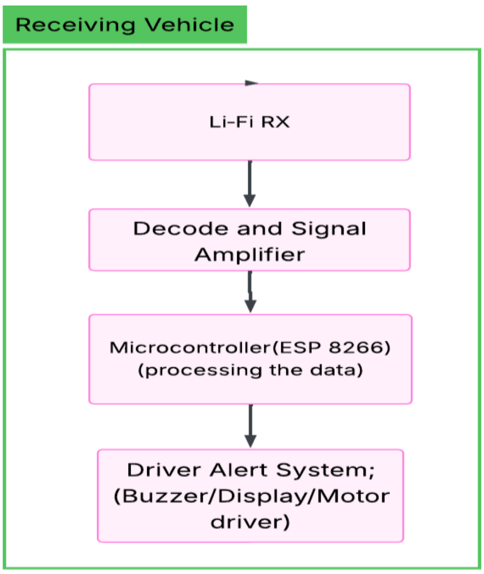

Figure 4 Flow diagram of Receiver end

The microcontroller handles signal processing and the display unit and motor driver circuit that are connected to the receiver system. A 16x2 LCD Display Module is connected to the Node MCU to provide visual feedback to the user. The status of the communication system and the operational condition of the vehicles is shown on the LCD. Messages such as 'Vehicle Running Normally' are displayed on the LCD when the system receives normal signals. The Li-Fi transmitter is activated to send a warning when Vehicle-1's speed drops by approximately 60%. A warning indicator, such as a buzzer or LED, is activated by the system after receiving and decoding this signal, and a warning message is displayed on the LCD. The driver of Vehicle-2 is told to slow down and maintain a safe distance by this notification, as depicted in Figure 4 Shows Flow diagram of Receiver end

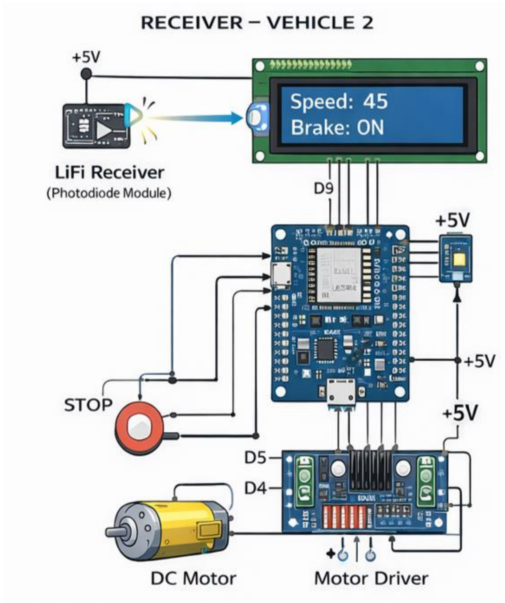

Figure 5 Receiver end

The transmitter sends an emergency message through the Li-Fi channel when Vehicle-1's speed decreases by about 90% in a critical situation. The receiver module picks up this signal, and the Node MCU quickly processes the data. After recognizing the emergency, the microcontroller sends a control signal to the motor driver circuit that uses the L293D Motor Driver IC. The L293D motor driver serves as

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a link between the microcontroller and the DC motor in the vehicle prototype. When the emergency signal comes in, the Node MCU shuts down the motor control output via the L293D driver, which automatically stops the DC motor of Vehicle-2. At the same time, the LCD display shows a message like "Emergency Brake Activated," letting users know the vehicle has stopped because of the sudden slowdown of the leading vehicle. The whole receiver system brings together all of these components, plus more, to create a dependable safety feature on vehicles using Li-Fi technology. With a combination of a photodiode sensor, cortex microcontroller (Node MCU ESP8266), LCD display module (to show information to the user), and motor driver (L293D), the system is able to provide near-instantaneous detection of any increase or decrease in speed from the vehicle ahead and provide timely warning and/or automatically stop the vehicle behind it to. Figure 5 Shows Receiver end.

4. Results and Discussion

The ESP32, LED transmitter, photodiode receiver, and infrared sensing module were all used to successfully set up the proposed Li-Fi vehicle-to-vehicle communication system. An LED in the transmitter section turns vehicle status signals into optical signals, which are sent through visible light. Tests in the lab showed that the system can send data quickly over short distances of about 2 to 4 meters with little delay. The IR sensor was able to find nearby obstacles and send warning signals through the Li-Fi link. But the system needs a direct line of sight between the transmitter and receiver, and bright light in the room may make it harder to pick up the signal. Even with these problems, the prototype shows that Li-Fi technology could be a good way to make roads safer by letting cars talk to each other more easily. The Figure 6 Shows the LCD Display at Receiver end

Figure 6 LCD Display at Receiver end

The experimental setup's outcomes demonstrate the successful use of Li-Fi technology for communication between vehicles. Visible light is a more effective method of transmitting data than traditional radio frequency communication systems. Our testing revealed that communication was quick and stable when there was a clear line of sight between the transmitter LED and the receiver sensor. The transmission of Li-Fi is best when there is sufficient light because it uses light signals. Sensor inputs were handled by the ESP32 microcontroller, which was vital to the system for data flow control. An IR sensor, a potentiometer, and a brake switch were necessary for the system to accurately simulate real vehicle parameters. Due to the high-intensity LED's reliable transmission of signals over short distances, it is a suitable option for communication between cars situated in close proximity. The Table 1 shows the comparison of Li-fi over Wi-fi.

Table 1 Comparison of Li-Fi over Wi-Fi

Table 1: Comparison of Li-Fi over Wi-Fi		
Parameter	**Li-Fi**	**Wi-Fi**
Medium	LED Lights	<Radio waves
Speed	Very High	Moderate
Power usage	Low	High
Security	More Secure	Less Secure

The communication range may decrease if there are a lot of light or obstructions, even with these problems, the suggested system shows how Li-Fi technology could work in smart transportation systems. By enhancing the sensors and LEDs, the system can be extended to be utilized in real-world vehicles. The prototype has demonstrated the ability to send data between vehicles in real-time, as evidenced by the results. By utilizing this, drivers can become aware of what other vehicles are doing and increase safety on the roads.

Conclusion

This document discusses the design and implementation of a Vehicle-to-Vehicle communication system utilizing Li-Fi technology,

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managed by the ESP32. The system employs LED-based optical transmission alongside a photodiode receiver to facilitate data exchange between vehicles. An infrared sensing module is incorporated to identify obstacles. Experimental findings indicate that the system can effectively transmit warning signals and vehicle data over short distances with minimal latency. The implementation demonstrates that Li-Fi technology presents a dependable and secure alternative for short-range vehicle communication, in contrast to conventional wireless methods. Although the system necessitates a clear line of sight and may be influenced by ambient light, it holds significant promise for enhancing road safety through rapid data transmission. Data Transmission project utilizing Li-Fi provides a practical approach for vehicles to communicate with one another through visible light technology. This system collects critical vehicle data, including speed, steering position, and brake status, using components such as the IR sensor, potentiometer, and brake switch. The prototype illustrates that visible light communication can relay real-time driving information between vehicles, potentially aiding drivers in responding more swiftly and mitigating the risk of accidents.

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