

# Design of vehicle to vehicle communication: accident collision prevention using light fidelity and wireless fidelity technology

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## ABSTRACT

Vehicle-to-vehicle (V2V) communication is a key component of intelligent transportation systems (ITS), enabling seamless data exchange between vehicles to limit collision risks. This study presents a hybrid communication framework that integrates light fidelity (LiFi) and wireless fidelity (WiFi) technologies to enhance safety and reliability in accident prevention. LiFi using visible light communication, provides line-of-sight for short-range communication, while WiFi ensures long-range coverage in dynamic traffic environments. The proposed system allows vehicles to share speed, braking, and positional data, enabling timely warnings to drivers in high-risk scenarios. The system fuses data communication protocol design, simulation, prototype development, testing, and evaluation. The prototype model was designed and simulated to evaluate the performance of the system in terms of functionality, timing and reliability. Results indicate that the hybrid LiFi-WiFi system improves data transmission efficiency and reduces delay compared to standalone wireless systems. This approach demonstrates significant potential in developing safer transportation networks by combining complementary wireless technologies for V2V communication.

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## 1. INTRODUCTION

With the advent of autonomous vehicles, intelligent transportation systems (ITS), and vehicular networks within the past years, the automobile sector is undergoing significant changes [1]. Recent developments in hardware, software, and communication systems, as well as the creation of numerous applications and standards, have made these technologies possible [2]. However, the rise in road accidents worldwide has become a serious concern that requires significant changes to help improve road safety [3]-[5]. These changes are due to the rising number of vehicles on the road, and it is estimated that the number of vehicles will exceed 2 billion by 2030 [6], [7]. The World Health Organization (WHO) reported that roughly 1.5 million people died in road accidents in 2018 [8]. Road accidents remain a leading cause of injury and mortality worldwide, emphasizing the need for advanced safety technologies [9], [10]. In this context, vehicle-to-vehicle (V2V) communication systems has emerged as a promising solution, enabling real-time data transfer such as location, speed, acceleration and distance between vehicles, thereby, improving safety and awareness to all vehicle users [11]-[13]. These systems use communication protocols such as; dedicated short-range communications (DSRC), cellular vehicle-to-everything (C-V2X), wireless fidelity (WiFi), and most recently, light fidelity (LiFi) technology [14]-[17].

Due to exponential growth in the number of vehicles on roads, it is expected that V2V communication will continue to increase [1]. Even though, V2V communication may be beneficial, wireless communication is typically unreliable [18], [19]. Many factors, for example, channel fading, packet collisions, and communication obstacles can prevent messages from being correctly delivered in time. Despite its advantages, V2V communication faces challenges such as scalability, interoperability among different vehicle manufacturers, and environmental interference [11], [13]. These issues underscore the need for further research and development to ensure widespread adoption and effectiveness.

In recent years, research has been conducted to solve this problem with the integration of modern technologies such as sensors, wireless communication, artificial intelligence for real time awareness and internet of things (IoTs) to minimize human error. For instance, Anbalagan *et al.* [20] present the design and prototype development of V2V using LiFi technology. The authors proposed light emitting diode (LED) bulbs that can send data through light spectrum as wireless optical link in the LiFi technology. The proposed design was able to provide fast and reliable communication without the need for communication protocols. Gelbal *et al.* [21] presented pedestrian collision avoidance system for low speed autonomous shuttles based on vehicle-to-pedestrian (V2P) communication. In the work, smartphone was used to detect pedestrians and dedicated short range communication inside vehicle (DSRC) were used for vehicle-to-everything (V2X) when line-of-sight sensors could not be effective. In allowing vehicle to move round the pedestrian, the authors used an elastic band technique. For real world experiment, the paper used a hardware simulator in the form of an automated driving vehicle model with Sensors and Traffic to simulate the vehicle and pedestrian communication. Suganyadevi *et al.* [22] presented an intelligent system with IoTs technology. The study developed and implemented an IoTs device that constantly manage car speed, monitors car distance and warn car users and police of an accidents. Tao *et al.* [23], integrated machine learning (ML) and IoTs technology to reduce road accident and provides real time assistance to drivers. The paper, proposed a system that integrates detecting obstruction mechanism with computer vision, sensors for checking vehicles, driver attitude analysis and situational alertness deep learning predictive model for real time sensing, automatic method to avoid potential accident, quick response time and improving accident victims. The results showed that, the proposed system properly limited accident probability while improving driver alertness. Also, Shinde *et al.* [24] proposed the combination of IoTs, artificial intelligence (AI), and ML for smart road safety and prevention (SRSP) system along mountain. The work utilized sensors for real time information gathering such as conditions of road, traffic volume and climate structure along mountain paths. The gathered data is analyzed with AI algorithm to detect and predict accident. The authors also provide safety prevention methods by the introduction of V2V and V2I communication protocols. Therefore, the proposed SRSP system was able to reduce danger associated with mountain road user, hence reducing social effect of accidents. Roy *et al.* [25], demonstrated and developed a smart technology for vehicle monitoring and accident prevention on mountain path. The study proposed the integration of global system for mobile communications (GSM), global positioning system (GPS), and sensors on an advanced reduced instruction set computer machine (ARM) microcontroller for preventing traffic caused accidents by enhancing situation alertness and improving solution time. The authors used GSM to automatically send contacts and vehicle's position via a short message service (SMS), GPS for monitoring the vehicle continuously and different sensors for checking collision, monitor speeds and obstacles. Therefore, the proposed system was able to provide a robust and better approach for preventing road accident. Wang *et al.* [26] presented a framework that prevent different kinds of accident such as rear end and head on collisions, T-bone and pedestrian accident with the aid of Raspberry Pi 4 Model B and open source computer vision (OpenCV) Library. The authors made use of deep learning algorithm to monitor, calculate distance and detect real-period material to give early warn signal. The outcome of the study showed that; the method was effective for distracted drivers with a speed of 0.09 seconds per frame.

The reviewed of the aforementioned literatures shows that existing systems relying solely on WiFi face limitations in latency, interference, and reliability, especially in high-density traffic. LiFi, which uses visible light communication, offers a complementary alternative with higher bandwidth and lower interference but is constrained by line-of-sight requirements. Integrating both LiFi and WiFi can overcome individual weaknesses, creating a robust hybrid communication system. Therefore, this study aims to design and test such a system for accident prevention, focusing on real-time data transfer, reduced latency, and improved reliability. Our main contribution are as follows: (i) design and simulate of LiFi-WiFi V2V accident collision prevention communication system circuit using Proteus software, (ii) develop and implement the proposed system, and (iii) testing of the proposed prototype system.

This paper is structured as follows: section 2 depicts the method utilized in the design and simulation of LiFi-WiFi V2V accident prevention communication system in Proteus software. It also outlines the system approach, system architecture, components selection, circuit design, integration of communication protocol, simulation testing and proposed system prototype development and implementation. Section 3

presents the results and discussion that focus on functionality testing and enhancement, time and system reliability and performance of LiFi-WiFi. Finally, section 4 gives conclusion on the outcomes of the study.

## 2. METHOD

The proposed V2V system integrates LiFi and WiFi communication for accident prevent, enabling real-time data exchange between vehicles. The system approach adopted in this study is selection of components, LiFi-WiFi transmitter, and receiver system design, data communication design, simulation and testing on Proteus software, breadboard testing, prototype development, testing and performance evaluation as outlined in Figure 1.

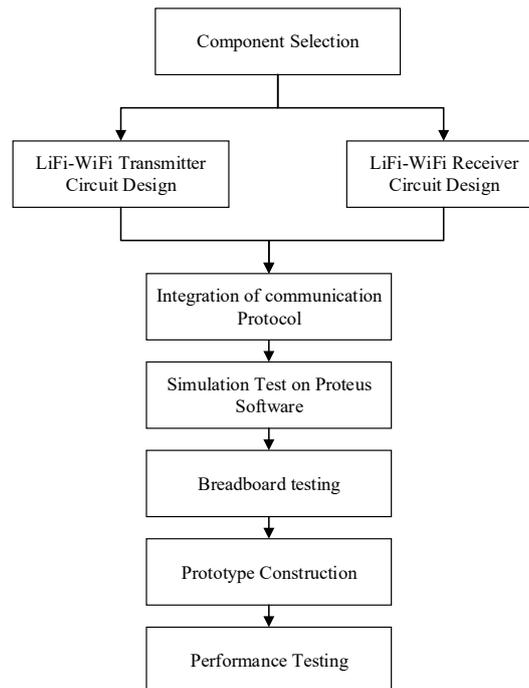


Figure 1. Block diagram of the system approach

### 2.1. System architecture

The system architecture in Figure 2 illustrates the real-life V2V communication system designed for collision prevention using LiFi and WiFi technologies. The diagram depicts two vehicles, each equipped with LiFi transmitters/receivers for short range communication and WiFi modules for extended connectivity. At the core of each vehicle's system is an ESP32 microcontroller, which processes data and handles WiFi communication [26]. The ESP32 interfaces with an HC-SR04 ultrasonic sensor to measure the distance of nearby vehicles. For LiFi, a high-intensity LED of 0.5 W, and 650 nm transmits data via light modulation [27], while a photodiode receives signals, enabling high-speed, short-range communication ideal for line-of-sight scenarios [26]. The LiFi modulation uses techniques such as on-off keying (OOK) and orthogonal frequency division multiplexing (OFDM) [27]. The ESP32's WiFi module, configured for the IEEE 802.11p standard, supports longer-range communication in non-line-of-sight conditions, such as highways [28]. IEEE 802.11p standard is employ in ITS for small latency and reliable communication between vehicles. The system switches between LiFi and WiFi based on line-of-sight availability to ensure reliable data transfer. A collision prevention algorithm processes distance data to calculate time-to-collision and triggers alerts via a liquid crystal display (LCD) display if a collision risk is detected. This architecture leverages LiFi's low latency and WiFi's robustness to enhance road safety.

### 2.2. Components selection

In order to build a prototype, and then modelled using advanced software tools, this study begins with a carefully chosen set of components. Premium components are incorporated into the system's chosen

architecture to guarantee dependability and functionality in practical applications. The hardware components chosen for this study are intended to guarantee V2V communication system's reliable operation and effectiveness. Two Arduino universal node (Arduino UNO) namely: Microcontroller ESP32 controls the central processing unit and coordinates the system's functions both at the transmitter and receiver end respectively [29]. A high intensity LED is another component used to transmit data through a light modulation at the vehicle headlight [30]. A photo resistor also known as light-dependent resistor (LDR) is used at the receiver to detect changes in light intensity and convert them into electrical signals [31]. Also, HC-SR04 Ultrasonic sensors known as transceivers is another component that is used to calculate the time interval between sending and receiving signal to determine the distance of object [32]. Other components are LCD screens [33] to notify drivers of collision risks, Jumper wires, breadboards, connectors, multi-meter, resistor, transistors, diodes, capacitors, 6 V transformer, and 12 V transformer for the power system unit. In addition to the hardware, the project includes a number of software elements necessary for its creation and functioning. The circuit design is tested and validated using Proteus simulations to make sure all electronic components work properly before physical assembly.

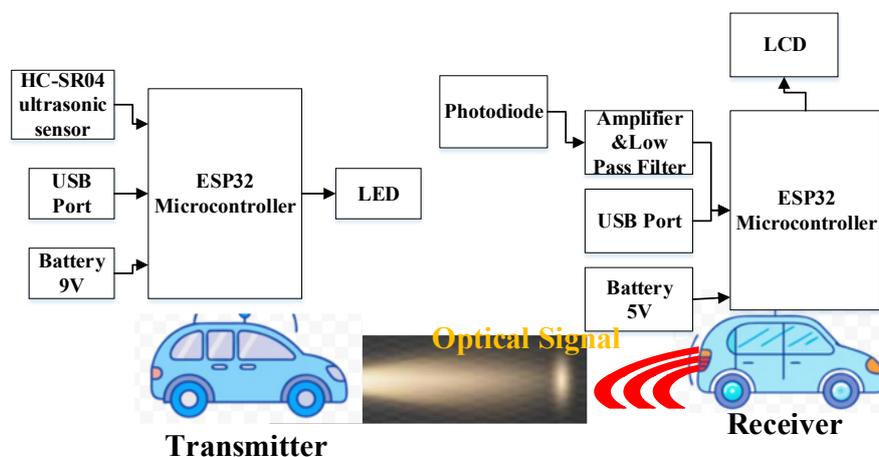


Figure 2. System architecture of LiFi-WiFi real-life V2V communication

### 2.3. Data communication design

The design phase of the LiFi-WiFi V2V communication system is a critical step in the system development. The design commenced with the programming of ESP32 microcontroller using Arduino integrated development environment (IDE) provide detailed physical environment of the devices for designing, simulating, and testing. The prototype design is divided in to three primary sections namely; ESP32 microcontroller programming, the transmitter and receiver design. The transmitter section collects data of vehicles, modulate the data into a high intensity LED for LiFi and display the status of the vehicle on an LCD screen, while the receiver detects the high intensity signal, amplify, recover and display the decoded data.

#### 2.3.1. ESP32 microcontroller programming

The programming of ESP32 microcontroller involves writing and uploading codes using the Arduino IDE. The process starts with initialization of transmitter and receiver nodes, then ultrasonic sensor distance measurement of distance. After computing of the distance, data packet is formed and transmitted through LiFi link in the transmitter node and photodiode at the receiver with the help of WiFi communication link. If LiFi signal is detected at the receiver, the packets are decoded and displayed on the receiver LCD, if not the receiver node waits for WiFi packet and passes the information. This cycle is repeated every 100 ms in order to ensure continuous updates of vehicle distance. The flowchart of the process is shown in Figure 3.

#### 2.3.2. Circuit design for transmitter

Transmitter circuit was design and simulated using Proteus software as the primary simulation environment and then integrated with Arduino IDE for the firmware code. Figure 4 shows the Proteus transmitter circuit schematic. Design of the circuit was carried out using six main components namely; microcontroller ESP32, WiFi module, HC-SR04 ultrasonic sensor, LED power transmitter module, driver circuit and LCD. The microcontroller ESP32 GPIO output is connected to the TRIG pin of ultrasonic while

ECHO pin of ultrasonic is connected to the GPIO input of ESP32. The driving circuit are the IRF540 MOSFET, power supply, 1 k $\Omega$  and 200 k $\Omega$  resistors. The serial output of the IRF540 metal–oxide–semiconductor field-effect transistor (MOSFET) was fed into the data input of the ESP32 WiFi module, which did the wireless transmission of the encoded information. The HC-SR04 ultrasonic sensor was powered from the same +5 V regulated supply as the Arduino to ensure stable operation and 9 V to power the LED circuit.

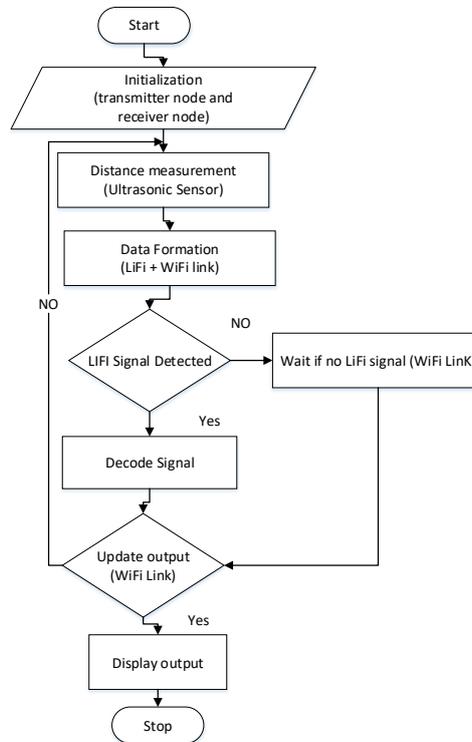


Figure 3. Flowchart of ESP32 microcontroller programming

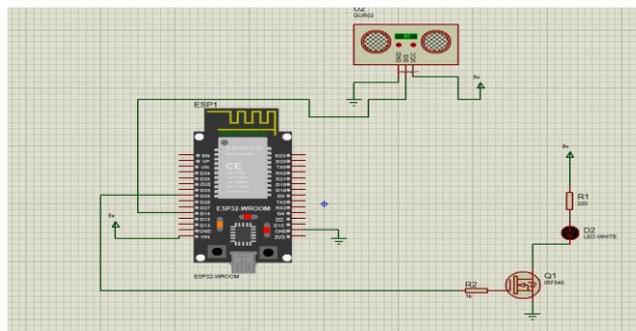


Figure 4. Transmitter circuit design on Proteus

### 2.3.3. Circuit design for the receiver

Receiver circuit was design on Proteus with four major components namely; microcontroller ESP32, KY 018 photodiode, comparator and LCD module as depicted in Figure 5. The KY 018 photodiode in reverse biased was connected to an operational amplifier with 10 k $\Omega$  resistor that set the gain of the amplifier. The amplified signal was then fed into a comparator, which was connected to ESP32 microcontroller to decode the data. ESP32 microcontroller was also connected to LCD interface to update and display the received data, which processes photodiode signals, hosts WiFi access point (AP), and drives LCD creating V2V network for hypertext transfer protocol (HTTP) POST from transmitter.

### 2.3.4. Integration of communication protocol

This section discusses the procedure employed in the integration of OOK communication into protocol into the designed LiFi-WiFi V2V system. The data to be transmitted was first formatted by the transmitter a well-delineated communications frame. The frame itself start with a preamble that allows the receiver acquire the signal, followed by synchronization of the byte, payload length, actual distance sensor value, error detection with checksum, and finally end marker. After building the frame, the transmitter converts each bit into light signals using OOK modulation, with a logic “1” represented by turning the LED on for a certain bit period, and a logic “0” by turning the LED off for the same period. To ensure accuracy and prevent timing errors, the LED is driven by a MOSFET switch with a precise timer in the ESP32, maintaining steady bit intervals despite simultaneous WiFi operations.

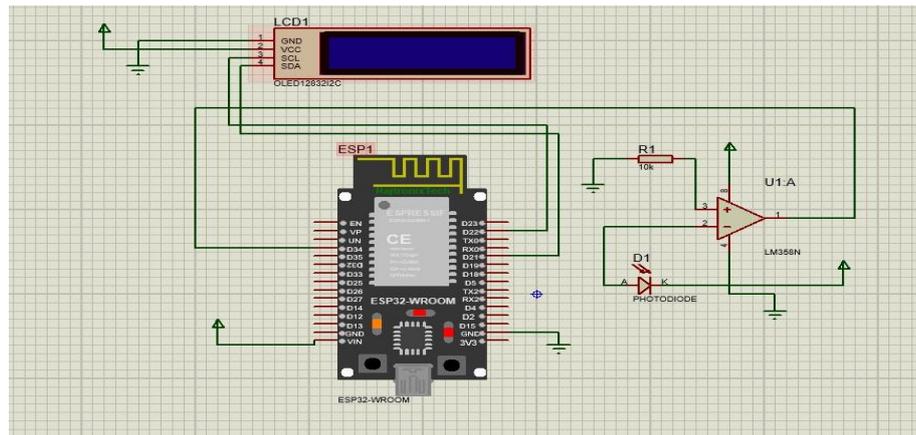


Figure 5. Receiver circuit on Proteus

## 2.4. Simulation and testing

Prior to hardware development, simulation and testing was carried out on Proteus to confirm the LiFi-WiFi V2V communication system operation. The main goals are to check if the transmitter can produce LED pulses that are proportionate to the distance, verify the receiver's ability to use KY-018 photodiode module in pulse detection and precise distances display on the LCD. The transmitter circuit design simulation begins with testing if ESP32 encodes the distance generated from the ultrasonic sensor and then checked if it's digital output connected to MOSFET through the 1 k $\Omega$  resistor is able to switch ON and OFF the LED. During the simulation, it was observed that the LED come up at high speed relating to the encoded data. This process indicate that the microcontroller performs both transmission and data gathering. Additionally, the photodiode at the receiver was exposed to the modulated LED signal from the transmitter and sent to an operational amplifier. An oscilloscope was used to check the effect of changing resistor value of the operational amplifier; the output produces same waveform related to ON and OFF modulated LED from the transmitter. The output from the amplifier was restructured to a digital pulse by a comparator then transferred and decoded by ESP32 microcontroller. The decoded distance was displayed on the LCD screen of the receiver, showing proper transmitted distance from the transmitter to the receiver.

## 2.5. Proposed system prototype development and implementation

The LiFi-WiFi V2V communication system prototype was developed after circuit design and simulation on Proteus software. Firstly, the transmitter hardware components namely: ESP32 microcontroller, HC-SR04 ultrasonic sensor and 0.5 W white LED powered by a 9 V battery and 5 V power supply were assembled on a breadboard for testing as depicted in Figure 6. The receiver hardware components namely KY-018 photodiode module, ESP32 microcontroller and 0.5 W white LED powered by a 9 V battery and 5 V power supply were assembled on a breadboard for testing as depicted in Figure 7. Transmitter and receiver ESP32 microcontroller codes were uploaded using Arduino IDE which was connected to a computer system using universal serial bus (USB) interface. After breadboard testing, debugging, troubleshooting, both circuits were mounted on a board with wheels. Figure 8(a) illustrate the proposed system prototype on a board with wheels' implementation and proposed system prototype on a board with wheels' communication testing has been illustrated in Figure 8(b).



Figure 6. Prototype of the transmitter circuit on breadboard showing the 0.5 W white LED and HC-SR04 ultrasonic sensor

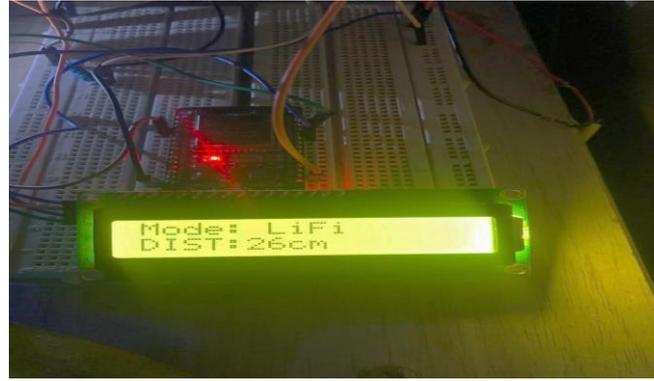
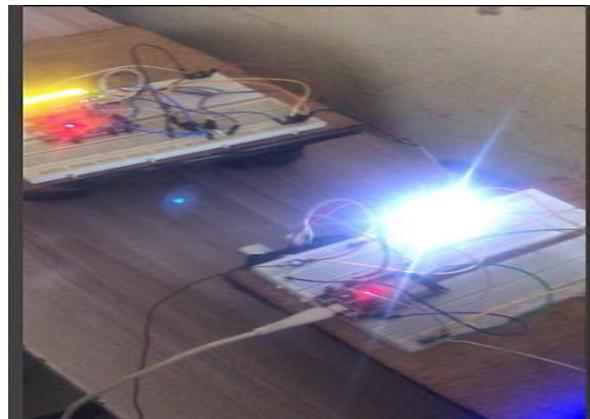


Figure 7. Prototype of the receiver circuit on breadboard showing the LCD and KY 018 photodiode



(a)



(b)

Figure 8. Proposed prototype system on a board with wheel showing the transmitter and receiver system: (a) implementation and (b) communication testing

### 3. RESULTS AND DISCUSSION

The LiFi-WiFi V2V communication that was now fully operational, programmed through Arduino IDE, the system dynamically detects vehicle collision based on real-time input from ultrasonic and photodiode sensor, ensuring responsiveness to the vehicle distance. The validation phase focuses on functionality testing and enhancement, time and system reliability and performance of hybrid LiFi-WiFi.

#### 3.1. Functionality testing and enhancement

The hardware system of the LiFi-WiFi V2V communication prototype was subjected to rigorous functionality testing to ensure it performs to the highest standard. This phase was critical for enhancing system performance and identifying any errors. Through an iterative process, issues detected were addressed and resolved, which was vital for the progressive optimisation of the system. For instance, tests were conducted indoors to minimize ambient light as illustrated in Figure 9, with transmitter and receiver aligned to measure various distances as the LED generates pulses which were being received by the photodiode using ESP32 as the microcontroller and configured it to be a wireless AP. WiFi tests sent HTTP GET requests through a smartphone on V2V receiver assessed KY-018 sensitivity. Outdoor tests showed KY-018's sensitivity to ambient light, requiring optics and indoor testing. Outputs were logged via LCD and Serial Monitor Tests were repeated several times per distance. LiFi and WiFi performance were compared in terms of speed, latency, reliability, range, and environmental robustness as shown in Table 1. A multi-meter was used to thoroughly inspect every connection. Wires were identified and tagged to make it easier to identify each component of the system's circuitry. Additionally, all cables are insulated and carefully enclosed in protective black tape for added safety and efficiency.



Figure 9. Functionality testing and enhancement

Table 1. Performance of LiFi against WiFi

Metrics	LiFi (KY-018)	WiFi (HTTP GET)
Speed	1100 ms per cycle (1000 ms window)	500 ms per request
Reliability	95% at 10-20 cm, 90% at 40 cm	98% with stable connection
Range	30 cm (LED power, KY-018)	10 m (ESP32 WiFi)
Environmental	Sensitive to ambient light	Unaffected by light, needs line-of-sight (LOS)

### 3.2. Time and system reliability

The system checks the sensor every 100 ms; therefore, it takes 23.3 ms to measure 4 meters, leaving about 76.7 ms for processing and sending data. If the distance is below 10 cm, the system sends an alert within one 100 ms cycle, ensuring drivers see the warning in time on the LCD. This ensures the system is fast and reliable for collision warnings as depicted in Figure 10.



Figure 10. LiFi-WiFi system performance time and distance testing

### 3.3. LiFi-WiFi system performance

The system performance of LiFi-WiFi shows that, LiFi prioritized short-range of 20-30 cm communication with collision risk alert when the distance is less than 10 cm. Also, WiFi ensured transmission after 3 s when there is misalignment in LiFi transmitting light. Therefore, LiFi provides low latency potential in close-range settings while WiFi response to long range communication when LiFi failed. Hence, this approach achieved nearly 100% communication ideal for V2V safety.

## 4. CONCLUSION

This study presented a hybrid LiFi-WiFi framework for V2V communication aimed at preventing accidents. The results demonstrate that integrating LiFi and WiFi reduces latency, enhances reliability, and supports real-time data exchange more effectively than WiFi alone. By leveraging the complementary strengths of both technologies, the proposed system provides a promising approach to improving road safety and reducing collision risks. Future work should focus on real-world deployment, optimization under varying weather and traffic conditions, integration with AI or fifth generation (5G) with V2X frameworks for comprehensive intelligent transportation solutions.

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## AUTHOR CONTRIBUTIONS STATEMENT

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C : Conceptualization

M : Methodology

So : Software

Va : Validation

Fo : Formal analysis

I : Investigation

R : Resources

D : Data Curation

O : Writing - Original Draft

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Vi : Visualization

Su : Supervision

P : Project administration

Fu : Funding acquisition

## CONFLICT OF INTEREST STATEMENT

The authors confirm that there is no competing interest that could have influenced the research, its interpretation, the writing of this manuscript, or the decision to submit it. They state that no financial, personal, or professional connections have affected any aspect of this work.

## DATA AVAILABILITY

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

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