Light Fidelity (Li-Fi) for Vehicular Communication: A Comprehensive Study

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***Abstract*—When taking on-the-road journey, people are at risk as accident may occur anytime. Committing small mistakes when driving in high traffic areas may lead to fatality. A combination of traffic signals and signboards has been put in place to assist the public in avoiding similar incidents. Nonetheless, accidents continue to occur as a result of people's ignorance. Therefore, it is essential to develop approaches that can inform drivers in a certain way, particularly in the vehicle environment. This study examined the acceptance of Light Fidelity, known as Li-Fi, as an alternative means of data communication between vehicles. The tool has been developed following an embedded system design approach that incorporates both hardware and software components. The information source was transmitted and received using photodiodes and integrated LEDs. The tool was tested in an experimental setup of two scenarios that warn potential vehicles of different contexts, such as sudden braking and road work ahead. Although the study proves the concept, further testing is required as actual implementation may vary and related factors need to be considered. The study contributes to the conceptual idea of how Li-Fi is incorporated into vehicles and could be a solution for inter-vehicle communication.**

***Index Terms*—Arduino Board; Data Transmission; Light Fidelity; Light Source; Vehicle Communication; Visible Light Communication; Wireless Communication.**

I. INTRODUCTION

The majority of countries globally have a worrisome track record of fatalities and disabilities caused by a massive number of accidents. Most of the traffic accidents are due to drivers' ignorance [1]. Researchers found that 57 per cent of accidents are caused solely by driver-related factors, including behaviour, decision making, speed of reaction, and alertness [2]. Studies reported that accidents may be prevented if drivers are warned a few seconds before selecting another route or taking precautions to avoid possible collisions. This may be rectified if both vehicles were equipped with means of communication and drivers could control their vehicles to avoid accidents based on their positioning [3] [4]. Li-Fi could be one of the possible means of communication for vehicles [5]. According to Harald Hass, the intensity and potential of a light-emitting diode are at the forefront of Li-Fi technology. Li-Fi is an emerging concept of the near future that uses visible information transmission light spectrum 10,000 times more than the WLAN technology. Since many users require Wi-Fi, the RF channel is used continuously, leading to signal congestion [6-8]--. In this case, Li-Fi could be the possible alternative solution to solve this issue.

Although high-intensity LED lights are already in use in vehicles, these can act as a transmitter or receiver. Li-Fi technologies on vehicles can reduce potential collisions by using inexpensive components [9][10]. Therefore, the feasibility of Li-Fi, as an alternate method of data transmission between vehicles has been examined in this study. This paper is organised as follows: A brief overview of vehicle communications and Li-Fi documentation are presented in Section II. Section III describes the sending and receiving mechanisms for Li-Fi-enabled vehicle communication. The details of a vehicle communication prototype that uses Li-Fi to reduce collisions are in Section IV. Section V is the conclusion of this paper.

II. RELATED WORKS

In general, with the support of a processing unit, data transmission is used to modulate the LEDs, for example turning the current on and off of the LEDs at a very high rate [11] [12]. This action makes it impossible for the human eye to notice the process of data transmission. Individuals could only view the optical flow between the light source and the receiver [13]. When the LED is turned on, the light source sends a digital "1", and when it is turned off, it sends a digital "0". The photodiode module generates energy in the beam and converts the energy into binary data streams, which are then sent to the receiving side [14] [15]. Figure 1 shows the operating mode of Li-Fi technology.

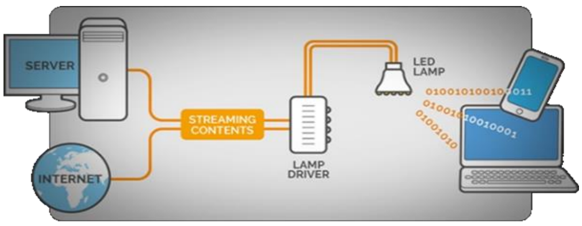

Figure 1: Working principle of Li-Fi technology [16]

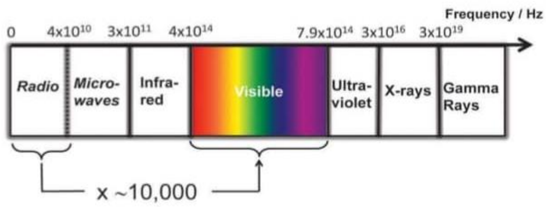

Figure 2: Electromagnetic spectrum [17]

With Li-Fi, there are numerous ways of facilitating communication and information exchange between vehicles and units along the road. This information can include the warning of an imminent hazard or traffic-related information for the primary purpose of preventing accidents on the road [18][19]. An example is the vehicle-to-vehicle communication frame (V2V), which is a technology that allows vehicles to exchange information with each other [20]. This may be accomplished through Li-Fi, which utilises LEDs as the light source and a photodiode as the receiver.

Kulkarni et al. (2017) highlighted that a light source, equipped in the vehicle enables data transmission through this source. The data can be any information related to a vehicle, for instance, speed or direction, which would be necessary for other vehicles to take precautions [21]. Variation in the intensity of light is made based on the data to be transmitted. The vehicles present in the vicinity (area of the situation) is also equipped with light detectors. These detectors capture the light variations to obtain the data. This is how communication can be accomplished with a light-medium. Li-Fi, which can be the future of data communication, appears to be a fast and cheap optical version of Wi-Fi. To function as an optical carrier for data transmission and illumination, Li-Fi uses visible light of the electromagnetic spectrum between 400 THz and 800 THz. Moreover, Li-Fi uses fast pulses of light to transmit information in the wireless medium. Table 1 summarises several studies on V2V communication, leveraging Li-Fi technology.

Table 1
Previous Studies on Li-Fi Technology for V2V Communication

Authors	Contribution
[22]	This paper familiarises vehicle to vehicle (V2V) communication to reduce road accidents. The authors utilise the Li-Fi technology to transmit data between two developed prototypes. The authors also aim to cut costs on the prototype development, including Arduino board, vibration sensor, ultrasonic sensor, buzzer, keypad, LED, DC motor, and power supply. The developed prototype has demonstrated that data can be transmitted through Li-Fi technology.
[23]	This paper suggests integrating vehicle to vehicle (V2V) communication with Li-Fi technology to avoid road accidents. The authors aim to provide a data transmission mechanism for vehicles through Li-Fi that could help to reduce accidents and promote safe driving. The prototype includes several sensors such as an Arduino board, vibration sensor, ultrasonic sensor, MQ3 sensor, webcam, LED, and solar panel for the prototype development. The developed prototype has been shown to send data through Li-Fi technology.
[24]	This paper presents a cost-effective vehicle to vehicle (V2V) communication system using Li-Fi technology. The authors aim to advance Li-Fi technology comprising LEDs in traffic lights and vehicles. The prototype developed includes an Arduino board, ultrasonic sensor, motor driver, speed sensor, and power supply. The prototype model demonstrated that the distance and speed of the preceding vehicle were successfully transmitted to the rear vehicle through Li-Fi.
[25]	This paper provides a solution for transmitting data from the vehicle to the toll via Li-Fi technology. The authors aim to reduce the queues at toll barriers and help people reach their destination on time. The prototype developed includes a microcontroller PIC16F877A, LED, buzzer, GSM, switch, and power source. Based on the working principle, the results show that data transmitted from vehicle could be received at a toll booth.
[26]	This paper presents an innovative method for avoiding collisions between two vehicles using Li-Fi technology. The authors aim to build a simple V2V communication module across Li-Fi that can be applied in future vehicles. The developed prototype contains one transmitter section and one receiver section, including the Arduino board, IR speed sensor, switch, LED, LCD screen, and power supply. As a result of the tests, the prototype was able to process the speed and braking state of the vehicles through the rear light.
[27]	This paper introduces an automatic traffic signal control system using Li-FI technology for emergency vehicles. The authors intend to modify a vehicle's headlamp and taillight so that they can function as Li-Fi emitters and receivers, respectively. The prototype developed includes a PIC16F877A microcontroller, a photodiode, an amplifier, a potentiometer, and resistors. As a result of the development, the alert message propagates from an emergency vehicle to a traffic light controller via a non-emergency vehicle using Li-Fi technology.
[28]	This paper proposes to reduce road accidents with the assistance of Li-Fi technology. The authors aim to introduce a system based on an LED transmitter and camera receiver and a new, improved image sensor. The prototype comprises a Raspberry Pi, LED, Camera, and CMOS image sensor to build the prototype. The prototype model can effectively respond to light intensity changes.
[29]	This paper introduces a wireless communication system for toll collection with Li-Fi technology. The authors use Li-Fi to communicate wirelessly to transmit vehicle user information to the toll booth. The development of the prototype consists of microcontrollers, LEDs, photodiodes, and amplifiers. The practical result made it possible to pass the vehicle number to the toll station with the designed prototype.
[30]	This paper suggests a vehicle-to-vehicle communication mechanism using Li-Fi technology. The authors aim to position the Li-Fi transmitter and the Li-Fi receiver in the front and rear lamps on the vehicles. The prototype developed comprises an Arduino board, LEDs as well as several other modules and sensors. The LED is present on the transmitter side, while the photodiode and the LCD screen will be on the receiving side. Results from the prototype indicate that the data was transferred using Li-Fi technology.
[31]	This paper introduces a new framework for V2I communication that makes use of Li-Fi technology. Through visible light communication, the authors convey audio safety information to the occupants of the vehicle. The prototype developed includes an Arduino board, a PIC 16F877 microcontroller, an infrared sensor, an APR module, a light-emitting diode, and a power supply. The designed prototype was able to provide audio safety information for the signals such as GO (green), STOP (red), and WAIT (yellow), respectively.

Following Table 1, the information about conceptual and theoretical frameworks and techniques was adequate for several reasons. First and foremost, the authors have assessed the degree to which the actual results and methods are consistent with the adopted framework and principle of action adopted. Second, understanding of the frameworks and methodologies enables the identification of the research strengths and weaknesses and its potential. Therefore, with such information deliberated, this study differs in terms of applicability. The prototype is designed by replacing the front and rear with LED and photodiode respectively, enabling transmitting and receiving data.

III. Methodology

A. Requirements

In this project, the software used is Arduino IDE and Tinkercad. The components used for integration are Arduino Uno, photodiode, LED, I2C LCD, and 4x4 keypad. Figure 3 depicts the integration block diagram, while Figure 4 depicts a flowchart that summarises the tool process that has been designed.

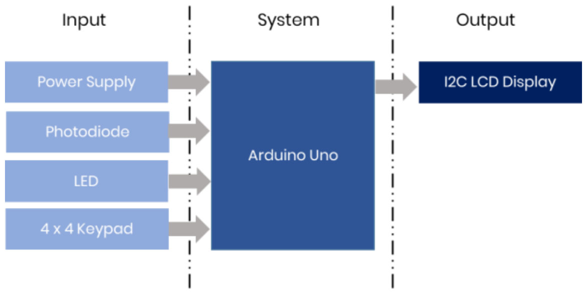

Figure 3: Block diagram

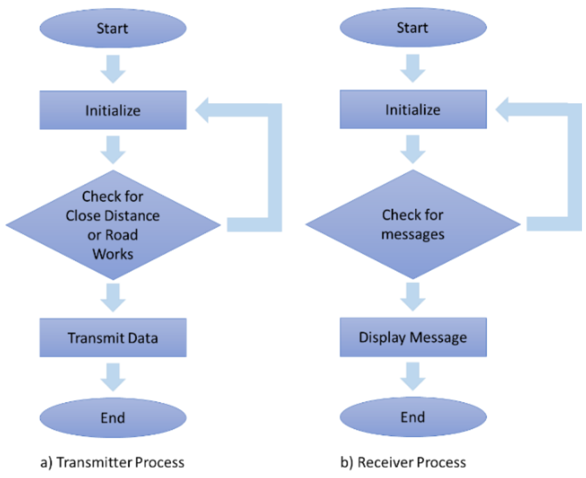

Figure 4: Flowchart

IV. Result and Discussion

The project prototype is constructed in the same manner as the block diagram and flowchart depicted previously. The transmitter in this prototype needs an entry through a keyboard. The LED serves as a light source for transmitting the data to the keyboard, transforming it into binary bits. On the receiver side, the photodiode picks up the light source of the inbound message. After that, the message is decoded and shown on the Lcd. As a result, the general picture shows the approaching vehicle-to-vehicle communication through Li-Fi. Two scenarios have been examined in the following subsection to determine that these occurrences occur. The initial circuit development and prototype development are shown in Figures 5 and 6, respectively.

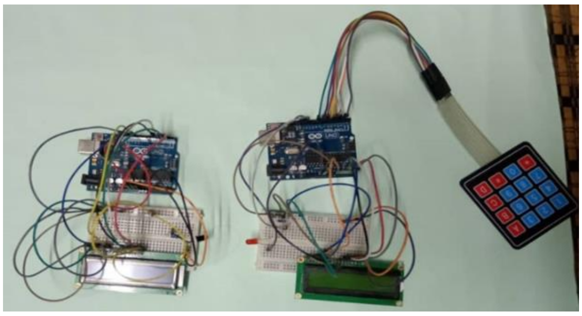

Figure 5: Initial circuit development

Figure 6: Final prototype development

Figure 7 shows the first scenario of vehicle communication using the Li-Fi, when vehicle 1 attempts to brake suddenly. Thus, a message will be sent by the transmitter positioned in the rear lamps of vehicle 1. The message will be received through the photodiode in front of vehicle 2. A warning ("SLOWDOWN! SUDDEN BRAKE") will be activated in vehicle 2 in the form of a visual, as shown in Figure 8.

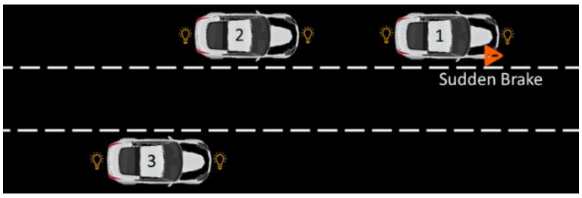

Figure 7: Sudden brake

Figure 8: Sudden brake visual display

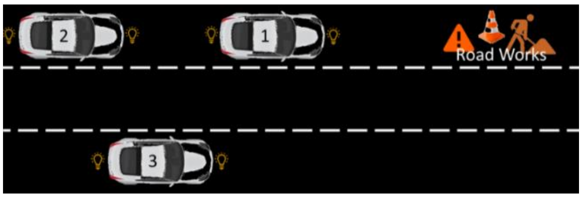

Figure 9: Road works ahead

Figure 9 shows the second scenario of vehicle communication using the Li-Fi, when vehicle 1 discovers a roadwork at the front. A message will be sent from the transmitter, which is located in the rear lights of vehicle 1. The message will be received via the photodiode on the front of vehicle 2. A warning ("SLOWDOWN! ROADWORKS AHEAD") will be activated in vehicle 2 in the form of a visual, as shown in Figure 10.

System testing is a test that is done when the system or project is finished. Therefore, this testing is carried out to ensure that the prototype can perform in a given scenario. Table 2 shows the testing result of the prototype model.

Figure 10: Road work visual display

Table 2
Prototype Development Result

Scenario	Input	Expected Output	Results
1	Key in "1"	Receiver message "SLOWDOWN! SUDDEN BRAKE"	Success
2	Key in "2"	Receiver message "SLOWDOWN! ROAD WORKS"	Success

V. CONCLUSION

Vehicle to vehicle (V2V) communication is a significant player in the automotive market as it is crucial for daily transportation. This includes various intriguing aspects to be identified and developed, starting with the standard communication model and performance evaluation. Over the last decade, Li-Fi technology has evolved significantly for vehicle communication. Thus, a cost-effective communication approach using Li-Fi technology has been presented in this paper. The project has a substantial V2V communication element using Li-Fi that can be used in future inter-vehicle communication deployments. This becomes feasible when LEDs are used as transmitters, and photodiodes are used as receivers with several components. In the future, the tool aims to incorporate LIDAR sensors, which will add precision and accuracy to the processing of the sensing distance. Besides, extensive testing criteria are required to ensure reliability.

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