Chapter

Vehicle Collision Avoidance System Using Li-Fi

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Abstract

In recent times, large numbers of road accidents occurring all over the world are mainly due to collisions between vehicles. More than 1.2 million peoples were died in road accidents in 2019, according to the World Health Organization (WHO). Human safety features are much needed in the manufacturing of vehicles. The proposed method mainly focuses on reducing the number of accidents in our daily lives by avoiding collision between the vehicles. There are several factors corresponding to such difficult conditions that may results in death or disabilities. The causes are sudden loss of concentration of the driver, braking failure and stability issues. These criteria can be reduced only if there is a possibility for communication between the vehicles and the drivers in order to avoid accidents. There are various vehicular communication system models like Dedicated Short Range Communication and Vehicular Ad-Hoc network operating less than 5.9 GHz. These radio frequency based communication also has some limitations such as interference, congested spectrum and security. These drawbacks can be reduced by implementing the Visible Light Communication (VLC) in vehicles. It provides larger bandwidth, security, interference immunity, and high data rate. High speed data transmission and reception can be achieved using visible light based data communication system. This technology is known as Light Fidelity (Li-Fi). This chapter presents the innovative method to evade collision between two vehicles (rear and front). This communication system is cost effective with high speed data rate capabilities.

Keywords: Li-Fitechnology, Arduino Microcontroller, Visible light communication, Vehicle to vehicle communication, Proteus software

1. Introduction

Li-Fi is transmission of data through illumination by taking the fiber out of fiberoptics, sending data through an LED light bulb that varies in intensity faster than thehuman eye can follow. As this technology offers a huge bandwidth, it is unlicensed socan be used for many applications such as streaming video and music, access to theinternet, etc. The data can be transmitted through LED light which is presently observed in Electronics Devices like Hamradio, Television remotes, etc. As the number of devices connected to a particular wireless network increases the speed of the network decreases. So, in order to overcome this problem Data transmission through LED is done. Generally, data is transmitted using EM waves or else through Data Illumination.

In future data can be transmitted through the light in a room for laptops, smartphones, and tablets. In the proposed system, LED light emits visible light with location data to the visible light receiver and the receiver receives the data.

The embedded system calculates the optimal path to a destination and speaks to the visually impaired through a headphone or speaker.

2. Li fi technology

The idea of Li-Fi was first given by Harald Haas from University of Edinburgh, UK, in his TED Global talks on Visible Light Communications. According to him Visible Light Communication is very simple, if the LED is on, the transmitted data is digit 1, if it is off, the transmitted data is digit 0. The LEDs can be switched on and off very quickly, which gives better opportunity for transmitting data. So the requirement in LEDs and a controller that code data into those LEDs (**Figure 1**) [1].

Depending on the data to be encoded or transmitted, the LED flicker rate is varied. Enhancements to be made in this method are like using combinations of red, green and blue LEDs or using parallel data transmission LED array to change the light's frequency with each frequency encoding a different data channel. By the above advancement it is possible to achieve a theoretical value of speed up to 10 Gbps, i.e. downloading a 1Gb file in just 30 seconds irrespective of the file format. It can be used in places such as hospitals, traffic signals and in modern medical instruments. Li-Fi can also be used underwater where 6 Wi-Fi [2].

In transportation applications, Vehicle-to-vehicle (V2V) communications are deliberated to play an important role in in the next decade to improve road safety and road capacity [1]. In recent years, V2V has been implemented using the mainstream technology called as Dedicated Short Range Communications (DSRC), a 5.9 GHz radio frequency (RF) technology. However, the conventional RF communications based V2V communications often agonized from low packet reception rate and long delay in high vehicle density scenarios, due to interference made by the huge number of nodes in the same network [3]. On the other hand, it is very difficult to visually identify the location of the transmitter sending a message is frequently difficult, as RF based transmissions are usually Omni directional and latest technologies have inadequate accuracy to support this. For vehicle localization, the most common technology used is GPS. However, the positioning error occurred in GPS devices is often more than 10 m creates it hard to find the transmitting vehicles when they are in close locations [4].

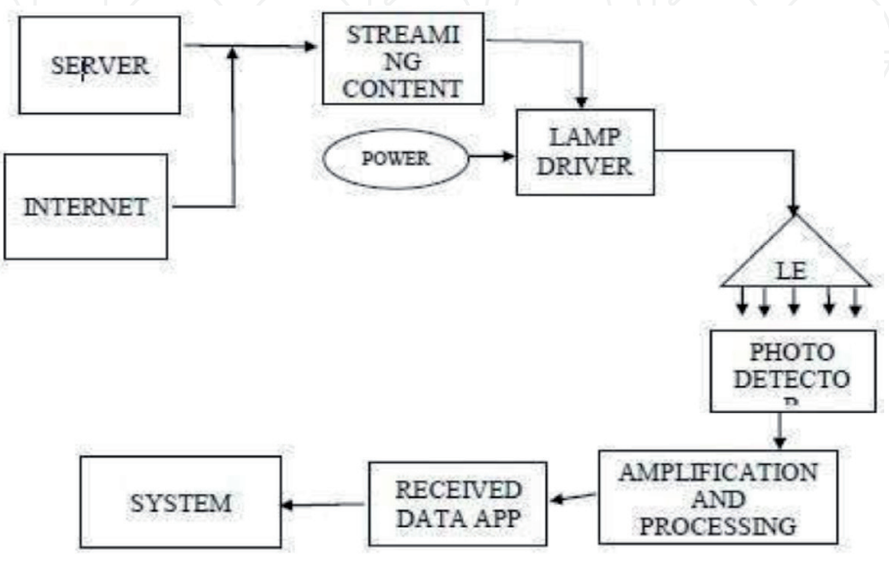

Figure 1.
Block diagram of Li-Fi.

3. Li fi –transmitter and receiver

The operational procedure of Li-Fi is very simple, it transmits binary 1, if the LED is in on condition, if the LED is off, it transmits a binary 0. The switching of LEDs between on and off positions can be implemented very quickly, which gives wonderful chances for data transmission. A controller which is used to program the LEDs and some LEDs are mainly needed. To implement the Li-Fi technology, it is required to just vary the LED's flicker rate based on the data we need to encode. All the data on the internet will be streamed on one end to a lamp driver when the LED is switched on the controller which converts the digital data in form of light. At the receiver end, the received signal is converted back to original signal with the help of a light sensitive device (photo detector). This method of wireless transmission of data using rapid pulses of light is technically denoted as Visible Light Communication (**Figures 2** and **3**) [5].

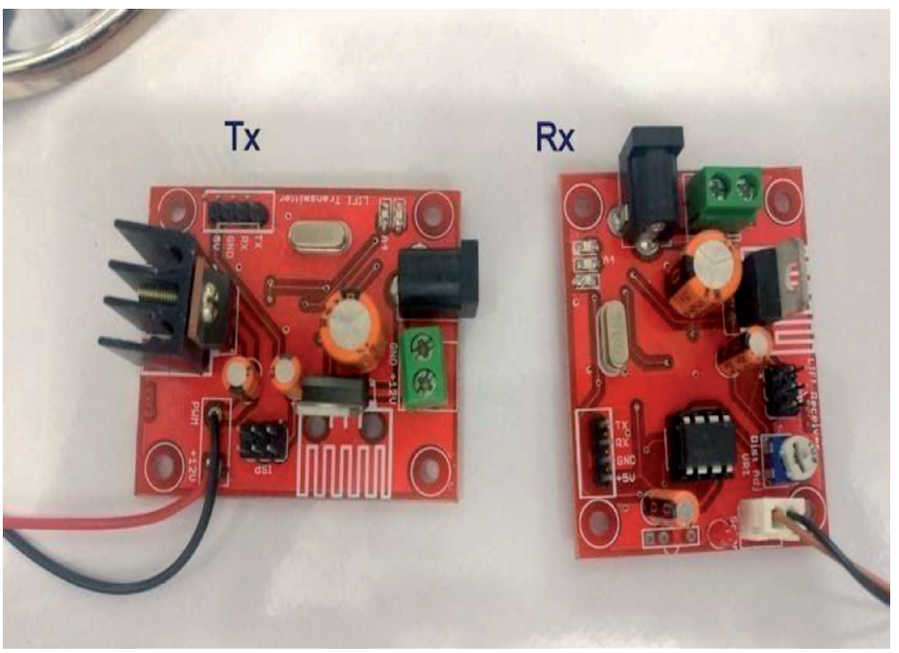

Figure 2.
Top view of Li-Fi transmitter and receiver.

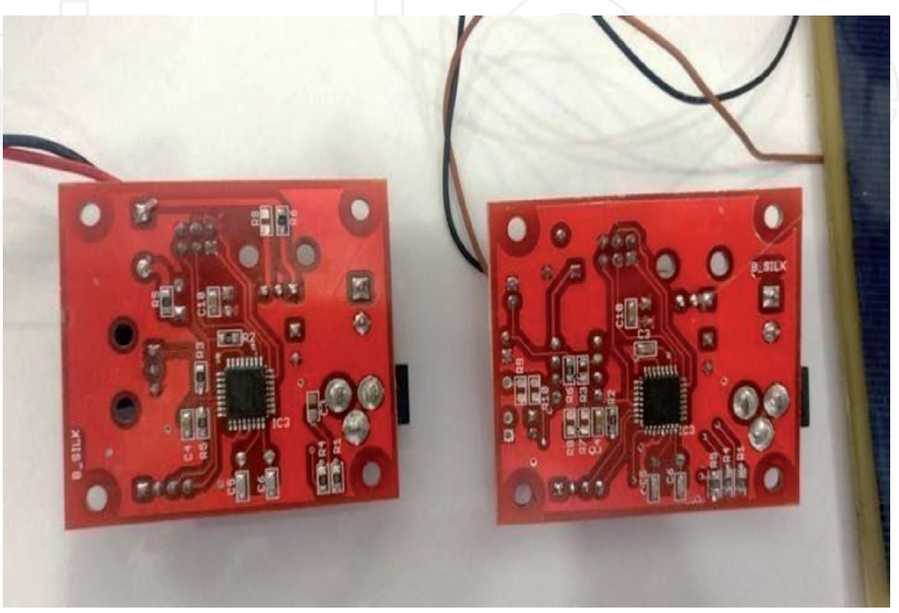

Figure 3.
Bottom view of Li-Fi transmitter and receiver.

Light based Wi-Fi is called as Li-Fi. It uses light signal instead of radio waves for data transmission. Li-Fi uses transceiver-fitted LED lamps instead of Wi-Fi modems. Transceiver-fitted LED lamps can be used to light a room as well as transmit and receive information [5]. Power supply is used to provide power to the transmitter and receiver section. Data stored in the controller is transmitted through a Li-Fi LCD display that is used to check whether the data is transmitted and received. Microcontroller is used to control both transmitter and receiver sections. A controller used in both transmitter side and receiver side. Using Proteus software tool program written to microcontroller. Li-Fi is a term used to describe the visible light communication technology applied to high speed wireless communication (**Figures 4** and **5**).

Figure 4.
Working module of Li-Fi Tx and Rx via LED.

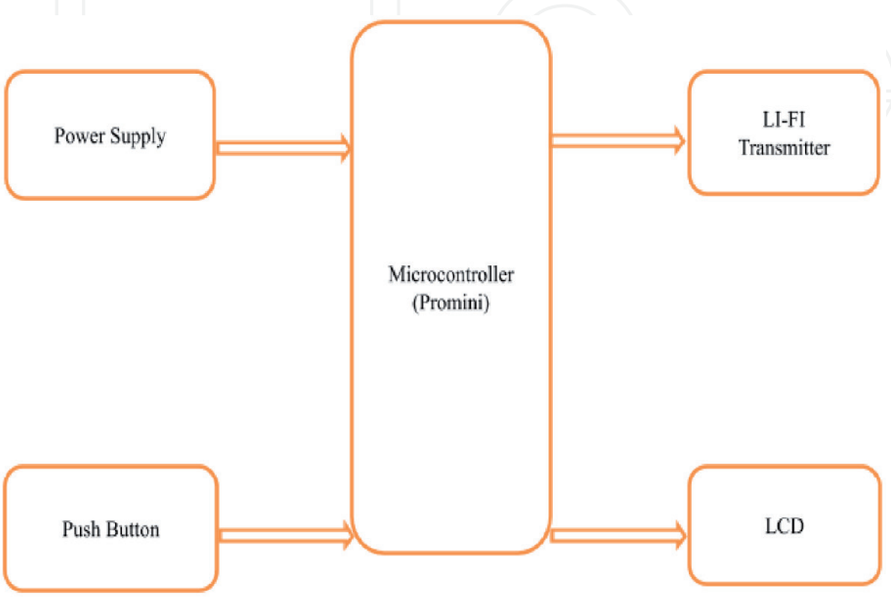

Figure 5.
Li-Fi transmitter.

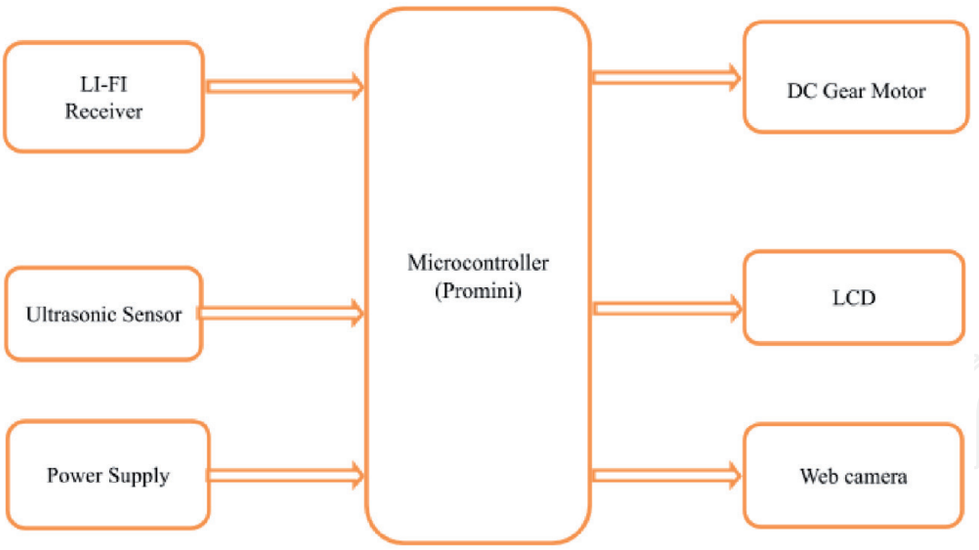

Figure 6.
Li-Fi receiver.

Receiver consists of Photo diode which receives the signal transmitted by transmitter. Transmit the received signal to the controller. FN-M16P module is a serial MP3 module which includes a perfect integrated WMV and MP3 decoder chip. Further, it includes micro SD card drivers and supports FAT32 and FAT16 file systems. It is able to play back specified sound files. Speaker or earphone is used to give audio signal to impaired person(**Figure 6**) [6].

4. Arduino pro mini – Microcontroller

Arduino Pro Mini is used in the system for application module. It does not have inherent programmer since it is an application module. Various connectors and USB port are useless and they are removed from the module because the module is connected with the application programmer. There are two versions of Arduino Pro Mini. They are classified based on the working voltage of controller. The voltage levels are +3.3 V and + 5 V. Based on the application, the designer can choose the appropriate board.

In recent years, Arduino boards are commonly used because its operation and architecture is easy to understand. Also the original module schematics and required software modules related to Arduino is available as an open source platform. Based on the requirement designer can customize the system using this open source platform. Different types of Arduino boards are available on the market for designing a system [7]. They are accessible with various packages and features. Appropriate boards can be chosen depending on the requirement.

The few reasons why pro mini is selected over other are listed below:

Case1: Permanent installation of the system is used. Only the board is required to be programmed once in permanent applications. In such systems, the features like a USB programmer, I/O connectors and other supporting hardware is not required. The pro mini is explicitly designed for those systems which uses permanent installation. It has some basic hardware modules that is just enough for those applications.

Case2: This pro mini board is one of the smallest boards of Arduino. Because of its small size it can be used in mobile applications.

Case3: The cost of the board is significantly lesser due to its basic hardware structure.

Case4: It can able to store most application programs in its 32Kbytes memory.

The operation of Pro Mini is similar to any other development board. All you have to do is to write the controller program and select the appropriate interfacing modules to get system running. The detailed step for the programming of pro mini is given below.

1. To program the pro mini, you cannot connect directly to PC because it does not have an inbuilt programmer. Select either SPI or UART programmer. UART programmer can be preferred.

2. Download ARDUINO IDE software and install the same in your computer.

3. List the roles to be accomplished by pro mini.

4. Write the functions as 'C' language programs in IDE.

5. Establish a communication between IDE and pro mini by connecting the programmer.

6. Burn the program and download to pro mini through IDE.

Remove the programmer module. Provide the power and connect the necessary peripherals. The desired output is obtained after resetting the control and executing the program.

5. Hardware components

5.1 Gear motor

A DC motor can be defined as the rotary electric motor that converts direct current electrical energy into mechanical energy. The forces produced by magnetic fields mainly define its types. In order to change the direction of current, all types of DC motors have some internal mechanism, either electromechanical or electronic periodically.

In robotics, DC motors are most commonly used as it is available in a large variety of shapes and size with permanent magnet iron core, permanent magnet

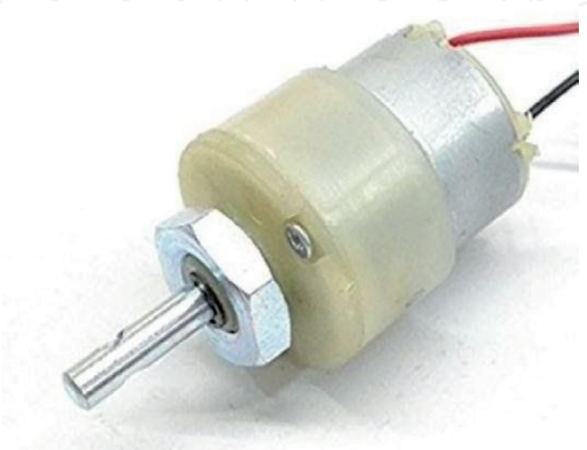

Figure 7.
Gear motor.

ironless rotor, permanent magnet brushless, wound field series connected, shunt connected, compound connected, variable reluctance stepper, permanent magnet stepper, and hybrid stepper motors (**Figure** 7).

The characterization of DC motor is based on brush type and brushless. It refers to the design of commutation used in motor, which converts direct current from the batteries into alternating current which are required to generate the action of motor. The brush type DC motors performs mechanically with brushes with the commutator segments at the ends of the rotating rotor physically slides against the stationary brushes that are connected to the terminals of the motor. In brushless motors, DC is converted to AC electronically with the position of sensors and microcontroller in the rotor; hence it does not require brushes [8]. A conventional DC motor is formed by an arrangement of coils and magnets that creates motion from electrical power [9].

5.2 Push button switches

Push button switches are small and sealed and the circuit gets completed by pressing it. If it is ON, a small metal spring inside makes contact with the two wires, passing the electricity to flow through the circuit. If it is OFF, means the spring retracts and the circuit is open, thus not allowing the current to flow through it. These buttons are made of hard material such as plastic or metal.

A simple Push Button switch is a type in which the switch consists of electric mechanism or air switch mechanism to turn ON or OFF. Based on the model of switch, the operations can be given as momentary or latching action function. The button is usually made of a strong durable material such as metal or plastic [9]. A push to make switch allows electricity to flow between its two contacts when held in. When the button is released, the circuit is broken. This type of switch is also known as a Normally Open (NO) Switch.

5.3 Ultrasonic sensors

An ultrasonic sensor is an instrument that uses ultrasonic sound waves to measure the distance of an object. It uses a transducer to send and receive the ultrasonic pulses that relay back information about an object's proximity. The distinct echo patterns are produced by the high-frequency sound waves reflected from boundaries.

The HC-SR04 Ultrasonic (US) sensor is a 4 pin module (Vcc, Trigger, Echo and Ground) respectively. This system has two features in the front which forms the Ultrasonic transmitter and Receiver. The sensor works based on the simple formula i.e. Distance = Speed × Time. The Ultrasonic transmitter transmits an ultrasonic wave, this wave travels in air and when it gets objected by any material it gets reflected back toward the sensor this reflected wave is observed by the Ultrasonic receiver module. HC-SR04 distance sensor is commonly used with both microcontroller and microprocessor platforms like Arduino, ARM, PIC, Raspberry Pie etc. The following guide is universally since it has to be followed irrespective of the type of computational device used. Power the Sensor using a regulated +5 V through the Vcc ad Ground pins of the sensor. The current consumed by the sensor is less than 15 mA and hence can be directly.

It is powered by 5 V pins and the Trigger and the Echo pins are both I/O pins. It can be connected to I/O pins of the microcontroller and to measure the trigger pin has to be made high for 10uS before turning off. This function instantly triggers an ultrasonic wave at a frequency of 40 Hz from the transmitter. At the same time, the receiver had to wait for the signal to return [10]. The wave is returned after it

is reflected by any object; here the echo pin will be high for a particular amount of time, which is equal to the time taken for the signal to return back to the sensor. Hence, the amount of time during the high position of Echo is measured by the MCU/MPU. It gives the measured value for the time taken by the wave to return back. Using this values the distance is measured as explained above.

The ultrasonic Sensors are efficiently used in the non-contact detection of Level, Position, and Distance. These non-contact sensors are also called as proximity sensors. It is also independent to light, smoke, dust and color. The material absorbs the ultrasonic sound wave and does not reflect sound except wool.

5.3.1 Ultrasonic distance measuring

Distance measurement is estimated with respect to the measurement of time-of-flight. The accurate distance is calculated with the time taken from sending the ultrasonic sound and receiving the reflected sound signal. In application such as, height monitoring, bin level measurement and proximity zone detection various ultrasonic sensor like MB7360 HRXL-Max Sonar-WR are used to obtain precise measurement.

- Ex. Distance measurement in a garage parking application uses the sensing method when a vehicle is pulled completely into a garage.

- An ultrasonic sensor, MB7360 occupies as bin level sensor to identify the materials in bins.

5.3.2 Ultrasonic obstacle detection

- The design of Unmanned Aerial vehicles and robots use ultrasonic sensor and proximity sensors for obstacle detection.

- Ultrasonic sensors are more precise for close range detection up to ten meters and provides multiple range measurement per second.

5.4 Webcam

A webcam is used to capture live video or image through computer interfaced network. Webcams are more compatible with user's monitor and hardware interface. Webcams finds popular application in video chat session with live audio and video streaming. The device such as Apple's iSight camera, iMacs webcams provides clear picture for video chat sessions. The software supported with Webcam records the video and also it can be live streamed through Internet. The video streaming over the Internet needs a wide bandwidth and it is compressed for live streaming. The maximum resolution of a webcam is lower compared with handheld video cameras and it suits for video chat session. Webcam are used to capture the view of camera over its web page. The evolution of webcam technology uses advanced webcams with the improvement from 1080 pixel to 2160 pixel for the better image quality and widely used in several industries including marketing, security, traffic management and healthcare systems.

5.4.1 Working of the webcam

Webcam works as a conventional digital camera to interact with the web pages and other internet pages. The camera technology is framed to capture the images

through a tiny grid of light-detectors, known as charge-coupled devices (CCD). The output of CCD is the digital format so that computers can access this data. Webcams do not provide the option of image storage and it transmits the data immediately to the host device through the USB cable. The advancement in technology leads to integration of microphone with camera. Webcam function in two ways as capture the image or video and to transfer it to the predestined device [9]. Similar as digital camera, the webcam has come with the appropriate software to interact with the host device. The Software provides the flexibility to edit the images and to record the videos for particular duration. This software collects the digital data of image from the camera at certain intervals of time. The frame rate decides the number of pictures or video streaming displayed on the computer or other display systems. The image frame is converted into a JPEG file and finally sends it to the web server using the file transfer protocol (FTP). To utilize the webcam in transferring the data, certain configuration steps to be followed in uploading the images and videos [10].

Modern day desktop and laptops are provided with built in webcam of small in size. Due to this compactible size, the provision for multi-piece lens is not possible and this results in the reduced image quality. To overcome the drawback in image quality, external webcams are chosen. Adjusting the camera position is difficult as it is fixed with the device [11]. The integrated webcam and external webcams are varied with respect to cost, focal length, stereo quality sound, light sensitivity and certification.

5.4.2 Image sensor

Image sensors are classified based on its structure type as CMOS or CCD. In CMOS image sensor uses a solid-state image sensor chip which is made up of light sensitive elements, micro lenses, and micro electrical components. In CCD the pixel exposure occurs at the same time in the technology of global shutters. The webcams are capable of providing VGA-resolution with the frame rate of 30 frames per second. Modern day devices are developed to produce video in multi-megapixel resolutions such as the PlayStation Eye, which can produce 320 × 240 video at 120 frames per second. Nintendo Wii Remote uses an image sensor with a resolution of 1024 × 768 pixels [10].

5.4.3 Webcam Interface

Typical interfaces such as Ethernet and IEEE 802.11 (denominated as IP camera) are used for webcam connectivity for desktop or Wi-Fi devices. To communicate with high quality video through single channel or with two or more channels, the interface such as composite video or S-Video interface is used. The video streaming functionality to USB enabled device is achieved through USB video class (UVC) specification to interface effectually with host machines.

5.4.4 Webcam features

5.4.4.1 Frame rate

The webcam with good image quality is obtained with the frame rate of 30 frames per second (fps). The frame rate less than 30fps leads to blurred in image quality. It is better to choose webcam which that supports 60 fps recording to obtain decent image quality. The increase in fbs rate occupies the modern day monitors to capture live image and the fps rate decides the speed at which the image moves on the screen. Webcam image is transferred with a range of 15 frames per second to

an ideal rate of 30 fps and this provides better video streaming with respect to the speed of the internet.

5.4.4.2 Resolution

The resolution of webcam has improved to 720 × 1080 pixel to meet high-definition capabilities. The higher end webcams are also available as 4 k range, which can be used for specific applications and it is supported with HD-capable monitor to view the true high definition. Webcams with 1080p are compatible with all interfacing devices to perform real time video streaming.

5.4.4.3 Autofocus

Autofocus is an option provided in webcam, which is used to focus the object automatically from camera position. Autofocus mode creates a delay for image capture as the camera takes the time to focus the object. In order to speed up the video streaming then the auto focus mode is turned to off condition.

5.4.4.4 Microphone

High-quality recording for episodes or other higher-tech films requires an upgrade. For those situations, invest in an external microphone.

5.4.4.5 Megapixels

It decides the quality of the picture or image. Most of the cameras provide reasonable quality images. It is good if we use 320*240 or 640*480 pixels. For better quality webcam should have 1280*720 resolutions.

5.4.4.6 Lens

Webcams are designed with glass lens or plastic lens based on the pixel range required and the cost convenience. For professional video presentation through Skype and other video chat software can use webcams with plastic lens, as it is more adequate for decent image quality [12].

5.4.5 Webcam resolution test

The Webcam Resolution Test is used to estimate the resolution of webcam through internet connectivity. The test results will show the clear list of resolutions supported by the camera and provides the information for attaining the ways of maximum resolution, minimum resolution and default resolution. The analysis provides the support to estimate each supported resolution for the image taken and each image quality can be compared. The webcam resolution test initially checks as default mode for possible resolution standards the major drawback occurs if the supported resolution is missed out.

The pixel value of captured image depends on the height and width of captured image. The image quality is specified as megapixel as one million pixel equals to one megapixel and abbreviated as Mpx or MPixel. The image quality of camera is determined based on the megapixel range as the manufacturer indicates the maximum supported value [13]. An webcam with a resolution of 1920 × 1080 can capture up to 2073600 pixels or 2.0736 megapixels, rounded off as 2MP. The resolution of camera is not the only parameter for better image quality as higher the resolution

provides more accurate details and good sharpness. The image taken with a higher resolution camera finds more clarity, when printing in large formats or viewing on big screens.

6. Result and discussion

Light Fidelity is a high speed wireless communication through light-emitting diodes leaf and Wi-Fi are quite similar as both transmit data electromagnetically however Wi-Fi gives radio waves, while Li-Fi transforms visible light waves. Visible light communication (VLC) accommodates a photo detector to receive light signals

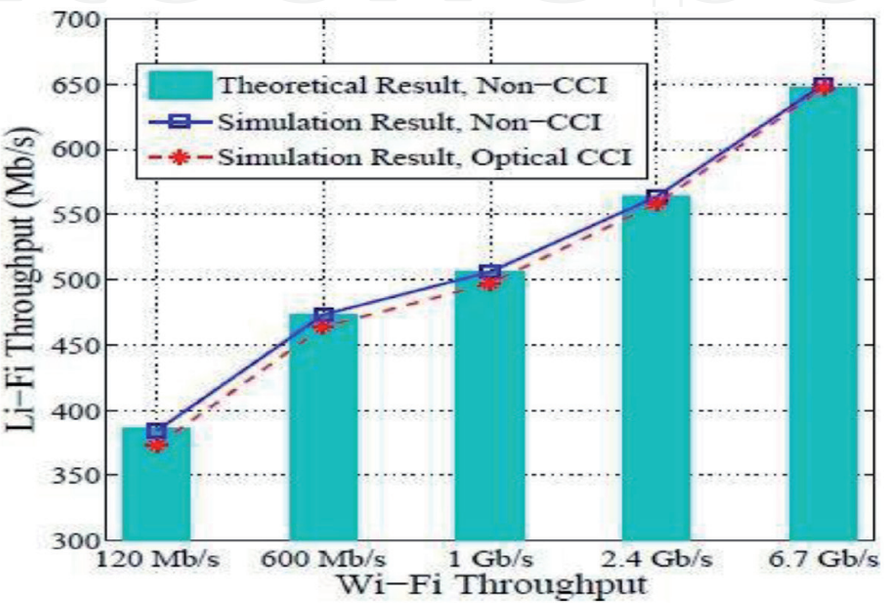

Figure 8.
Simulation results of Wi-Fi vs. Li-Fi.

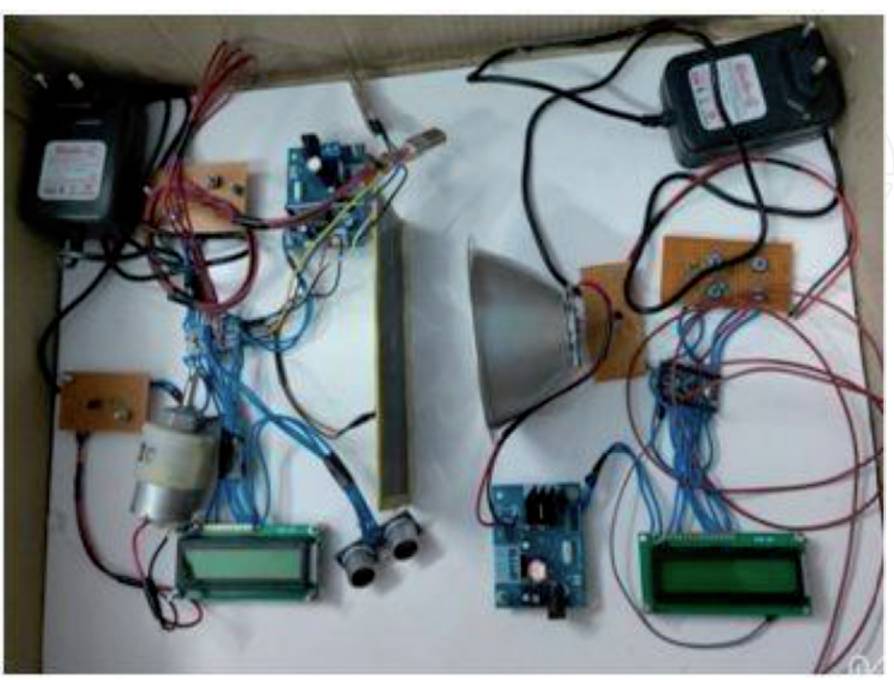

Figure 9.
Hardware model of proposed system.

and uses a signal processing elements to convert the data into stream-able content. A semiconductor light source is operated at extremely high speed to perform visible light communication. The light source is dimmed below human visibility to carry the data [14]. For short distance communication can be preferred with this and it is possible in electromagnetic sensitive areas. The proposed model uses a leaf architecture with two modules, in which one act as leaf transmitter and the other as leaf receiver (**Figure 8**).

At transmitting sides we have buttons, when we press the right button the microcontroller will send data through the leaf and the module at the receiver receives the data by the leaf and sends it to the microcontroller. At the transmitter side the data transmitted through UART communication and receiver side we have a solar band receiver [11]. So that both the data are displayed on both by LCD modules. According to the instructions they have been programmed to display right, left, brake instructions by the vehicles. The proposed system hasa face recognition safety authorization system. The ultrasonic sensor detects the vehicles which are less than threshold distance and sends an alert message by displaying brake in the LCD display. The relay will apply the brake on the second vehicle automatically when the data is received (**Figure 9**).

7. Conclusion

Similar as Wi-Fi technology, Li-Fi can be used as a bi-directional wireless communication method. Li-Fi uses visible light for data transmission as the RF communication is used for Wi-Fi and cellular networks. Compared with Wi-Fi technology for data transfer the use of visible light makes Li-Fi technology 100 times faster with minimum cost. Li-Fi communication can be performed in low power mode and no external power source is required as it operates with the glowing LED light. Li-Fi finds major advantage in electromagnetic sensitive areas, such as hospitals, aircrafts, and nuclear power plants, as it does not cause any electromagnetic interference. The technical advantages of Li-Fi drive its market in various application sector such as retail, aerospace, defense and indoor networking. These technical advancement over LI-Fi communication finds a great demand in the market within next few years.

We have presented a Visible Light Communication (VLC) system designed with Li-Fi transmitter and receiver introduced its characteristics and capabilities for precise communication. The VLC system in traffic signal are modeled to communicate with the LED lights of the cars and the traffic information can be shared with the vehicle which further reduces the accident [15]. Li-fi is more suitable for high density coverage with in a confined region and the technology yields a high speed communication of 10 Gbps. Li-Fi technology will advance to replace Wi-Fi communication for high speed data transfer application in near future.

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References

[1] Y. Goto, I. Takai, T. Yamazato, H. Okada, T. Fujii, S. Kawahito, S. Arai, T.Yendo, and K. Kamakura, "A new automotive VLC system using OpticalCommunication image sensor," IEEE Photonics Journal, vol. 8, no. 3, pp. 1-17,2016.

[2] K. Siddiqi, A. D. Raza, and S. S. Muhammad, "Visible light communication forV2V intelligent transport system," in 2016International Conference onBroadband Communications for Next Generation Networks and MultimediaApplications (CoBCom). IEEE, 2016, pp. 1-4.

[3] S.-H. Yu, O. Shih, H.-M. Tsai, and R. Roberts, "Smart automotive lighting forvehicle safety," IEEECommunication sMagazine,vol.51,no.12,pp.50– 59,2013.

[4] D.R.Kim,S.H.Yang,H.S.Kim,Y.H.Son, andS.K.Han,"Outdoor Visible light communication for inter-vehicle communication using controller area network,"in 2012 FourthInternational Conference on Communications and Electronics(ICCE), Aug 2012, pp.31-34.

[5] A.-L.Chen,H.-P.Wu,Y.-L. Wei,andH.-M.Tsai,"Time Variation Vehicleto-vehicle visible light communication channels,"in Proc. IEEE VehicularNetworking Conference (VNC), Dec 2016, pp.1-8.

[6] P. Luo, Z. Ghassemlooy, H. L. Minh, E. Bentley, A. Burton, and X. Tang,"Performance analysis of a car-to-car visible lightcommunication system," Applied Optics, vol. 54, no. 7, pp. 1696-1706, Mar2015.

[7] P. M. B. Mansingh, T. J. Titus and V. S. S. Devi, "A Secured Biometric Voting System Using RFID Linked with the Aadhar Database," *2020 6th international conference on advanced computing and communication systems (ICACCS)*, Coimbatore, India, 2020, pp. 1116-1119, doi: 10.1109/ICACCS48705.2020.9074281.

[8] Mansingh, P.M.B., Yuvaraju, M. Improved data transmission using Li-Fi technology for home automation application. J Ambient Intell Human Comput 12(5), 5581-5588 (2021).

[9] "Li-Fi Based A New Home Automation System", P.M Benson Mansingh, M. Nithya, M.Krithika, Department of Computer Science, Anna University, IJRASET Volume 4 Issue II, February 2016IC Value: 13.98 ISSN: 2321-9653.

[10] P M Benson Mansingh *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **932** 012091,Ber Analysis Of Channel Coding Techniques For 5G Networks, IOP Conference Series: Materials Science and Engineering, Volume 932, 1st International Conference on Science, Engineering and Technology (ICSET) 2020 27 February 2020, Penang, Malaysia.

[11] S. M. Motaghiannezam et al., "Single chip 52 Gb/s PAM4 transmission through −58 and +10ps/nm chromatic dispersion using directly modulated laser," in Proc. Conf. Opt. FiberCommun.,2016, Paper Th2A.59.

[12] P. Zhang and Q. Li, "Performance of UWB impulse radio with planar monopoles over on-human-body Propagation Channel for wireless body area networks," IEEE Transaction onAntennas and Propagation, Vol. 55, No. 10, October 2007, pp. 2907-2914.

[13] H. H. Lu et al., "45 Gb/s PAM4 transmission based on VCSEL with light injection andoptoelectronic feedback techniques," Opt. Lett., vol. 41, no. 21, pp. 5023-5026, 2016.

[14] S. Lange et al., "Low switching voltage Mach–Zehnder modulator

monolithically integrated withDFB laser for data transmission up to 107.4 Gb/s," J. Lightw. Technol., vol. 34, no. 2, pp. 401-406,Jan. 2016.

[15] S. Bates, D. Elliot, and R. Swamy, "Termination sequence generation circuits for low-densityparity-check convolutional codes," submitted to IEEE Trans. Circuits and Systems I, March 2005.