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Optical Wireless Communication: A Li-Fi Module for Secure and Efficient Data Transmission

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Abstract: Light-Fidelity (Li-Fi) technology, established in 2011, has garnered significant attention in recent years as a viable alternative to conventional radio frequency (RF) wireless communication methods. Li-Fi leverages light waves for data transmission, offering a more secure and efficient means of communication. This project aims to showcase the potential of Li-Fi technology by creating a bidirectional communication system capable of transmitting digital data using a laser and a micro-controller.

The system allows for data transmission and reception between two endpoints. For data reception, a solar panel is employed to convert the laser-emitted light waves into electrical signals, which are subsequently interpreted by a micro- controller. The received data is then displayed on an LCD screen for convenient readability.
Index Terms: Light Fidelity, Li-Fi Technology, Wireless Data Transmission, Optical Wireless Communication

I. INTRODUCTION

Li-Fi, or Light Fidelity, a technology founded in 2011, is a wireless communication technology that uses visible light to transmit data. It is a relatively new technology and can be used for Single Carrier Modulation (SCM) as well as various Multi Carrier Modulation (MCM) techniques [1]. Li-Fi is based on the principle of modulating the intensity of light emitted by a Light source to carry information.

The modulation isdone at a very high frequency that is imperceptible to the human eye, allowing for high-speed data transmission. With the proliferation of mobile devices over RF networks and the increasing demand for high-speed internet, the existing wireless communication technologies are becoming congested and unable to keep up with the demand. A hybrid Li-Fi/Wi-Fi system or ’HLWNets’ on the other hand, offers a potential alternative [2],[3],[4].

Li-Fi has several advantages over traditional wireless com- munication technologies such as Wi-Fi and Bluetooth. One of the main advantages is its high data transfer rates, which can reach several gigabits per second, making it ideal for high- bandwidth applications such as streaming video and down- loading large files[5]. Another advantage is its security, as the visible light signal cannot penetrate through walls, making it more difficult for hackers to intercept the signal. Li-Fi also has some limitations. It requires a light source to function, which means that it cannot be used in environments with low light levels or where lighting is not required.

Other limitation is thatit requires a direct line of sight between the transmitter and receiver, which means that it is not suitable for applications that require transmission through walls or other obstacles and lead to channel blockage. In [6], a novel access point assignment (APA) method is proposed for hybrid LiFi and WiFi networks for reducing this blockage. Authors have also assured that this method improves throughput significantly.

Despite its limitations, Li-Fi has the potential to revolutionize wireless communication, particularly in applications wherehigh data transfer rates and security are essential. Some potential applications include in-flight entertainment, smart home automation, and industrial automation. Overall, Li-Fi technology is an emerging technology that has the potential to revolutionize the way we transmit data wirelessly.

The relevance of a Li-Fi based communication lies in the fact that it addresses a growing need for faster and more secure data transmission. Furthermore, Li-Fi has several potential applications in various fields, such as healthcare, aerospace, transportation, and smart cities, IOT, to name a few.

For instance, Li-Fi access points (APs) are helful in sustainingthr growing demand of IOT. An optimal data rate-based slicing scheme that dynamically virtualizes a networked LiFi AP downlink channel bandwidth according to the data rate demands of users and the requested services is proposed by authors of [7].

II. LITERATURE SURVEY

Li-Fi (Light Fidelity) facilitates the wireless method of datatransmission through Visible Light Communication (VLC) technology and can be up to 100 times faster than Wi-Fi[8]. Li-fi is a both-sided wireless communication system that releasesinformation via a light source. Li-fi technology first came into use in the year 2011. The working or the implementation of Li-fi is not very complex like Wi-fi communication. It is straightforward to send information through light. The receiverthen collects the sent data or information and understands the transmitted data.

For instance, for a small module using LEDs,if the LED is on then a digital '1' is transmitted and in case theLED is off then a digital '0' is transmitted and can be switched on and off very quickly, which gives great open gateways for sending data [9]. In some cases, we need to alter or modifythe rate of transmission in which the light source flashes depending upon the information which is to be encoded. As westated above, the Light source is the main component in this communication, so that light source will serve as the central hub for data transmission from one point to another destinationpoint. The current state of Li-Fi technology is still in its early stages of development and commercialization. Which is why itstill has certain misconceptions like, it is a LoS technology, or that it does not work in sunlight conditions, or that it is only for downlink etc [10]. However, the technology has shown promising results in several areas, including data transfer rates,security, and energy efficiency.

In terms of potential applications, Li-Fi technology could be used in a variety of settings, future IOT applications as the authors of have by presenting the current state-of-the-artof LiFi systems and introducing new features and discussed results from a MIMO topology using plastic optical fibre [11],[12]. Li-Fi technology could also be used for high-speed data transfer in areas where Wi-Fi signals are congested, such as stadiums or concert venues. However, Li-Fi technologyalso has some limitations that need to be addressed, such as the need for direct line-of-sight between the transmitter and receiver, and its susceptibility to interference from other light sources. Research is currently ongoing to address these limitations and further improve the performance and potential applications of Li-Fi technology[13].

While Li-Fi technology has shown great potential, there are still some gaps and areas for further research in the field. Research is mainly going on in these areas to overcome the challenges:

1) *Standardization:* Currently, there is no standard for Li-Fi technology, which can lead to issues between different devices and systems.
2) *Range and Coverage:* Li-Fi technology is limited by its range and coverage area. The signal is unable to penetratesolid objects such as walls, which can limit its usefulnessin certain environments[13].
3) *Mobility and Handover:* In a mobile environment, such asa vehicle or airplane, Li-Fi signals can be disrupted by movement and handover can be challenging.
4) *Interference and coexistence:* As more devices and sys- tems use Li-Fi technology, there may be issues with interference and coexistence with other light sources[14].
5) *Integration with other technologies:* Li-Fi technology hasthe potential to complement and enhance other wireless technologies, such as Wi-Fi and Bluetooth.

Based on the literature survey, the key findings and conclu- sions are:

a) Li-Fi technology offers much faster data transfer rates compared to traditional Wi-Fi technology.
b) Li-Fi technology has high levels of security and is poten- tially attractive for applications that require high levelsof security.
c) Li-Fi technology has potential applications in indoor positioning, smart lighting, and wireless communicationsin areas where traditional Wi-Fi signals are not suitable.
d) There are still gaps and areas for further research in the field of Li-Fi technology, including standardization, rangeand coverage, mobility and handover, interference and coexistence, and integration with other technologies.

The recommendations for future research and development of Li-Fi technology include:

- Standardization efforts are needed to ensure that Li-Fi devices from different manufacturers can work together seamlessly.
- Research is needed to develop ways to extend the range and coverage of Li-Fi signals.
- Solutions are needed to provide seamless handover be- tween different Li-Fi networks in mobile environments.
- Techniques are needed to mitigate interference and ensurecoexistence with other systems.
- Research is needed to develop ways to integrate Li-Fi with other wireless technologies to create a seamless wireless ecosystem.

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III. BLOCK SCHEMATIC AND REQUIREMENTS

A. Block Diagram

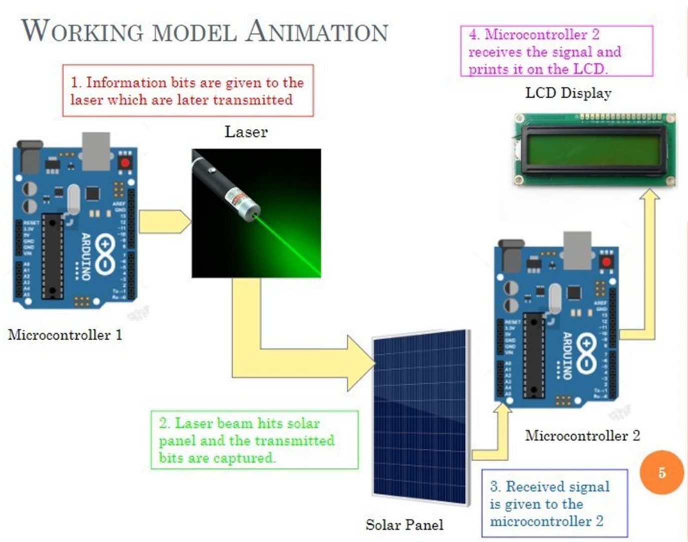

Fig. 1. Receiver Side

1) Block 0 : Power Supply
2) Block 1 : Microcontroller 1, it transmits the binary datain form of an array
3) Block 2 : Laser Module, it sends the data with the helpof light
4) Block 3 : Solar Panel, it captures the light and accordinglyreceives data
5) Block 4 : Microcontroller 2, it receives data and sends itto LCD
6) Block 5 : LCD, to display the received data

To summarize, information in binary format is given tothe light source(Laser) with the help of a microcontroller.The Laser gets modulated according to the information bit signal provided[15]. The data transmitted is displayed on the LCD display. This laser beam is then injected on the solar panel mounted at some distance from it. The solar panel captures the light beam and accordingly receives the data signal transmitted. The information bits received by the solar panel is then given to another microcontroller at the receiver end. This microcontroller displays the received signal on an LCD display.

B. Hardware and Software Requirements

1) *Software*

a) Arduino IDE : It is a software platform used to program and develop code for Arduino microcontrollers.
b) Proteus 8 : It is a software suite used for electronic circuitdesign, simulation, and PCB (printed circuit board) layoutdesign.
c) KiCad : KiCad is an open-source software suite used for electronic design automation (EDA) and printed circuit board (PCB) design.

2) *Hardware*

a) Arduino: An Arduino board is a physical computing platform that consists of a microcontroller and other components.
b) Solar Panel: A 6V solar panel is a type of photovoltaic panel that is designed to convert sunlight into electrical energy with a voltage output of 6 volts.
c) Laser Module: A laser is a device that produces a beam of coherent light through the process of stimulated emission.
d) LCD: It stands for Liquid Crystal Display. It is a typeof flat-panel display that uses liquid crystals to display images or text.

C. Selection of major components

1) *Laser Modules Comparison:* There are different types of laser modules available in the market, and they vary in terms of their specifications, features, and applications. Some of the common types of laser modules of different colors and their characteristics are shown in the table I.

Table I
Comparison of Laser Modules

Laser Color	Wavelength Range	Applications
Red	630-680nm	Pointers, scanners, alignment
Green	515-535nm	Projectors, displays, astronomy
Blue	445-470nm	Shows, research, imaging
Yellow	580-595nm	Displays, advertising, research
Violet	400-420nm	Excitation, engraving, research
IR	800-1064nm	Sensing, communication, security

When comparing different laser modules, some of the key factors to consider include their wavelength, output power, beam divergence, operating voltage, operating temperature, and size. It is important to select the right laser module for the specific application, considering factors such as safety, cost, and performance requirements[16]. It is also important tofollow proper safety guidelines when handling and operating laser modules. Our model uses a red-colored laser moduleso as to have better results and to avoid scattering of lightfor demonstration purposes and clearer results. As red color scatters the least and is clearly visible from a longer distance we use a red color laser module.
The output power range of all of the listed laser modules ranges between a few mW to Watts. They are directly modu- lated along with having good beam quality.

2) *Chip Comparison:* As can be seen from the table II, both microcontrollers are 8-bit RISC devices with similar program memory and data memory sizes. The PIC18F4520 has a higherCPU speed at 40 MHz compared to the Atmega328p's 16 MHz However, the Atmega328p has more PWM channels anda greater number of ADC channels, making it more suitablefor applications that require analog inputs or output control. The Atmega328p also has a larger EEPROM, making it more suitable for data storage.

TABLE II
Comparison Between ATMEGA328P and PIC

Feature	Atmega328p	PIC18F4520
Architecture	AVR 8-bit	PIC 8-bit
Instruction Set	RISC	RISC
CPU Speed (MHz)	16 MHz	40 MHz
Program Memory	32 KB	32 KB
Data Memory	2 KB SRAM	1.5 KB SRAM
EEPROM	1 KB	256 Bytes
ADC Channels	6	8
PWM Channels	6	2
Timers	3	4
1/0 Pins	23	40
Operating Voltage	1.8 - 5.5V	2.0 - 5.5V
Price	Inexpensive	Inexpensive

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D. List of Components

The list of the components used to make a small scale Li-Fimodule are described in table III.

Table III
List of Components

Sr. No	Name and description of part	Value / model number
1	Arduino chip	Atmega328P
2	Red Light Laser Module	5V 650 nm
3	LCD display	1602
4	Solar Panel	6V
5	Power Supply	5V 1A

E. Algorithm and Flowchart

1) Transmitter Side:

a) Define the LASERPIN constant as 9.
b) Include the LiquidCrystal library
c) In the setup function, set the LASERPIN pin as an outputand begin serial communication at 19200 baud rate.
d) In the loop function, create an instance of the Liquid- Crystal class with the following parameters: RS pin 12, EN pin 11, D4 pin 5, D5 pin 4, D6 pin 3, and D7 pin 2.
e) Set up the LCD with 16 columns and 2 rows with lcd.begin(16, 2).
f) Set the cursor position to the first row and first column with lcd.setCursor(0,0).
g) Create an integer array of bits with the values 1,0,1,0,1,0,1,0.
h) For each iteration of the for loop, do the following:

- Print the value at index i of the bits array to the LCD.
- Set the output of the LASER PIN pin to the valueat index i of the bits array.
- Wait for 100 milliseconds before repeating the loop.
- If the reading value is greater than AMBI- ENT+THRESHOLD, print 1 to the serial port and display 1 on the LCD.
- If the reading value is less than or equal to AMBI- ENT+THRESHOLD, print 0 to the serial port and display 0 on the LCD.
- Wait for 1000 milliseconds before repeating the loop.

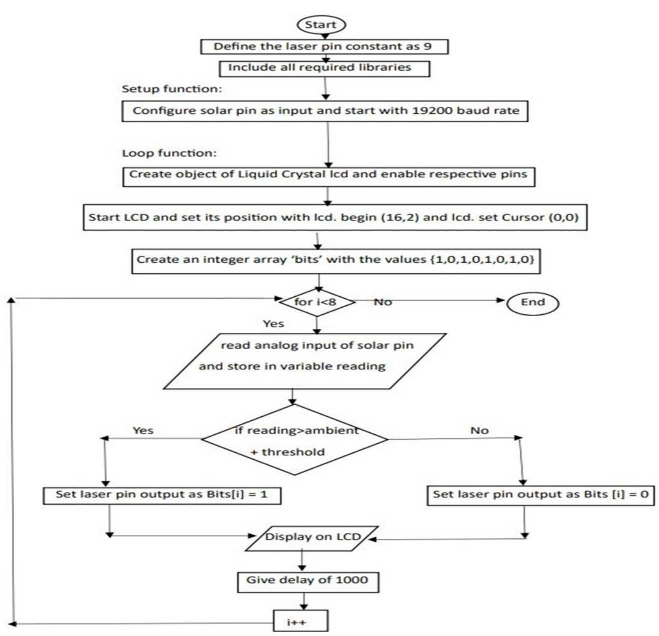

Fig. 2. Transmitter side

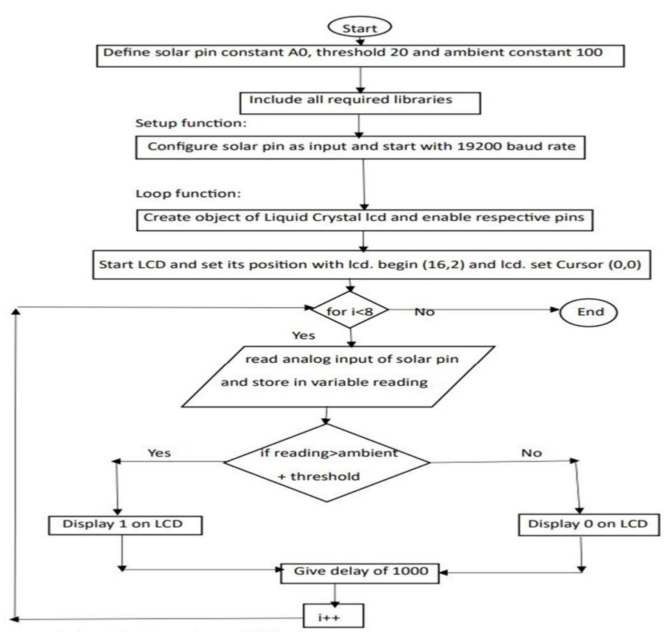

Fig. 3. Receiver Side

2) Receiver Side

a) Define the SOLARPIN constant as A0 and the THRESH-OLD constant as 20.
b) Define the AMBIENT constant as 100.
c) Include the LiquidCrystal library.
d) In the setup function, set the SOLARPIN pin as an input and begin serial communication at 19200 baud rate.
e) In the loop function, create an instance of the Liquid- Crystal class with the following parameters: RS pin 12, EN pin 11, D4 pin 5, D5 pin 4, D6 pin 3, and D7 pin 2.
f) Set the Contrast variable to 100 and apply it to the LCD with analogWrite(6, Contrast).
g) Begin the LCD with 16 columns and 2 rows with lcd.begin(16, 2).
h) Set the cursor position to the first row and first column with lcd.setCursor(0, 0).
i) For each iteration of the for loop, do the following:

- Read the analog input value of the SOLAR PIN pinand store it in the reading variable.

IV. IMPLEMENTATION

The images of small Li-Fi module as implemented is shownbelow.
Complete Li-Fi module as implemented is also shown below.

V. RESULTS

Overall efficiency of the system is approximately 87%
The above table represents the transmitted and receivedvalues for a given input sequence by the system. The systemis supposed to have 100% efficiency theoretically, but due to challenges in current LiFi technology such as obstacle in the line of sight the efficiency is reduced drastically and can be overcomed by the using various techniques like using multiple transmitters, transmitting the light in such a way that it reachesthe receiver panel, using minimal sequence and repetition of signal so as to reduce loss of information etc.

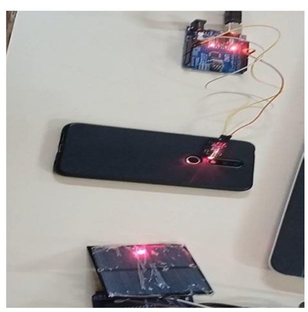

Fig. 4. Transmitter module

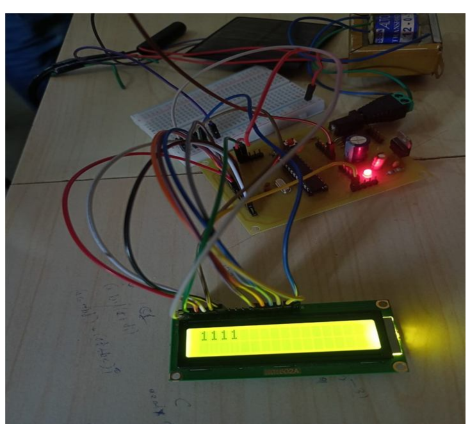

Fig. 5. Receiver Module

In excess ambient light, due to the light in the room some of the information may be distorted leading to error in detection of messages. This can be solved by setting the threshold limit by more vast data available for a particular environment.

Compared to Wi-Fi, Li-Fi communication has the potential to be more energy efficient due to the use of light as a medium of communication. Unlike Wi-Fi, Li-Fi does not rely on the transmission and reception of radio frequency (RF) waves, which require significant amounts of energy to generate and propagate[17]. One of the major energy-saving benefits of Li-Fi is that it can be used to create highly localized communication links, where the optical signal is confined to a small area. This reduces the amount of power needed to generate the signal and improves energy efficiency. Additionally, Li-Fi can be used to provide data communicationand illumination simultaneously, which can reduce energy consumption by eliminating the need for separate lighting and communication systems.

A. *Graphical Representation of Energy Efficiency*

However, it is important to note that the energy efficiency of Li-Fi depends on various factors such as the type of modulation used, the quality of the photodetectors, and the design of the transmitters and receivers. Furthermore, in order to achieve high data rates and reliable communication, Li-Fi may require high-intensity light sources, which can consume significant amounts of power.

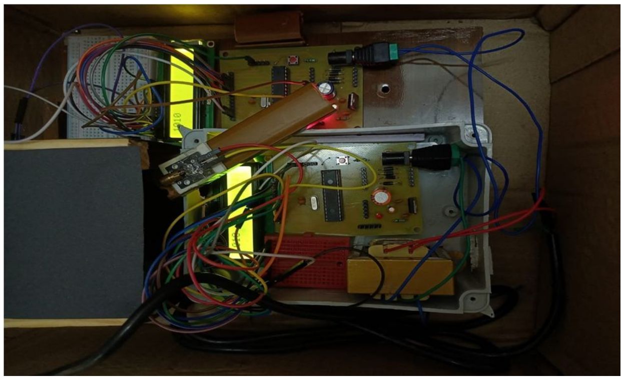

Fig. 6. Complete Li-Fi module

TABLE IV
Observation Table For Various Test Cases

Transmitted Data	Received Data	Result
Before Obstacle		
10101010 10100101 11111111 11110000	10101010 10100101 11111111 11110000	Working Fine
After Obstacle		
11110000 10101010	11000000 00001010	Different methods have been discussed abovefor the given problem.
In Excess Ambient Light		
11110000 10101010	11110000 11101011	Set the Threshold limit with more precise datafor accuracy.
In Low Light		
10101010 10100101	10101010 10100101	Working Fine

In conclusion, while Li-Fi has the potential to be moreenergy efficient than Wi-Fi, it is important to consider the specific application and implementation details to determine the true energy efficiency of each technology.

B. Data rate Comparison with Respect to Distance in li-fi Module

In Li-Fi communication, data rate and distance are inverselyproportional to each other. As the distance between the trans- mitter and receiver increases, the data rate decreases due to the attenuation of the optical signal in the medium. Thedata rate in Li-Fi communication depends on the modulation technique used to encode the data onto the light signal, aswell as the bandwidth of the optical signal. Some commonly used modulation techniques in Li-Fi communication include on-off keying (OOK), pulse position modulation (PPM), and orthogonal frequency-division multiplexing (OFDM).

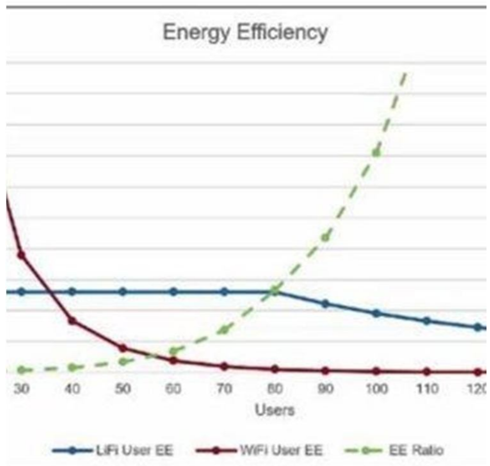

Fig. 7. Energy efficiency

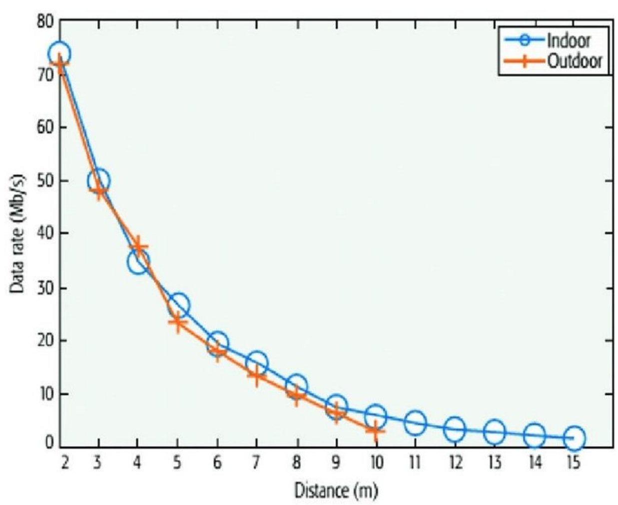

Fig. 8. Data rate comparison

For short distances of up to a few meters, Li-Fi can achieve data rates of several gigabits per second (Gbps), surpassingthe data rates of traditional Wi-Fi communication. However, as the distance between the transmitter and receiver increases, the data rate decreases significantly. For example, at 10 meters, thedata rate in Li-Fi communication may drop to a few megabits per second (Mbps) or less.

In summary, the data rate in Li-Fi communication is highly dependent on the distance between the transmitter and receiver,as well as the modulation technique and bandwidth of the optical signal. While Li-Fi can achieve very high data ratesfor short-range communication, it may not be suitable forlong-range communication or applications where the distance between the transmitter and receiver is highly variable.

VI. CONCLUSION

In conclusion, LiFi technology is a promising alternative to traditional wireless communication methods. A basic LiFi transmitter and receiver can be designed using commercially available components such as laser modules and Solar panels. The principle behind LiFi communication is the use of light waves to transmit data, which has advantages such as increasedsecurity and higher bandwidth than the traditional wireless methods. Additionally, LiFi technology can be used in variousapplications such as indoor positioning, healthcare, and trans- portation. While LiFi technology is still in its early stages, it has the potential to revolutionize the way we communicate wirelessly and can be an important part of the future of technology.

A basic Transmitter and receiver for demonstrating a Li-Fi system is built. Also implemented our own Arduino module for the transmitter as well as receiver. The different obstacles while implementing the system were identified. The potential solutions were also discussed for the same.

The current applications of the technology are listed. Afew of which can be that this system can be used for basic transmission if modulated with a PN Code sequence for Secureand encrypted communication. The system, if integrated with an alarm, can be used for security purposes. The system canbe used for dual purposes like electricity generation as wellas information transfer.

VII. FUTURE SCOPE

1) As light is everywhere and free to use, there is a great scope for the use and evolution of Li-Fi technology. More no. of light sources can be added so that the system can be used to transmit more data. Its use canbe extended for communication operations, in improving security systems, Mobile Internet transmission, etc.
2) It can complement 5G networks by providing high-speed indoor wireless connectivity[18],[19]. The integration of Li-Fi and 5G can offer seamless and efficient data trans- fer in areas with high user density, such as stadiums, shopping malls, and transportation hubs[20].
3) LiDAR (Light Detection and Ranging) systems, com-monly used in autonomous vehicles and robotics, relyon laser-based technology for sensing and mapping. Integration of Li-Fi capabilities within LiDAR systems can enable simultaneous data communication and object detection, enhancing their performance and reliability.
4) It can find applications in healthcare settings, where secure and high-speed data transmission is crucial. It can be used for patient monitoring, real-time transmission of medical data, and seamless communication between med-ical devices, improving healthcare efficiency and patient care.
5) Li-Fi's inherent immunity to electromagnetic interferencemakes it suitable for use in hazardous environments such as oil rigs, mines, and manufacturing facilities. Li-Fi can provide reliable communication in these challenging environments where traditional wireless technologies may be limited or unsafe.
6) It can be leveraged for precise indoor positioning sys- tems, enabling location-based services, asset tracking, and navigation within buildings. Li-Fi's ability to provide location-specific data can enhance user experiences in retail, hospitality, and logistics industries.
7) Integration with Visible Light Communication (VLC):VLC is a broader concept that encompasses Li-Fi, using visible light for data communication. Future develop-ments may explore the integration of Li-Fi with other VLC technologies to create hybrid systems that optimize the benefits of different light-based communication ap- proaches[21].

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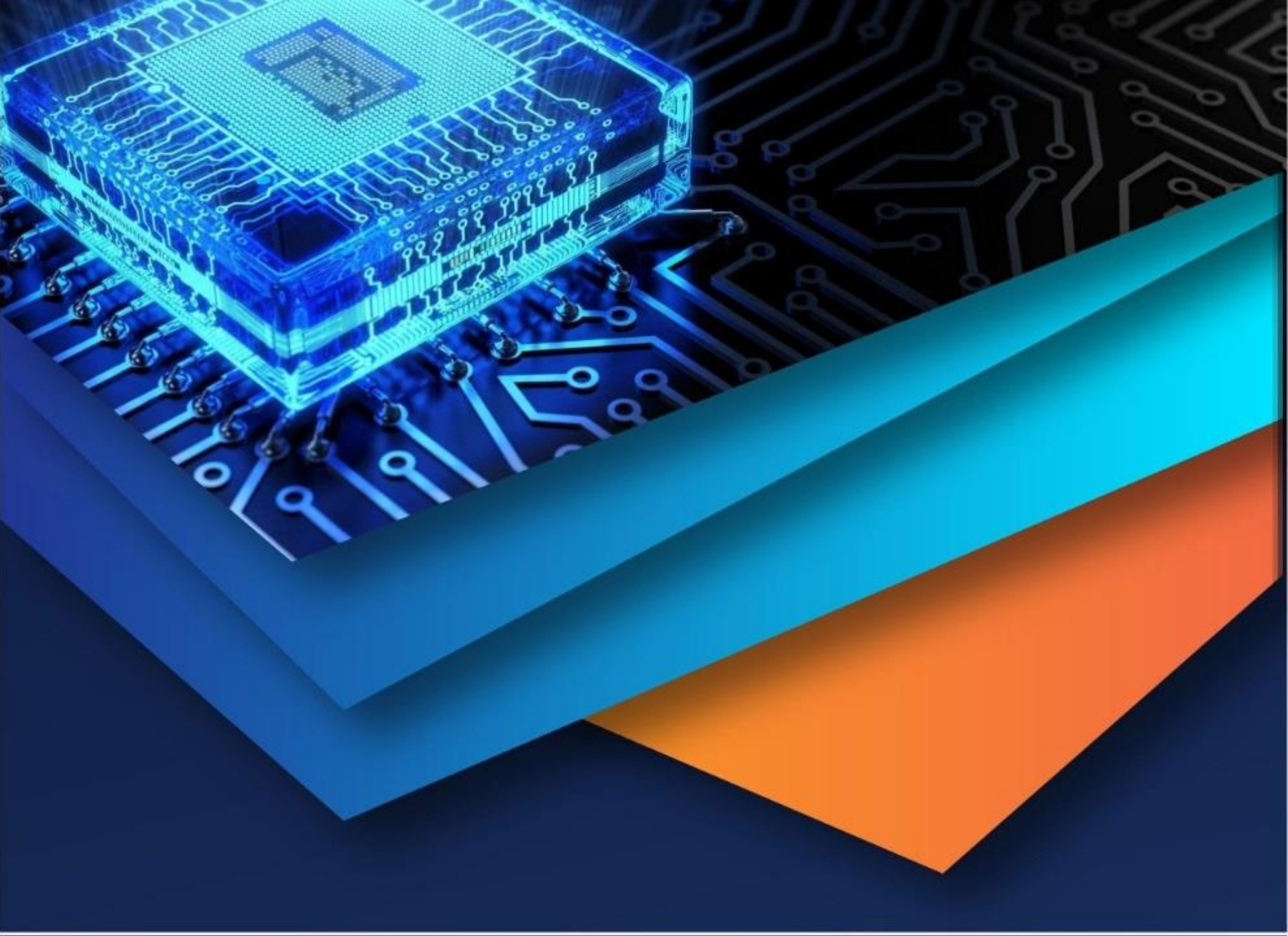

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