Free Space Optic Communication: A Survey

Akash A[1], A Abhinav[2], S. Bharath V Reddy[3], Meghana B N[4], Dr Manasa Charitha[5]
[1,2,3,4]*Student, Vemana Institute of technology*
[5]*Asst.Prof, Vemana Institute of technology*

***Abstract*—The survey presents Free Space Optical (FSO) communication integrated with Li-Fi technology has emerged as a promising alternative to traditional RF communication systems due to its high bandwidth, security, low interference, and energy efficiency. This survey reviews recent advancements in Visible Light Communication (VLC) and Li-Fi based communication systems focusing on text, image, audio, and video transmission using LED-based optical links. The paper analyzes various techniques involving Arduino, ESP32, photodiodes, and optical modulation methods used in recent research. Challenges such as line-of-sight dependency, ambient light interference, and limited communication range are also discussed. Finally, the paper highlights future research directions in secure optical wireless communication systems integrated with encryption and FSO architectures.**

I. INTRODUCTION

Free Space Optical (FSO) communication and Light Fidelity (Li-Fi) technologies are emerging as promising alternatives to conventional radio frequency (RF) wireless communication systems. These technologies utilize visible light spectrum for high-speed and secure data transmission using LED-based optical sources and photodiode receivers. Unlike traditional RF communication, Li-Fi and FSO systems offer advantages such as larger bandwidth availability, reduced electromagnetic interference, improved security, and energy efficiency. Since light signals cannot penetrate walls, optical communication provides a highly secure line-of-sight transmission system that minimizes unauthorized access and signal leakage. Recent advancements in Visible Light Communication (VLC) have enabled the transmission of text, image, audio, and video data over short distances with high reliability and low latency. Researchers have implemented various Li-Fi systems using Arduino, ESP32 microcontrollers, LEDs, photodiodes, and signal conditioning circuits to achieve efficient wireless communication. However, challenges such as ambient light interference, alignment sensitivity, and limited communication range still affect system performance. This survey paper reviews recent developments in Li-Fi and FSO communication technologies, analyzes existing methodologies and hardware implementations, and discusses their applications, limitations, and future scope in secure optical wireless communication systems.

II. LITERATURE SURVEY

This section reviews key contributions from recent advancements in wireless communication technologies have increased the demand for secure, high-speed, and interference-free data transmission systems. Visible Light Communication (VLC), Li-Fi, and Free Space Optical (FSO) communication have emerged as promising alternatives to traditional radio frequency (RF) communication due to their large bandwidth availability, improved security, and energy efficiency. Several researchers have explored the use of LEDs, photodiodes, Arduino, ESP32 microcontrollers, and optical modulation techniques for transmitting text, image, audio, and video data through visible light signals. Existing studies mainly focus on multimedia transmission, low-cost embedded implementations, hybrid communication systems, and performance analysis under practical lighting conditions. Researchers have also investigated advanced approaches such as solar panel-based receivers, energy-efficient communication, and secure indoor optical networks. However, challenges including line-of-sight dependency, ambient light interference, limited transmission range, and communication reliability still remain significant issues in VLC and FSO systems. The following literature survey reviews important contributions and recent developments in Li-Fi and optical wireless communication technologies, highlighting their methodologies, advantages, limitations, and future research scope.

Ankush R. Bichewar, Anshu A. Bandawar, Rajashree S. Kale, and V. M. Rohokale proposed a Visible Light Communication (VLC) system capable of transmitting text, audio, image, and video data over short distances using LED-based transmitters and photodiode receivers. The system modulates visible light signals to encode multimedia data without utilizing the radio frequency spectrum. Efficient optical modulation techniques were employed to achieve stable communication with minimal signal distortion. Experimental results demonstrated reliable multimedia transmission with low interference and improved security. The paper concludes that VLC technology is a feasible solution for high-speed short-range multimedia communication systems [1].

Rushikesh V. Ambalkar and Monika Rokade presented a comprehensive review of Li-Fi technology and its role as an alternative to conventional wireless communication systems. The authors explained the working principle of Li-Fi, where LEDs rapidly switch on and off to transmit digital data detected by photodiodes. The study compared Li-Fi and Wi-Fi in terms of bandwidth, speed, security, and interference. The authors emphasized that Li-Fi provides higher bandwidth availability and reduced electromagnetic interference, making it suitable for hospitals, aircraft, and secure indoor environments. However, challenges such as line-of-sight dependency and ambient light interference were also identified [2].

Omkar V. Zad, Pragalbha S. Rawool, Pramod Bhavarthe, Viral R. Makwana, and Tejas H. Sawant developed a Li-Fi communication system for transmitting image and text data using LED light signals. In this implementation, digital data from a computer was converted into binary signals to modulate the LED transmitter. A photodiode receiver detected the modulated light and reconstructed the original information. The system demonstrated reliable short-distance communication with minimal delay and improved data security. The authors concluded that Li-Fi technology can effectively support multimedia communication applications using visible light [3].

S. Deva Prasad, M. D. Saif Uddin, K. Uday Kumar, and M. D. Salauddin proposed a Li-Fi based text communication system using LEDs as optical transmitters and photodiodes as receivers. The system converted text data into binary signals that modulated LED light intensity at high speeds. At the receiver side, the photodiode detected these light variations and reconstructed the transmitted message. The study demonstrated secure indoor communication since light signals cannot penetrate walls, thereby reducing the risk of unauthorized access. The authors concluded that Li-Fi is a promising low-cost technology for secure wireless text communication [4].

Shahuraj Sable, Mahesh Jagtap, Rajesh Jagtap, and Kalyani Wagh focused on implementing data transfer using LED light intensity variations in a Visible Light Communication system. The receiver section employed photodiodes and signal conditioning circuits to recover transmitted information accurately. Experimental results indicated that VLC systems offer higher bandwidth, lower interference, and improved security compared to conventional RF communication systems. The study demonstrated that LED-based communication provides a cost-effective and efficient wireless communication solution [5].

Vishal Shankar Bhanavase, Rohan Rajendra Misal, Prasann Satish Kasar, Prajwal Dashrath Waghamare, Kumar Nomidas Salunkhe, and Nandan Utpat implemented a Li-Fi data transmission system using Arduino microcontrollers for LED modulation and data encoding. Digital information was converted into light pulses and transmitted through LEDs, while photodiodes at the receiver reconstructed the original data. The system demonstrated a simple and low-cost approach for implementing visible light communication using embedded hardware. The authors highlighted the suitability of Arduino-based Li-Fi systems for short-range indoor wireless communication [6].

Juan F. Gutiérrez, Nhung Nguyen, Jesús M. Quintero, and Andres Gomez proposed a novel VLC system where solar panels were used as optical receivers instead of conventional photodiodes. The system aimed to develop battery-less communication systems capable of harvesting energy and receiving data simultaneously. Experimental results showed that solar panels could effectively detect modulated light signals and convert them into electrical signals for decoding. The proposed approach improved energy efficiency and demonstrated the potential of sustainable VLC systems for IoT and low-power communication applications [7].

K. Rojamani, M. Meghana, R. Dhanarjana, G. Syam Kumar, and J. Vyshnavi proposed a wireless communication system integrating Li-Fi technology with Arduino Uno and GSM modules. The system used LED transmitters to encode digital data into light signals, which were then received and decoded using photodiodes and microcontrollers. Integration with GSM modules enhanced communication capability and enabled hybrid wireless communication. The study demonstrated that Li-Fi can be effectively combined with other wireless technologies to improve communication reliability and performance [8].

M. Zeng, H. Wang, Y. Zhang, and Z. Xu studied the performance of indoor VLC systems under practical lighting conditions. The authors analyzed the effects of ambient light, illumination intensity, optical alignment, and receiver positioning on data transmission quality. Experimental and analytical results showed that noise and improper alignment significantly affect communication reliability. The paper also proposed methods to improve signal quality and reduce interference from background lighting. This research provides important insights for designing robust and efficient indoor VLC communication systems [9].

M. A. Khalighi and M. Uysal presented a comprehensive survey on Free Space Optical (FSO) and Visible Light Communication (VLC) systems, focusing on recent advancements, challenges, and future opportunities in optical wireless communication technologies. The paper discusses the fundamental principles of FSO and VLC communication, where light waves are utilized for high-speed wireless data transmission instead of conventional radio frequency signals. The authors reviewed various modulation techniques, channel models, system architectures, and performance parameters used in modern optical communication systems. The study highlighted several advantages of VLC and FSO technologies, including large bandwidth availability, high data rates, low electromagnetic interference, improved security, and energy efficiency. In addition, the paper analyzed practical challenges such as atmospheric attenuation, ambient light interference, line-of-sight dependency, and alignment issues that affect communication reliability. The authors concluded that optical wireless communication systems have strong potential for future applications in 5G/6G networks, indoor communication, IoT devices, underwater communication, and smart city infrastructures, making VLC and FSO promising technologies for next-generation wireless communication systems [10].

III. RESEARCH GAP

From the reviewed literature, it is observed that most existing Li-Fi and Visible Light Communication (VLC) systems primarily focus on short-distance transmission of text, image, audio, or video data using basic LED and photodiode communication models. Although several researchers demonstrated reliable optical data transfer, many systems lack strong security mechanisms such as encryption and secure authentication. Existing studies also show limitations related to line-of-sight dependency, ambient light interference, signal attenuation, and alignment sensitivity in Free Space Optical (FSO) communication. In addition, most implementations are designed only for low-range indoor communication and do not address scalability, hybrid communication, or energy-efficient operation. Very few works integrate ESP32-based embedded systems with secure optical communication and noise filtering techniques. Therefore, there is a need for a secure, low-cost, high-speed, and interference-free optical communication system capable of improving transmission reliability and communication security.

IV. RELATED WORK

The proposed work focuses on recent advancements in Li-Fi, VLC, and Free Space Optical communication systems for secure wireless data transmission. The survey analyzes various communication techniques that utilize LEDs, photodiodes, Arduino, ESP32 microcontrollers, and optical modulation methods for transmitting multimedia data through visible light. It also reviews systems involving secure encryption, signal conditioning, and hybrid communication models integrated with GSM and IoT technologies. The survey aims to compare existing methodologies, identify research gaps, and evaluate the performance of different VLC systems in terms of security, bandwidth, communication range, interference handling, and energy efficiency. Additionally, the survey highlights future trends and emerging applications of optical wireless communication systems in next-generation communication networks.

V. PROPOSED METHODOLOGY

The proposed methodology is based on secure optical wireless communication using Li-Fi and FSO technologies. At the transmitter side, data from Laptop A is sent to the ESP32 microcontroller through serial communication. The ESP32 performs encryption and converts digital data into optical pulses using high-speed LED modulation. These modulated light signals are transmitted through free space using LEDs or laser sources. At the receiver side, a photodiode detects the incoming optical signals and converts them into electrical signals. Signal conditioning circuits and operational amplifier filters are used to remove ambient light noise and improve signal quality. The ESP32 receiver then decodes and decrypts the received information before displaying the original data on Laptop B. This methodology ensures secure, line-of-sight, and interference-free communication using visible light technology.

VI. ADVANTAGES & LIMITATIONS

Li-Fi and Free Space Optical communication systems offer several advantages over conventional RF communication technologies. These systems provide high-speed data transmission, larger bandwidth availability, improved communication security, and immunity to electromagnetic interference. Since visible light signals cannot penetrate walls, optical communication systems reduce the risk of unauthorized access and data leakage. In addition, LED-based communication systems are energy efficient and cost-effective, making them suitable for hospitals, underwater communication, smart transportation, and secure indoor communication environments. However, these systems also have certain limitations. VLC and FSO communication require strict line-of-sight alignment between transmitter and receiver, and communication performance can be affected by ambient light interference, physical obstructions, and receiver misalignment. Moreover, the communication range is limited compared to traditional RF systems, reducing mobility and long-distance communication capability.

VII. FUTURE SCOPE

Li-Fi and Free Space Optical communication technologies have significant future potential due to the increasing demand for high-speed, secure, and interference-free wireless communication systems. Future research can focus on improving communication range, adaptive optical alignment, and noise reduction techniques to enhance system reliability. Integration of Li-Fi with Wi-Fi, 5G, and upcoming 6G networks can enable hybrid communication systems with improved coverage and performance. Advanced encryption techniques and AI-based signal processing can further strengthen communication security. Researchers can also explore applications in underwater communication, smart cities, intelligent transportation systems, military communication, and IoT networks. Energy-harvesting communication systems using solar panels and battery-less VLC devices also represent promising future developments in sustainable optical communication technologies.

VIII. CONCLUSION

Li-Fi and Free Space Optical communication technologies provide an efficient alternative to conventional RF-based wireless communication systems by utilizing the visible light spectrum for secure and high-speed data transmission. The reviewed literature demonstrates that VLC systems can effectively support text, image, audio, and video communication using LEDs, photodiodes, Arduino, and ESP32-based embedded systems. These technologies offer advantages such as higher bandwidth, reduced interference, energy efficiency, and enhanced communication security. However, challenges including line-of-sight dependency, ambient light interference, and limited communication range still affect system performance. With further advancements in optical modulation, signal processing, and secure encryption techniques, Li-Fi and FSO systems have strong potential to become key technologies for future wireless communication networks and next-generation smart communication applications.

REFERENCES

[1] Ankush R. Bichewar, Anshu A. Bandawar, Rajashree S. Kale and V. M. Rohokale, "VLC-Based Text, Audio, Image and Video Transmission over Small Distance," International Journal of Creative Research Thoughts (IJCRT), vol. 13, pp. d95–d104, June 2025.

[2] V. Ambalkar and Monika Rokade, "Li-Fi Technology Review," International Journal of Research Publication and Reviews, vol. 3, pp. 1215–1220, November 2022.

[3] Omkar V. Zad, Pragalbha S. Rawool, Pramod Bhavarthe, Viral R. Makwana and Tejas H. Sawant, "Image and Text Transmission Using Li-Fi Technology," International Journal of Advanced Research in Science, Communication and Technology (IJARSCT), vol. 3, pp. 270–274, April 2023, doi: 10.48175/IJARSCT-9413.

[4] S. Deva Prasad, M. D. Saif Uddin, K. Uday Kumar and M. D. Salauddin, "Text Communication Using Li-Fi," International Journal of Innovative Research in Technology (IJIRT), vol. 8, pp. 1428–1433, May 2022.

[5] Shahuraj Sable, Mahesh Jagtap, Rajesh Jagtap and Kalyani Wagh, "Data Transfer Using LED with Li-Fi Visible Light Communication," International Journal of Advanced Research in Science, Communication and Technology (IJARSCT), vol. 3, pp. 229–236, May 2023, doi: 10.48175/IJARSCT-10036.

[6] Vishal Shankar Bhanavase, Rohan Rajendra Misal, Prasann Satish Kasar, Prajwal Dashrath Waghamare, Kumar Nomidas Salunkhe and Nandan Utpat, "Li-Fi Data Transmission System Using Arduino," International Journal of Research Publication and Reviews, vol. 6, pp. 5066–5072, February 2025.

[7] Juan F. Gutiérrez, Nhung Nguyen, Jesús M. Quintero and Andres Gomez, "Solar Panel-Based Visible Light Communication for Batteryless Systems," in Proceedings of the ApplePies Conference, pp. 1–6, 2025, arXiv:2601.04190.

[8] K. Rojamani, M. Meghana, R. Dhanarjana, G. Syam Kumar and J. Vyshnavi, "Wireless Data Transfer Using Li-Fi Technology Using Arduino Uno and GSM Module," International Journal of Creative Research Thoughts (IJCRT), vol. 11, pp. b911–b916, June 2023.

[9] M. Zeng, H. Wang, Y. Zhang and Z. Xu, "Performance Analysis of Indoor Visible Light Communication Systems under Practical Lighting Constraints," IEEE Access, vol. 8, pp. 102965–102977, June 2020, doi: 10.1109/ACCESS.2020.2999023.

[10] M. A. Khalighi and M. Uysal, "Recent Advances in Visible Light Communication Systems: Survey on Free Space Optical and Visible Light Communication Systems," MDPI Photonics, vol. 8, no. 2, Article no. 56, February 2021, doi: 10.3390/photonics8020056.