International Journal of
Electrical and Communication Engineering Technology

Volume 2, Issue 2, 2024
July–December
DOI (Journal): 10.37591/IJECET

https://journals.stmjournals.com/ijecet

Review IJECE

The Potential of Li-Fi for High-Speed Underwater Data Transfer

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Abstract

Recently, there has been a growing interest in using underwater communication (UC) to monitor obstacles and marine life in oceans. Unlike conventional methods which struggle due to the absorption of radio waves in water, Li-Fi technology has emerged as a promising solution. Li-Fi utilizes light to transmit data, making it effective for underwater communication as light can penetrate deep into the ocean. In a recent study, researchers successfully demonstrated real-time audio transmission using a Li-Fi transmitter. Remarkably, this system achieved a maximum transmission distance of 100 m underwater, showcasing its potential for various applications in marine environments. The system performance is analysed in terms of intensity, and distance. This system is simulated on proteus to transfer data in real time. The system demonstrates the transfer of voice signal with the help of Li-Fi communication. The unique transmission properties of the undersea environment have long posed challenges for underwater communication. Conventional techniques, such as radio frequency and acoustic communication, are limited by high attenuation and slow data transfer rates, respectively. Light Fidelity (Li-Fi), a wireless communication system that uses visible light, offers a promising solution for high-speed data transfer underwater. This article explores the potential of Li-Fi in addressing underwater communication challenges. It discusses the fundamentals of Li-Fi, its advantages over traditional methods, and the technical difficulties associated with its implementation in underwater environments. Additionally, potential use cases are highlighted, including military applications, underwater robotics, and oceanographic research.

Keywords: Underwater Li-Fi wireless, wireless communications (WC), leaser, optical beam propagation, underwater communications (UC)

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Received Date: August 08, 2024
Accepted Date: August 14, 2024
Published Date: August 25, 2024

Citation: Abhishek G. Mudhol, S.A. Shirsat, Vishal R. Puri, Jayesh S. Pinjarkar. The Potential of Li-Fi for High-Speed Underwater Data Transfer. International Journal of Electrical and Communication Engineering Technology. 2024; 2(2): 10–17p.

INTRODUCTION

Underwater Wireless Communications (UWC) have become a hot topic for both research and commercial applications due to their ability to offer faster data transfer rates compared to traditional acoustic methods, especially over short distances. The advancement of high-speed underwater optical communication has become increasingly vital, offering promising applications across a spectrum of environments. From deep-sea exploration to coastal regions, this technology holds significant potential for revolutionizing various sectors. Unlike acoustic methods that face limitations like frequency attenuation, optical communication is seen as a promising solution to overcome these challenges.

The demand for more bandwidth is increasing as users require higher data access. Optical communication presents itself as a cost-effective solution for broadband communication industries, allowing the same hardware to transmit data both in the air and underwater at higher speeds and lower costs. In this context, we present an underwater optical communication system that utilizes Laser as a source of light. The system includes a transmitter that converts electrical data signals into optical signals by directing a light beam towards the receiver. The transmitter receives data through a serial interface, encodes it according to specifications, and generates light pulses using Laser.

Since water has special qualities as a transmission medium, underwater communication has always been difficult. In underwater conditions, conventional wireless communication technologies like radio frequency (RF) and acoustic waves have severe limits. Researchers have looked to Light Fidelity (Li-Fi) as a potential solution to these problems. Underwater applications can benefit from Li-Fi's high-speed and secure connection features, as it employs visible light to transfer data. The possibilities and design considerations of employing Li-Fi for underwater communication are examined in this study.

LITERATURE REVIEW

Li-fi's use of the visible light spectrum has minimal impact on the environment and other organisms. With greater security, reduced power consumption, and environmental friendliness, Li-Fi is considered a greener and more efficient technology [1]. Li-Fi utilizes visible light to transmit information at very high speeds. It is more efficient and reliable way to communicate in underwater world [2]. In this study, exploring the capabilities of Li-Fi, the study underscores its operation in the vast visible light spectrum, which is multiple times larger than radio waves. This technology stands out by transmitting data through visible light, departing from traditional radio wave methods [3]. Providing insights into Li-Fi's fundamental operation, the study explains how it utilizes visible light to achieve exceptionally highspeed transmission of information, making it a promising technology for future communication systems [4]. Li-Fi is the use of the visible light portion of the electro-magnetic spectrum to transmit information at very high speeds [5]. The study introduces a compact Li-Fi system tailored for facilitating short-range teleoperation control of underwater vehicles. This technology enables control either directly from a diver situated closely to the robot or through a communication relay system from support stationed on the surface [6]. A voice guidance system using Li-Fi is proposed to guide both normal and blind individuals. Programming the guidance into a chip and connecting it to an illuminating device can lead a person entering a building to different regions through pre-recorded audio using Li-Fi technology [7].

Need for Li-Fi for Communication Below the Surface?

When compared to conventional techniques for underwater communication, Li-Fi, a technology that uses light-emitting diodes (LEDs) for high-speed data transmission, offers the following advantages:

- *High Bandwidth:* Li-Fi allows for quicker data transfer rates because it has a far larger bandwidth than RF and acoustic communication.
- *Low Latency:* Real-time communication can occur with as little delay as possible because to light's quick transmission.
- *Security:* There is less chance of interference and eavesdropping because light waves stay inside the designated area.
- *Environmental Compatibility:* Li-Fi can be used in delicate underwater situations since it is unaffected by electromagnetic interference [8].

METHODOLOGY

In our study, we are looking at the challenges of wireless communication underwater, which are caused by how light travels through ocean water. Understanding the properties of ocean water is a tricky task for oceanographers, much like measuring temperature, salinity, and density has been for centuries. The optical properties we are interested in are influenced by various physical, biological, and chemical processes, leading to significant variability [9].

One reason for the scattering of seawater is the interaction between pure water and suspended particles in the ocean. Scattering of signal due to water results by factors like temperature and sea depth, while scattering from suspended particles is influenced by volume and thickness. Typically, the amount of light absorbed by seawater depends on its wavelength, with the 500 nm range showing low absorption, making it suitable for underwater communication.

System Design

Our system is designed with a light emitter placed in one corner and a photo detector in another. The photo detector records a binary 1 when the laser is activated and a binary 0 when the laser is deactivated. By flickering the laser multiple times and creating an array with different coloured laser, we can form a message, achieving data rates of up to 100 Mbps. Once the optical data is received, it goes through a photo detector at the receiving end, converting it into an electrical signal. Following signal conditioning, which involves amplification, processing, and retrieving binary data, the information is then directed into voice signals for further use [10].

Problem Statement

Underwater communication is challenging, and it is a big problem for scientists and industries that work in the ocean. Right now, they mostly use sound to talk underwater, but it is slow, and there are delays. This makes it hard to do things like explore the ocean or work in offshore industries.

But there is a cool technology called Li-Fi that uses light to send data underwater. This is like using a flashlight to send messages. Li-Fi can make data go faster, reduce delays, and make communication more reliable underwater.

Transmitter

Figure 1 shows the transmitter section of Li-Fi system. The transmitter circuit is ingeniously engineered to ensure that the blinking of the laser remains imperceptible to the human eye, thereby meeting the dual requirements of functioning as a lighting system while also transmitting data seamlessly. Within the transmitter module, key components include a microphone, microcontroller, amplifier, laser, and a power supply block. The microphone plays a pivotal role in detecting audio signals, which typically possess small amplitudes. Consequently, amplifying these signals becomes imperative to ensure effective transmission. amplification is done at factor of about 10x. The laser operation requires the switching on and off. This is performed at high speed in response to the voltage levels at the laser input. But if the voltage increases further to maximum value, the lifetime of laser will decrease.

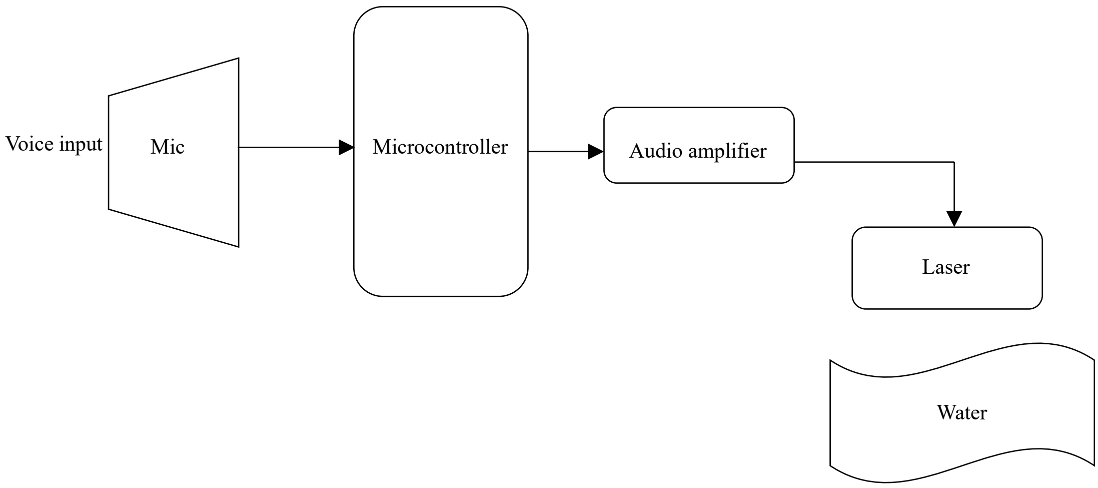

Figure 1. Transmitter Section of Li-Fi communication system.

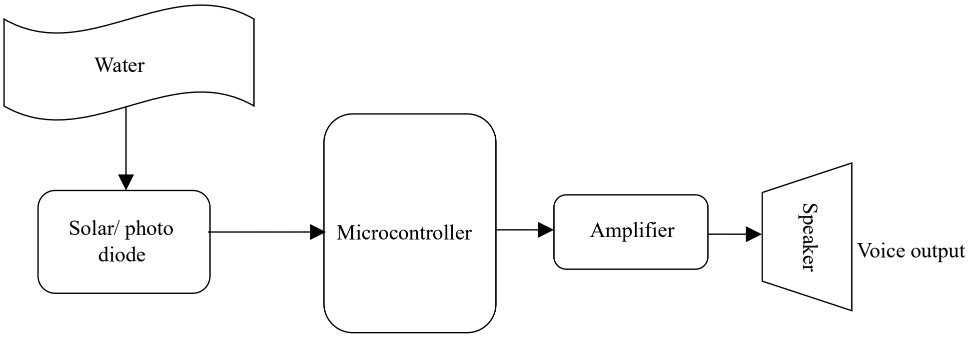

Figure 2. Receiver section of Li-Fi communication system.

Receiver

Figure 2 shows the receiver section of Li-Fi system. An optical detector or photo detector converts the optical input power falling on it into a voltage output. This is given to microcontroller which is further given to audio amplifier. In the receiver circuit, the concluding stage comprises an audio amplifier, crucial for elevating the signal to a suitable level for further processing. This amplification step is essential to ensure that the signal is robust enough for subsequent stages. Once amplified, the signal is routed to the loudspeaker, where the goal is to deliver clear and audible messages to the listener.

Underwater Li-Fi System Design Considerations

Light Source and Modulation

- *LED Selection:* For Li-Fi systems, the selection of light emitting diode (LEDs) is essential. It is preferable to use high-power, energy-efficient LEDs that have a particular operating wavelength. Since blue and green LEDs pierce water more easily than other colors, they are frequently employed.
- *Modulation Techniques:* Reliability and data transmission rates can be improved by effective modulation systems like On-Off Keying (OOK), Pulse Position Modulation (PPM), and Orthogonal Frequency Division Multiplexing (OFDM).

Optical Elements

- *Lenses and Filters:* Proper lens and optical filter design can aid in reducing signal loss and focusing the light beam. By ensuring that the light beam is focused, and narrow, collimating lenses increase the transmission range.
- *Photodetectors:* To detect the light signal, sensitive photodetectors are needed. Due to their great sensitivity and quick response times, silicon photomultipliers (SiPMs) and avalanche photodiodes (APDs) are frequently used.
- *Features of the Channel:* Water absorbs and scatters light, which modifies the strength and quality of the signal. Creating a Li-Fi system that works requires an understanding of the water body's unique absorption and scattering characteristics.
- *Turbidity and Clarity:* The way light travels through water is affected by its clarity. The transmission range may be restricted in murky waters, necessitating the use of more sensitive detectors and higher power LEDs.

Environmental Elements

- *Salinity and Temperature:* Changes in salinity and temperature can impact water's refractive index, which in turn can change how light travels through it. The design of the system must take these considerations into consideration.
- *Biofouling:* When marine life builds up on optical parts, it can impair functionality. To lessen this problem, anti-fouling coatings and routine maintenance are required.
- *Integration of Systems:* Networking: By combining Li-Fi with currently in place underwater communication and sensor networks, total capabilities can be improved. Systems that combine Li-Fi and RF or audio transmission, known as hybrids, can offer reliable solutions.

- *Power source:* It is critical to make sure underwater Li-Fi systems have a dependable power source. For long-term deployments, battery life and energy usage must be optimized.

RESULT AND DISCUSSION

This study presents a developed voice transmission system utilizing Li-Fi technology, with transmission carried out using light source i.e. laser and reception facilitated by a speaker on the receiving end.

Figures 3 and 4 show simulation of system. The system is simulated using Proteus 7 software, where data transfer is simulated through variations in light intensity. As the intensity of light increases, data is transferred, and the corresponding information is displayed on a liquid crystal display (LCD).

Figure 5 shows the hardware implementation of Li-Fi system. The hardware implementation provides real-time voice data transfer, allowing for immediate playback on the speaker at the receiver's end when speaking into the microphone data travel up to 100 m.

This innovative approach combines simulation and practical hardware implementation, showcasing a reliable method for voice transmission using Li-Fi technology, with seamless reception and playback capabilities. Despite challenges like water type, absorption, and scattering affecting the beam's distance and scope, underwater optical communication demonstrates promise.

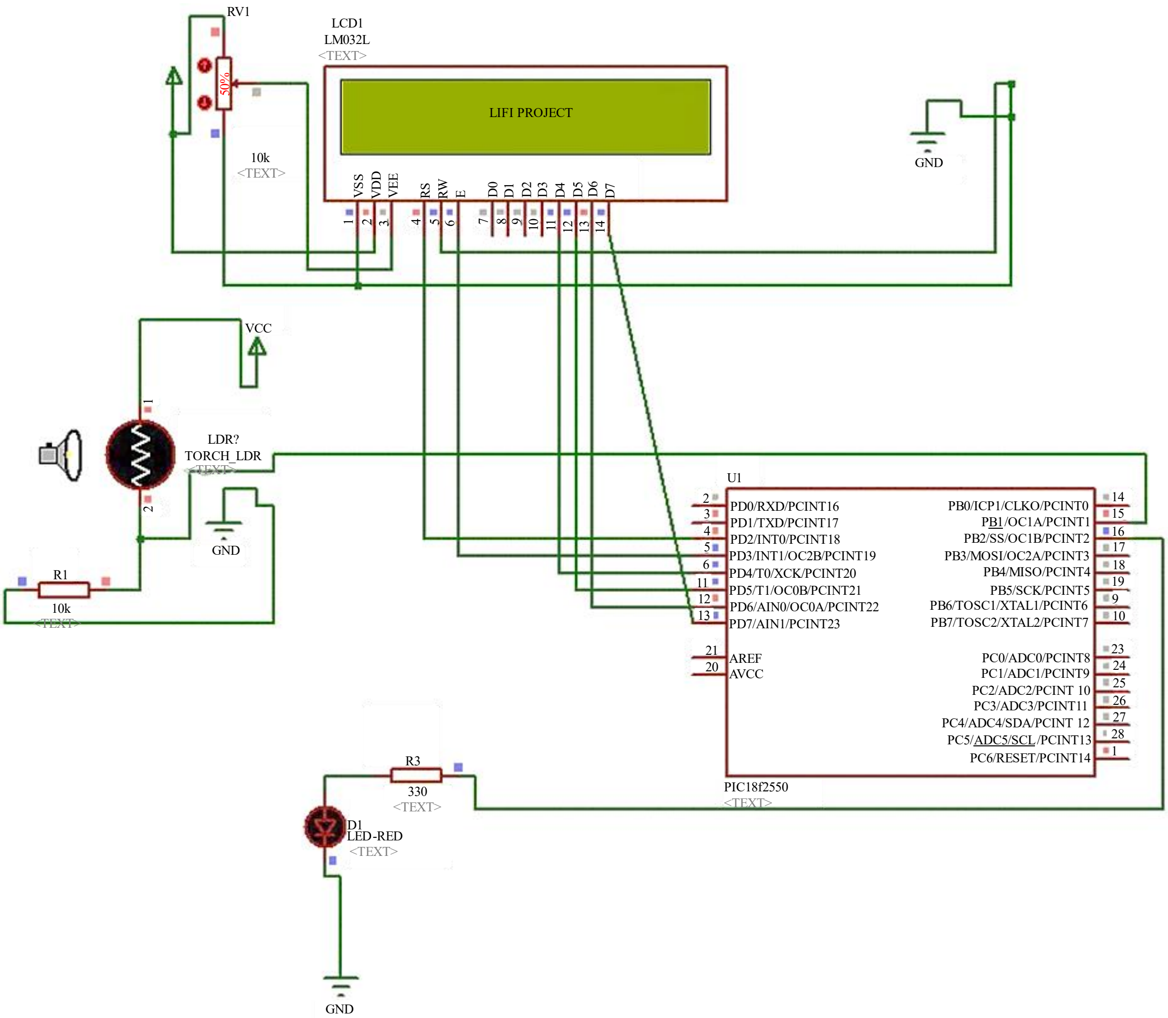

Figure 3. Simulation of Li-Fi communication system.

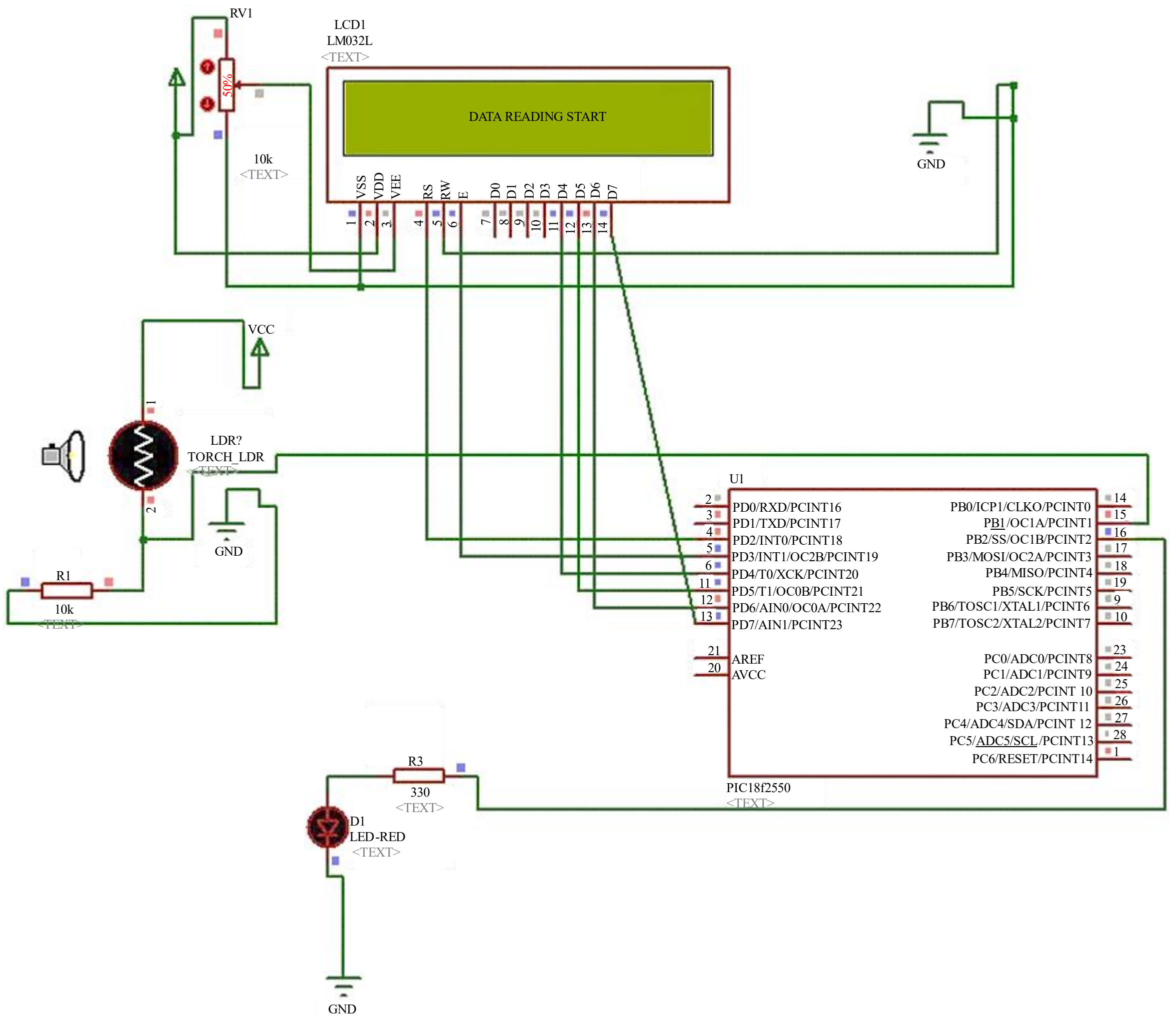

Figure 4. Simulation of Li-Fi communication system when data reading start.

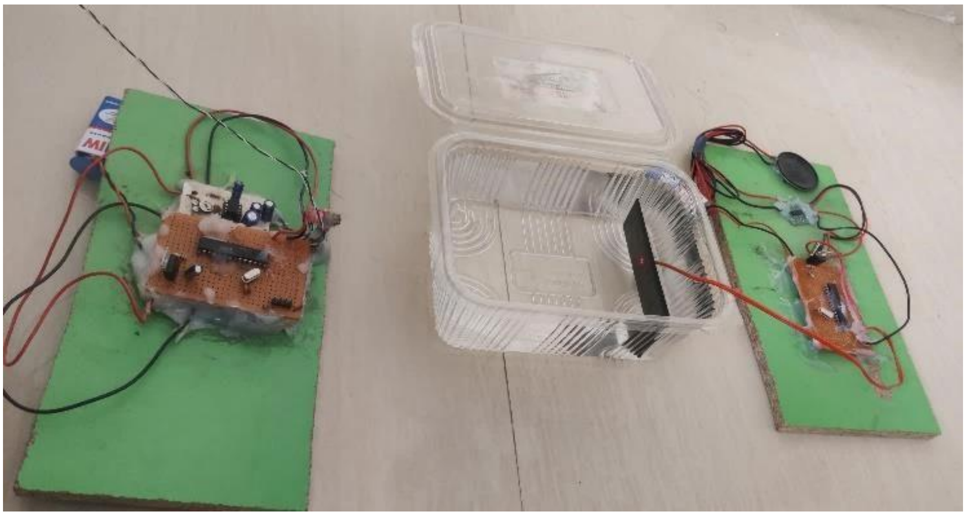

Figure 5. Result of Li-Fi communication system.

The utilization of blue-green wavelengths helps alleviate these challenges. While traditional underwater communication often necessitates precise pointing and tracking systems, the incorporation of advanced transmitters and receivers, segmented fields of view, or electronic beam steering enables relaxation of the stringent pointing and tracking requirements associated with a narrow optical beam. Although acoustic waves currently serve as reliable means, ongoing technological advancements and active research in underwater communication strongly indicate that underwater optical communication holds significant promise for the future.

CONCLUSION

A model has been developed for underwater data transmission and reception utilizing laser transceivers, employing visible light communication to achieve high data rates and density. This innovative system proves advantageous for speech communication among divers underwater or between submarines. The increasing presence of self-driven vehicles in space and underwater environments has underscored the necessity for enhanced underwater communication systems. Conventional underwater communication heavily relies on acoustic signals, facing challenges in providing sufficient bandwidth and low latency.

The use of radio-frequency signals for Underwater Optical Wireless Communication is constrained to Extremely Low Frequencies due to signal absorption. Optical Fibers and coaxial cables, while employed, impose limitations on the range and flexibility of underwater operations. In contrast, optical underwater communication exhibits substantial future, offering advantages such as high data speeds, low latency, reduced power consumption, and compact packaging. Drawing inspiration from advancements in terrestrial optical wireless communication, the system utilizes Bluegreen wavelengths in the visible spectrum. This wavelength choice establishes a low attenuation, facilitating high-bandwidth communication over distances of 10–100 m.

Acknowledgement

We extend our heartfelt gratitude to Dr. S. A. Shirsat for her invaluable guidance and unwavering support throughout our project, which empowered us to excel under her mentorship. Prof. C. R. Kuwar's encouragement as the BE project coordinator was instrumental in overcoming challenges and achieving our objectives. Additionally, we appreciate Dr. M. B. Mali's cooperation and insightful suggestions, which significantly enriched our learning experience. Finally, we acknowledge Dr. S. D. Lokhande's inspirational leadership as the Principal of Sinhgad College of Engineering, Pune, whose dedication to excellence has profoundly influenced our academic journey. Everyone mentioned has played a pivotal role in our success, and we are sincerely grateful for their contributions.

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