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Implementation of Li-Fi Technology in Smart Home Systems: Development and Analysis of a Prototype for Enhanced Wireless Communication

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ABSTRACT

Exploring innovative communication technologies has been a pressing need due to the need for reliable and efficient data transmission in networks such as industrial automation, IoT devices, and healthcare systems. This research investigates a wireless communication system that uses visible light, called microcontrollers, with Li-Fi technology instead of radio waves to enhance data accuracy and resilience. Unlike traditional legacy systems, Li-Fi technology provides a buffer against electromagnetic interference, making it a promising alternative for smart home automation. This research includes a developed prototype that uses visible light communication (VLC) through LEDs and an LDR receiver, controlled by an Arduino microcontroller. The KNX standard was adopted in building the proposed system, which has been widely adopted in building automation. The results showed that the Li-Fi-based system improves the accuracy of data transmission as well as the data transmission power. This research, along with other researches on Li-Fi, contributes by demonstrating its applicability in smart home environments, and thus this technology will revolutionize wireless communications across various fields.

MSC.

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1. Introduction

Technological advancements have a profound impact on economic and social growth, with most new research and innovations always aiming to create opportunities that enhance user demand and promote further development. The emergence of smart technologies has had a significant impact on various sectors, resulting in smart structures that increase efficiency, enhance sustainability and make the user experience more successful. These smart structures, which replace traditional wiring in buildings, integrate advanced management technologies to create environments that are not only user-friendly but also highly efficient and cost-effective.

The concept of smart home has gained great importance due to the increasing reliance of society on technology, as it represents an advanced environment by linking many systems and devices to each other in order to improve and facilitate the daily lives of the residents of these societies. Given the large amount of time that people spend in their homes, this innovation has gained great importance, however, there are still many potential health

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concerns about the effects of adopting these wireless technologies, especially those based on radio waves, and there are many studies that have addressed this aspect, highlighting the harmful biological effects of electromagnetic radiation, including increased risks of cancer, memory impairment, sleep disorders, neurological issues, and other health problems [1-2].

With these concerns growing, interest in non-radio wireless technologies for smart home automation has increased. One of these technologies is Li-Fi (Light Fidelity), which relies on visible light to transmit data. This technology has been recognized as a promising alternative to traditional wireless systems because it provides many benefits such as low costs of cables, accuracy and speed of data transfer, safety enhancement and improvement of safety for users. This research explores the application of the Li-Fi technology in smart homes, showing the capabilities of this technology in addressing the challenges related to radio-based wireless systems while contributing to achieving the broader goals of economic and social development [3].

The rest of the paper has been organized as follows: Section 2 provides an introductory explanation and a general view of the intelligent house strategies. Section 3 provides system design details, including all relevant elements. Finally, the section offers 4 final ideas.

2. RELATED WORKS:

In recent years, with the spread of mobile devices such as smartphones, tablets and laptops increasing in the education sector, interest in technologies such as LI-FI to enhance Internet connection [4] [5], with the adoption of many technologies as an applicable alternative to wireless communication methods Traditional like Li-Fi or Light Fidelity, which provides high-speed data transmission capabilities. These technologies are also useful for applications such as video conferences and fast downloads for digital textbooks and online education, where fast and reliable internet connections are very important [6].

Li-Fi is an effective solution to create reliable communications in environments where traditional wireless frequency signals are less effective. For example, in underwater connections, wireless frequency signals suffer from great attenuation and sound waves can be harmful to marine life. In these cases, the Li-Fi technology, which uses visible light, is an applicable solution because the signal loss in the water is low [7]. In addition, this technique is very suitable for highly electromagnetic interference, as it provides stable connections and reduces the need for intense cables, thus reducing equipment weight and enhancing system elasticity [8].

The use of visual light to transmit data for short distances, using LED lights as a basic source, attracted widespread attention from researchers, as the results showed that the adoption of Li-Fi technology can achieve safe and reliable communications in different environments, including systems where data security is It is very important such as industrial automation systems, military applications and banking institutions [9]. It can be said that Li-Fi's inherent safety stems from the fact that light signals are limited to the luminous area, unlike the Wi-Fi signals that can spread to areas outside the material borders, which makes them vulnerable to unauthorized access [10].

Despite all the advantages of Li-Fi technology, it faces many challenges such as the need for a clear line of sight between the transmitter and the receiver, which limits the work of this technology in some cases, in addition to the exposure of this technology to interference from other light sources and the possibility of intercepting the signal in open or unsafe places [11] Therefore, finding a solution to these obstacles is necessary for the wider adoption of Li-Fi technology.

The researchers have investigated various modification techniques such as monochrome and multi-tanker modification that can improve data transfer efficiency [12] in order to enhance the performance of Li-Fi technology. In one of the research projects, one of the researchers merged Li-Fi with solar panels, allowing energy harvesting and data transfer simultaneously, which may significantly increase the power efficiency of the system [13]. Others explore the use of laser diodes as an alternative to LED lamps. It has been proven that laser diodes can achieve data transfer rates of up to 100 GB in light of the ideal lighting conditions of the room, providing a significant improvement on the traditional LED systems [14].

Li-Fi offers many advantages in the field of wireless communication compared to the traditional Wi-Fi technology, as it enables data transfer rates of up to 10 GB (GBPS), which far exceeds the current Wi-Fi standards

[15]. This technology also allows information to be transferred more efficiently, as the broad-range light spectrum uses the Li-Fi Li-Fi Spectrum Spectrum of Loving Wireless Frequency [16]. Li-Fi signals also provide enhanced safety because they are limited to the luminous area, unlike Wi-Fi signals that can be accessed from outside the physical environment [17].

Li-Fi technology is also energy-saving as it relies on existing LEDs used for lighting, so adopting Li-Fi technology reduces the energy consumption associated with data transmission [18]. LEDs are already widely available and thus provide a suitable infrastructure for deploying Li-Fi technology in various applications.

Despite all of the above, the future of Li-Fi depends on overcoming its current limitations. Therefore, future research should focus on developing more powerful modulation technologies, improving signal processing algorithms, and exploring hybrid systems that combine Li-Fi with other wireless technologies. These advancements will be critical to realizing the full potential of Li-Fi across diverse industries and applications.

3. Methodology

This section provides a comprehensive overview of the design of a Li-Fi-based home automation system, and includes a detailed explanation of the experimental and test setup environment. It also includes the specific roles of each component of the system and provides key performance metrics to measure system efficiency and reliability.

System Components and Roles:

I. Arduino Uno Microcontroller:

Arduino Uno is the core processing unit, responsible for receiving, analyzing and acting on data signals from an LED Li-Fi receiver. Arduino Uno was chosen because of its simplicity of programming, its wide availability in the market and its cost-effectiveness compared to other microcontrollers [19]. Arduino processes data received from the optical sensor and converts it into executable commands, such as controlling the power supply for smart home devices.

II. Li-Fi LED Receiver and LDR (Light Dependent Resistor):

The Li-Fi receiver detects light signals from the LED, which the Li-Fi receiver interprets as analog inputs. These inputs are then processed by Arduino, triggering predefined actions such as opening doors or turning on lights.

III. Relay Module:

The relay unit acts as an electronic key controlled by Arduino. It enables the system to manage the electrical circuits of smart home devices by turning them on or off based on the received data signals.

IV. LCD Display:

The LCD display provides instant feedback to the user. The LCD displays the system status and any actions performed, i.e. it provides instant feedback to the user. This allows the system to be monitored and troubleshooting easily.

V. Mobile Application:

A mobile app has been developed using open-source software and is available on the Google Play Store. This app acts as a user interface to control the system, allowing users to send pre-programmed commands to the Arduino by pointing their smartphone camera at the light sensor.

4. Experimental Setup and Testing Environment:

The system was tested in an environment designed to simulate typical home settings with standard indoor lighting conditions. The room was equipped with adjustable LED lights to simulate different lighting intensities and ensure that Li-Fi signals could be transmitted and received effectively.

- Figure 1 shows the initial wiring diagram, which shows the pin configuration of the Arduino Uno board to receive encoded data from the optical sensor. The working principle can be summarized as the sensor captures the optical signals emitted by the LED, which are integrated into the data stream sent to the microcontroller. The microcontroller then processes these optical signals, converts them into electrical data, and decodes the information.

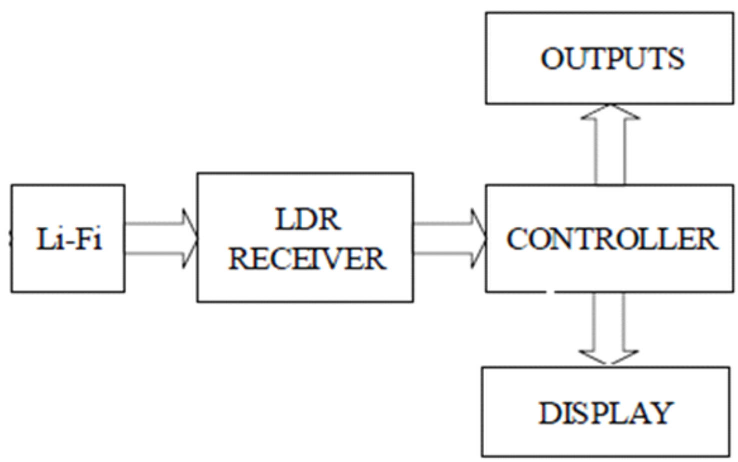


Fig (1): Initial connection diagram

- In practical implementation, pin 7 on the Arduino microcontroller is set to send a digital signal (either 0 or 1) to the relay module, which in turn controls the smart devices via Li-Fi technology. This configuration is illustrated in Figure 2.

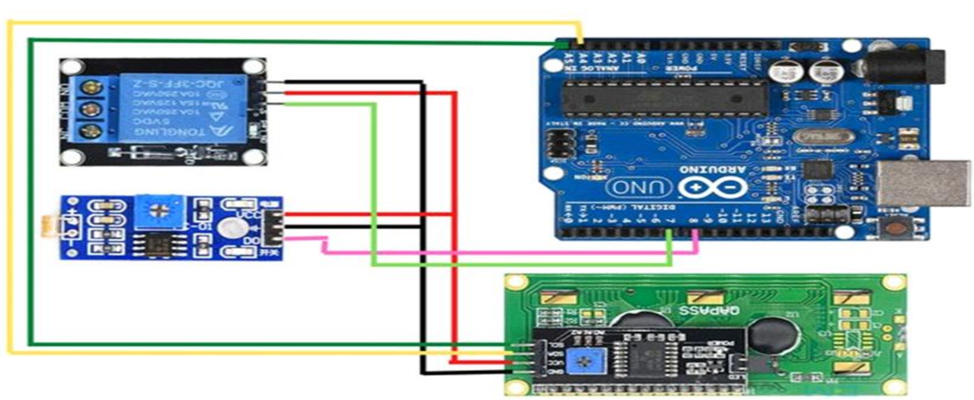
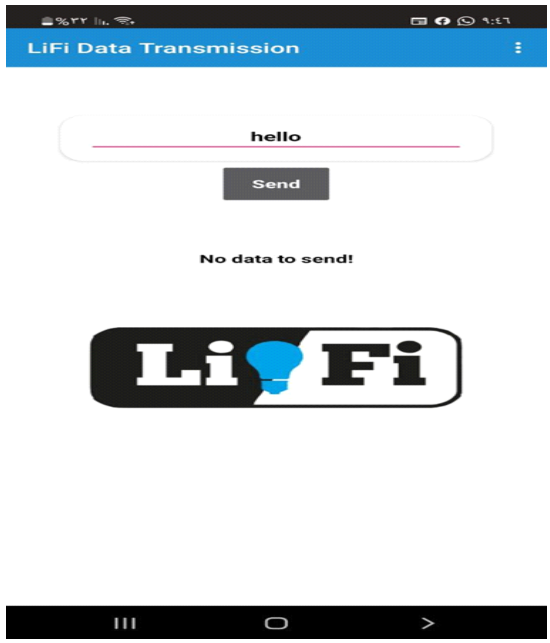


Fig (2): Connecting hardware parts

- A mobile application was developed for user interaction (as shown in Figure 3) where the application allows users to control the system by sending pre-programmed commands via their smartphone camera. The camera then captures light signals from the LED which are then processed by the Arduino to perform the corresponding actions.



FIG(3) : Mobile application to control and issue instructions for the system

Table 1 lists the pre-programmed messages and their associated functions within the system:

Table 1: Suggested instructions and their associated functions.

Message	Function
Good morning	Switching on
Sorry	Switching off
Hi	Door unlocked
Hello	Door locked

5. RESULTS AND DISCUSSION

Performance Metrics:

The system was evaluated based on several key performance metrics to evaluate its efficiency and reliability:

- **Response Time:**

The system showed an average response time of about 150 milliseconds to execute commands, which is within the acceptable range for most smart home applications.

- **Success Rate:**

In terms of accurately recognizing and executing commands, the system achieved a 98% success rate during the test, and thus the high success rate indicates the reliability of the Li-Fi communication system in a typical home environment.

- **Signal Range:**

The effective range of Li-Fi communications has been tested up to 5 meters and beyond this distance the signal strength and reliability decreases and therefore a clear line of sight is needed between the transmitter and receiver.

- **Energy Consumption:**

Arduino consumes about 0.5 watts of power during operation, so the system is designed to work efficiently. Using energy-efficient LEDs to transmit Li-Fi reduces overall energy consumption, making the system a sustainable choice for home automation.

Discussion:

Experimental results show that the LI-Fi-based automatic operating system is effective and reliable to control smart devices. The Arduino UNO controlling also has proven to be a strong and cost -effective solution to manage data processing and control tasks. However, the system dependence on a clear view line for Li-Fi is a restriction that must be addressed in future repetitions. Possible solutions include combining hybrid systems that combine Li-Fi and traditional communication methods based on radio frequency to expand the range and improve reliability.

Another field that needs improvement is the modification techniques used to transfer data. By using more advanced technologies, we can improve data transfer rates and general performance of the system. Future research can also explore the inclusion of solar-powered Li-Fi transmitters, which would reduce the system consumption of energy and increase its sustainability.

6. CONCLUSION

This study emphasizes the decisive importance of choosing the appropriate type of LED lights and improving the distance between the Li-Fi Reception and the Li-FI. The main results show that high -bright and high -energy LED lights are best suited to transmit data via broader domains and faster rates with improved signal quality, LED RGB lights provide flexibility for dynamic signals, and white LED lights provide an effective cost solution where low data rates are sufficient.

It is also worth noting that with an increase in the distance between the transmission and reception, the signal strength decreases, which may negatively affect the quality of the data. However, technologies such as the optics of the formation of the package and the improved LED group arrangements can reduce these effects, thus ensuring a stable VLC connection across larger distances. In addition, to process advanced signals and the publication of multiple VLC networks, the challenges imposed by internal environments, such as shading, repercussions and obstacles.

7. Key Findings and Implications for the Future:

The success of the design and implementation of this initial model shows us the effectiveness of Li-Fi technology and its ability to revolutionize the field of home automation applications due to its ability to provide a safe and effective alternative compared to traditional wireless communication technologies.

We also see the possibility of integrating the Li-Fi technology easily into modern smart homes, as this technology has the ability to take advantage of the current lighting infrastructure to transfer data and thus enhance all functions and achieve energy efficiency, and the continuous development of Li-Fi will lead to more intelligent and safest living environments By applying home automation systems.

8. Future Research and Improvements:

We should not lose sight of the numerous restrictions that this study suffers from and despite the promising results, as it may be limited to applying it in the planning for the most complicated homes due to the dependence of this initial model on a clear vision line for communication, and therefore future research should work to explore the combined hybrid systems Between Li-Fi and other communication technologies such as Wi-Fi or Bluetooth in order to enhance coverage and reliability.

In addition, examining the effect of surrounding lighting conditions and potential interference from other light sources would provide a more comprehensive understanding of the system's performance in the real-world scenarios. More work can also focus on developing the most advanced signaling technologies and improving the energy efficiency of Li-Fi. Explore Li-Fi integration with other emerging technologies, such as IOS and AI, can open new horizons for creating smart and adaptable home automation systems that respond dynamically to the needs of users.

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