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# The Correlation Coefficient for Different Distances in The Transmission and Receiving Process of The Optical System Model

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# معامل الارتباط لمسافات مختلفة في عملية الإرسال والاستقبال لنموذج النظام البصري

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**Abstract:**
This paper presents the design and calculation of the autocorrelation coefficient for varying distances between the transmitter and receiver in an optical communication system. A prototype was developed utilizing the Arduino Uno microcontroller to achieve key performance metrics, such as enhanced optical wireless transmission and reception speeds, minimized interference, and reduced physical dimensions. Furthermore, the integration of multiple wireless technologies offers the potential for optical wireless devices to operate across various frequency bands. In comparison to traditional wireless technologies that utilize the radio frequency spectrum, data transmission via visible light communication (VLC) provides a more secure medium with the potential for significantly higher data transfer rates. This research explores optical wireless communication techniques by transmitting data and establishing a VLC system capable of sending text data between two computers through visible light. In this setup, a light-emitting diode (LED) serves as the transmitter, air as the transmission medium, and a solar panel as the receiving element. Texts of varying lengths, ranging from 10 to 160 characters, were transmitted over distances between 2 cm and 100 cm. Through multiple experimental trials, data was successfully transmitted, and the speed of text reception was measured using C language embedded in the Arduino Uno controller on the receiving circuit. The results were further analyzed by calculating the correlation coefficients for each data pair measured at different distances between the transmitter and receiver circuits. The findings demonstrate that VLC operates as a linear system with reliable connectivity.

**Keywords**: LED, OWC, Optical, Li-Fi, FSO, PD, VLC, Linear system.

**الملخص**
تقدم هذه الورقة تصميم وحساب معامل الارتباط التلقائي لمسافات متغيرة بين جهاز الإرسال والاستقبال في نظام الاتصالات الضوئية. تم تطوير نموذج أولي باستخدام متحكم Arduino Uno لتحقيق معايير أداء رئيسية، مثل تحسين سرعة الإرسال والاستقبال عبر الاتصالات الضوئية اللاسلكية، تقليل التداخل، وتقليل الأبعاد الفيزيائية. علاوة على ذلك، فإن دمج تقنيات لاسلكية متعددة يتيح للأجهزة اللاسلكية الضوئية العمل عبر نطاقات تردد مختلفة. مقارنة بالتقنيات اللاسلكية التقليدية التي تستخدم طيف الترددات الراديوية، يوفر نقل البيانات عبر الاتصال الضوئي المرئي (VLC) وسيلة أكثر أمانًا وإمكانية لتحقيق معدلات نقل بيانات أعلى بشكل كبير. تستكشف هذه الدراسة تقنيات الاتصال الضوئي اللاسلكي عن طريق إرسال البيانات وإنشاء نظام VLC قادر على إرسال بيانات نصية بين جهازين كمبيوتر باستخدام الضوء المرئي. في هذا النظام، يعمل الصمام الثنائي الباعث للضوء (LED) كجهاز إرسال، بينما يعمل الهواء كوسيط نقل، وتعمل اللوحة الشمسية كعنصر استقبال. تم إرسال نصوص بطول متغير، تتراوح من 10 إلى 160 حرفًا، عبر مسافات تتراوح بين 2 سم و100 سم. من خلال تجارب متعددة، تم نقل البيانات بنجاح وتم قياس سرعة استقبال النصوص باستخدام لغة C المدمجة في وحدة التحكم Arduino Uno على دائرة الاستقبال. تم تحليل النتائج بشكل أكبر من خلال حساب معاملات

الارتباط لكل زوج من البيانات المقاسة عند مسافات مختلفة بين دوائر الإرسال والاستقبال. تُظهر النتائج أن نظام VLC يعمل كنظام خطي مع اتصال موثوق.

**الكلمات المفتاحية:** الصمام الثنائي الباعث للضوء (LED)، الاتصالات الضوئية اللاسلكية، بصري، دقة الضوء، بصريات الفضاء الحر، كاشف الضوء، اتصالات الضوء المرئي، النظام الخطي.

## 1. Introduction

The adoption of LED-based room lighting is steadily growing, as it paves the way for innovative applications such as enabling mobile devices to connect to the Internet with a broader frequency spectrum and faster response times compared to traditional Wi-Fi technology. LiFi, a groundbreaking technology, leverages LEDs to facilitate data transmission, evolving from wireless optical communication that utilizes light from LEDs to provide high-speed connectivity. Visible Light Communication (VLC) functions by rapidly switching LEDs on and off at rates imperceptible to the human eye. The density of LiFi LED emitters is carefully calibrated to remain invisible while still maintaining sufficient intensity to ensure seamless connectivity.

LiFi technology is highly secure against hacking due to the fact that light cannot penetrate walls, though this characteristic also limits its range of coverage.[1] This makes it particularly advantageous in environments sensitive to electromagnetic interference, such as hospitals, nuclear power plants, and airplanes, where traditional electromagnetic communication methods are typically avoided. While both WiFi and LiFi utilize the electromagnetic spectrum for data transmission, WiFi relies on radio waves, whereas LiFi employs visible light.

Clearly, LiFi faces almost no capacity limitations, as the visible light spectrum is 10,000 times broader than the entire radio frequency spectrum. Optical signals are transmitted wirelessly to the receiver, where a detector converts them into the original data message. Since light cannot pass through walls, LiFi signals are physically contained, providing enhanced security within specific spaces. Additionally, Ultraparallel Visible Light Communication, which employs multiple light colors, enables the creation of high-bandwidth connections over short distances. Though LiFi holds promise as a supplement or even potential replacement for traditional WiFi, competing with the widespread and increasingly popular radio-based technology will be a significant challenge.

This subsection synthesizes various experimental studies conducted by other researchers in the field of data transmission through visible light communication (VLC). In [1], the authors outlined the fundamental principles of data transmission via light, focusing on the mechanism of data encoding and decoding, while also experimenting with the transfer of an audio file through the same VLC system. The objective of their project was to create a functional VLC system and demonstrate its data transmission capabilities. In [2], the authors emphasized the increasing scarcity of frequency spectrum, which is a critical resource for telecommunications engineers. Given the exponential growth in wireless communication, optimizing spectrum usage has become imperative, leading to bandwidth depletion in frequently used frequencies. One of the proposed solutions involves using visible light frequencies, which are currently unoccupied, to facilitate data transfer between computers.

The transformative role of light-emitting diodes (LEDs) in indoor wireless communication is explored in [3]. The study highlights how the use of LEDs as transmitters in VLC represents a burgeoning area of research, with substantial commercial potential. In [4], the researchers implemented a VLC system between two personal computers using Arduino microprocessors. Their system successfully transmitted and received up to 18 characters over a short distance of up to 6 cm, demonstrating the viability of VLC for short-range data transmission.

## 2. Tendency of Using VLC

The invention of the first cell phones in the 1980s marked the advent of commercial mobile communications. Over the past 30 years, wireless communication has evolved into an essential component of modern life, now considered a basic utility comparable to gas, electricity, and water. However, the tremendous success of wireless communications, including the rise of visible light communication (VLC), has led to an impending shortage of radio frequency (RF) spectrum. In the coming years, the volume of data transmitted via wireless networks is projected to increase tenfold, while the availability of RF spectrum for allocation remains finite. Despite significant advancements in wireless technology over the past decade, the efficiency of spectrum usage, measured by the number of bits transmitted per Hertz, is approaching its limit. In response, the U.S. Federal Communications Commission (FCC) has issued warnings about a potential spectrum shortfall. In contrast, the visible light spectrum, which is 10,000 times larger than the entire RF spectrum (as depicted in Figure 1), offers the potential for much higher data transmission rates, providing a promising solution to the growing demand for bandwidth [5].

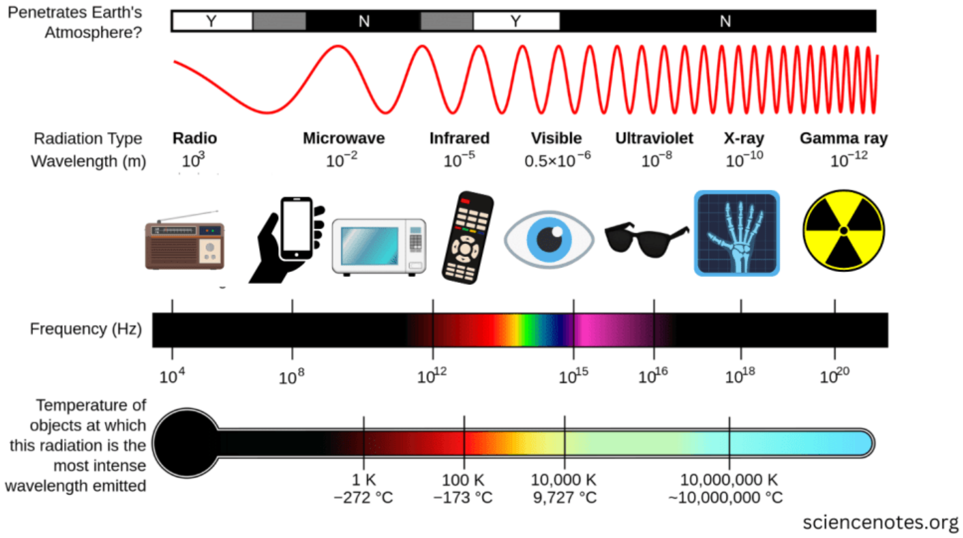


**Figure 1:** The electromagnetic spectrum.

### 3. Free Space Optics

The transmission of modulated visible or infrared (IR) beams through open air to achieve broadband communication is known as free-space optics (FSO), also referred to as free-space photonics (FSP), as illustrated in Figure 2. While laser beams are commonly employed for this purpose, non-lasing sources, such as light-emitting diodes (LEDs) or infrared-emitting diodes (IREDs), can also be utilized. The theoretical foundation of FSO closely mirrors that of fiber optic transmission, with the key difference being that in FSO, the energy beam is not confined by an optical fiber but is instead collimated and transmitted through clear air or space from the source to the destination. If the energy source does not naturally produce a sufficiently long parallel beam, lenses can be used to collimate the light. The data to be transmitted is modulated onto visible or infrared energy at the source [6].

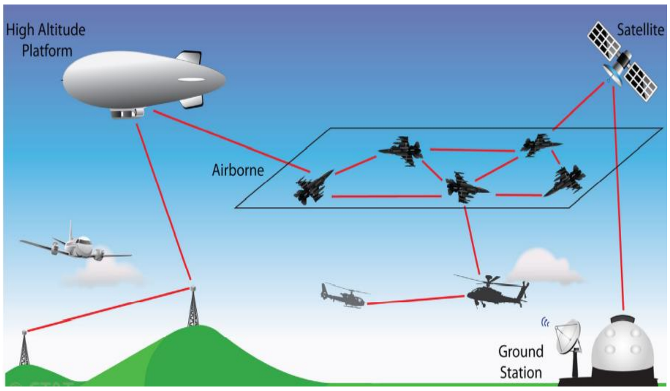


**Figure 2:** Free space optics.

FSO systems are capable of operating over long distances, provided there is a clear line of sight between the source and destination. Even when a direct line of sight is not feasible, strategically positioned mirrors can reflect the energy to the target. These beams exhibit minimal or no attenuation when passing through clean glass windows [6]. Additionally, the narrow nature of the light beam in FSO makes it difficult to intercept, thereby enhancing security. For further protection, data transmitted via FSO can easily be encrypted. Compared to microwave-based systems, FSO demonstrates superior behavior in terms of electromagnetic interference (EMI) resistance [7].

### 4. Text Data Streaming Experiment

In this experiment, a prototype for a Text Data transmitter and receiver was developed to demonstrate the transmission of text data signals. The system setup is depicted in Figure 3, which provides a block diagram outlining the key components and process flow of the Text Data transmission and reception system. This prototype highlights the practical implementation of text-based communication using visible light communication (VLC) principles.

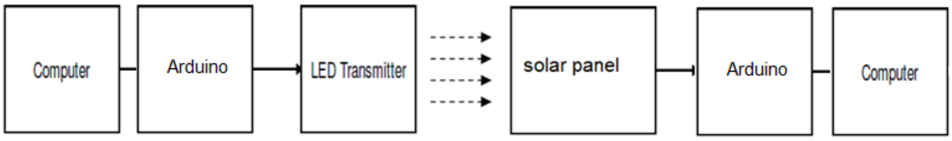


**Figure 3:** Block Diagram of VLC Text Data Transmitter and Receiver

The Figure 3 illustrates a system for transmitting text data using visible light communication. Here's a breakdown of how the system works based on the diagram:

- Computer (Sender): The process begins with a computer that contains the text data to be transmitted. This data is sent to the Arduino board.

- Arduino (Transmitter Side): The Arduino on the transmitting side receives the text data from the computer and processes it. It prepares the data to be sent over the communication system.

- LED Transmitter: The processed data from the Arduino is then passed to an LED transmitter. The LED will modulate light (turn on and off at a rapid speed) to encode the text data into a light signal. This is the core part of visible light communication (VLC).

- Transmission through Space: The modulated light signal is transmitted through free space towards the receiving side. The dashed arrows in the diagram represent the direction of the light signal traveling from the LED to the receiver.

- Solar Panel (Receiver): On the receiving side, a solar panel is used as a light detector. It captures the modulated light signal and converts it back into an electrical signal. Essentially, the solar panel is functioning as a photodetector, sensing the changes in light intensity and converting it to a usable electrical signal.

- Arduino (Receiver Side): The Arduino on the receiver side processes the electrical signal received from the solar panel. It demodulates the signal and converts it back into its original form (text data).

- Computer (Receiver): Finally, the decoded text data is sent from the receiving Arduino to a computer, where it can be displayed or further processed.

In summary, the diagram represents a simple VLC system where text data is transmitted using an LED and detected using a solar panel, with Arduino microcontrollers handling the data processing on both the transmission and reception sides.

**5. Final Prototype Design**

The operating principle of the LED communication system closely resembles that of fiber optic communication links, with the key distinction being that the beam is transmitted through free space rather than through a fiber optic cable. In this setup, a basic LED communication system transmits serial data through the air from the transmitter to the receiver via a modulated LED beam. The complete system is composed of three main components:

- **Transmitter End**: This section includes the source of the data (e.g., a computer) connected to an Arduino microcontroller, which processes and encodes the data. The data is then transmitted via an LED, which modulates light based on the data signal.

- **Receiver End**: On the receiving side, the system captures the modulated light using a photodetector, such as a solar panel, which converts the light back into an electrical signal. An Arduino then decodes this signal and relays the data to the receiving computer.

- **Transmission Medium**: The medium of communication is free space, meaning the modulated light beam travels through the air from the transmitter to the receiver. This medium is highly dependent on the line of sight between the two ends and is free from the physical constraints found in fiber optic systems.

This design demonstrates how serial data can be effectively transmitted wirelessly using visible light, offering a simple yet functional approach to data communication.

**6. Transmitter Circuit Side**

On the transmitter side of the Visible Light Communication (VLC) system, a personal computer (PC 1) serves as the data source. To enable proper functioning of the system, the Arduino IDE software must be installed on PC 1. The Arduino UNO board is connected to PC 1 via a USB cable, acting as the main controller for the data transmission process. The digital pin number 7 of the Arduino is linked to a white LED, which is used to transmit the data through modulated light. The transmission process begins with PC 1, where a string of text is entered through the keyboard. This text is processed by a code written in C language within the Arduino IDE. The code converts the text string into a binary bitstream and defines the Arduino's digital pin 7 as an output. The Arduino then transmits this binary data in the form of light pulses via the connected LED.

The transmitter setup includes both the PC and the Arduino. When text is entered (e.g., "AbCdE"), the Arduino converts each character into its corresponding 8-bit binary representation. Additionally, synchronization and parity bits are appended to the data packet to ensure accurate transmission. The data packet is then transmitted through the LED with precise timing. For example, if the transmitted string is "5," its binary equivalent is 00000101. A high pulse (representing bit 1) will cause the LED to blink on, and a low pulse (representing bit 0) will turn the LED off. In designing the prototype, careful consideration was given to ensure that the LED could handle the required voltage. A simple circuit was created to fulfill the task, and the design is depicted in Figure 4. Additionally, the Arduino was programmed to generate data as a frequency using the "Tone" function, further enhancing the system's performance.

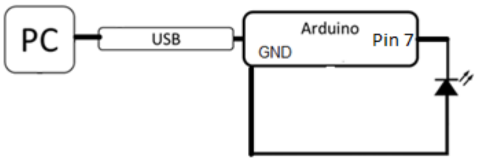


**Figure 4:** Transmitter Module

**7. Receiver Circuit Side**

The receiver circuit consists of three primary components: a small solar panel, an Arduino, and a personal computer (PC) with a monitor. The solar panel serves as the key component for detecting the incoming modulated light signal from the transmitter. When the LED beam carrying the data is directed at the solar panel, the panel converts the light signal into an electrical current. This current is then processed by the connected Arduino (2). The Arduino at the receiver end is programmed to convert the received electrical signals (representing binary data) back into their corresponding alphanumeric characters. These characters are then displayed as the output on the computer monitor, which serves as the final output interface for the system. A simple circuit has been designed to meet the necessary performance requirements for the receiver. The circuit ensures efficient conversion of light signals into digital data for further processing by the Arduino. Figure 5 illustrates the layout and connections of this receiver circuit, providing a clear depiction of how the components are interconnected to achieve successful data reception.

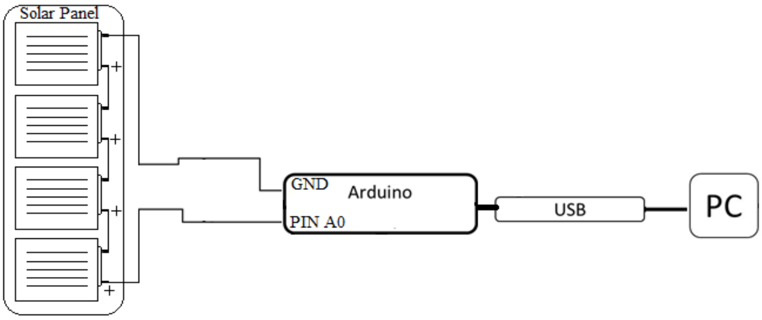


**Figure 5:** Receiver Module

**8. Sender and Receiver Circuit**
The diagrams in Figure 6.a and Figure 6.b depict the architecture of a visible light communication (VLC) system, showcasing both the transmitter and receiver modules, each controlled by an Arduino microcontroller.

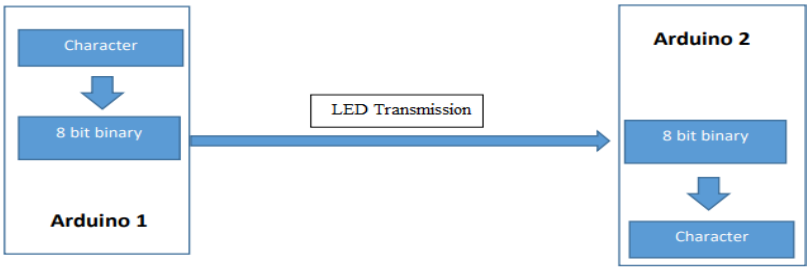


**Figure 6. a**: sender and receiver module

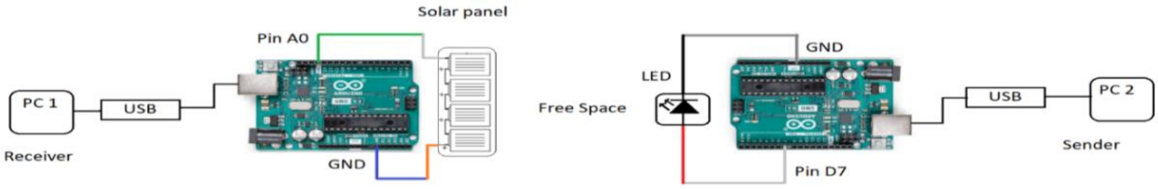


**Figure 6.b:** sender and receiver module

The visible light communication (VLC) system depicted in the diagrams uses Arduino microcontrollers for both transmitting and receiving data. On the transmitter side, a computer sends text data to Arduino 1, which converts it into an 8-bit binary format and transmits it using a modulated LED light. The receiver side consists of a solar panel, Arduino 2, and another computer. The solar panel detects the LED's modulated light, converting it into an electrical signal, which Arduino 2 processes to decode the binary data back into readable text, displayed on the receiving computer. This system demonstrates how VLC can transmit data wirelessly through free space, offering a secure and bandwidth-efficient alternative to radio frequency communication.

**9. Steps for Sending Data Using the Transmission Circuit**
At the transmitting end, Arduino 1 is responsible for converting alphanumeric characters into their corresponding 8-bit ASCII code. The steps to achieve this, with the ASCII code reference provided in Appendix-A, are as follows:

- Input the characters that need to be transmitted.
- Convert the input characters into their respective 8-bit ASCII codes, ensuring that the start bit is set to 1.
- Set a delay of 10 milliseconds between the transmission of two consecutive bits.
- Introduce a delay of 100 milliseconds between the transmission of two consecutive bytes.
- Upload the code to the Arduino to initiate the transmission process.

These steps ensure that the data is properly encoded and transmitted via the LED using visible light communication.

**10. Steps for Receiving Data Using the Receiver Circuit**
At the receiving end, **Arduino 2** is used to receive a byte of data, which is then parsed by the code into its corresponding alphanumeric character. The process can be referenced in the code provided in Appendix-B, and the following steps outline the procedure:

- Start the receiving process.
- Capture and store the received bit stream from the transmission.
- Extract 8 bits for each character from the received bit stream.
- Store the extracted bits in an array for further processing.
- Convert the array of bits into a string format.
- Reverse the string to correct the order of the bits.
- Convert the binary bits into their corresponding ASCII values.
- Translate the ASCII values into their respective alphanumeric characters.
- Store the obtained characters in a new string.

- Display the string on the monitor or other output device.
- Stop the process once data transmission is complete.

These steps ensure the successful reception and decoding of transmitted data from the VLC system.

**11. Data Experiment**

In this experiment, we tested the performance of the VLC system by transmitting varying lengths of character strings over different distances. We began by sending 10 characters and measured the time taken to transmit the string. At each subsequent stage, we added an additional 10 characters, increasing the total to 160 characters. These tests were conducted at distances ranging from 2 cm up to 1 meter, as illustrated in Figure 7 and detailed in Table 1.

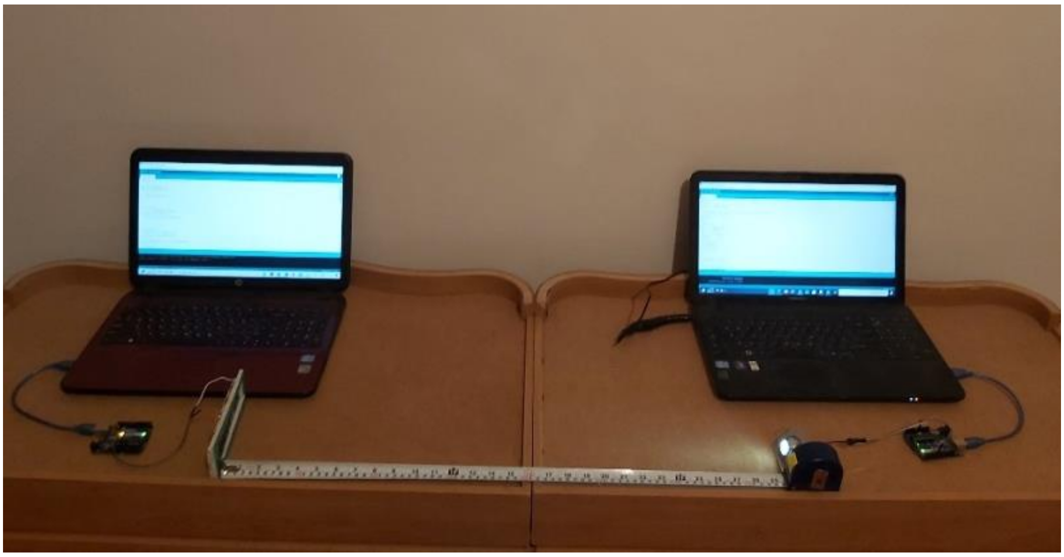

**Figure 7:** distance between sender and receiver is 75 cm.

The experiment aimed to observe how transmission time and accuracy are affected by the increasing length of the character string and the distance between the transmitter and receiver. This analysis provides insights into the system's efficiency and reliability over different distances and data loads.

**Table 1:** The time average of the previous measured distances, this table will be used to calculate the correlation coefficients.

| Char | Avg 2cm | Avg 5cm | Avg 10cm | Avg 25cm | Avg 50cm | Avg 75cm | Avg 100 cm |
|---|---|---|---|---|---|---|---|
| 10 | 948.3333 | 941.6667 | 960.6667 | 962.6667 | 976.3333 | 956.3333 | 948.6667 |
| 20 | 1810.667 | 1805 | 1826 | 1838 | 1811 | 1802.333 | 1807 |
| 30 | 2674.667 | 2659.333 | 2667.333 | 2662.333 | 2657 | 2667 | 2658.333 |
| 40 | 3529.667 | 3525.333 | 3545 | 3528.333 | 3510 | 3505 | 3513 |
| 50 | 4383.667 | 4375.667 | 4366 | 4381 | 4365.333 | 4382.333 | 4376.667 |
| 60 | 5251 | 5218.667 | 5248.667 | 5235.333 | 5253 | 5162.333 | 5244 |
| 70 | 6100.667 | 6059.667 | 6105.667 | 6090.333 | 6081.333 | 6075.333 | 6090 |
| 80 | 6944.667 | 6915.333 | 6959.333 | 6948.333 | 6967.333 | 6956 | 6961.667 |
| 90 | 7779 | 7781.333 | 7787.667 | 7811.333 | 7791.667 | 7819.667 | 7799 |
| 100 | 8646.667 | 8625 | 8669.333 | 8668 | 8636.333 | 8636 | 8651.333 |
| 110 | 9515 | 9510.333 | 9507.333 | 9535 | 9505.333 | 9539.667 | 9515 |
| 120 | 10367 | 10363 | 10351 | 10354.67 | 10374.33 | 10374.67 | 10391.67 |
| 130 | 11196.33 | 11194 | 11206.67 | 11235.67 | 11256 | 11212.67 | 11198.67 |
| 140 | 12068.33 | 12063 | 12043 | 12072.33 | 12092.33 | 12069.33 | 12070.67 |
| 150 | 12887.67 | 12888.33 | 12899.67 | 12919 | 12978.67 | 12915.67 | 12943.33 |
| 160 | 13792 | 13773 | 13756.67 | 13782 | 13782.33 | 13786 | 13802 |

**12. Calculation of Correlation Coefficient**

The correlation coefficient is a statistical metric used to quantify the strength and direction of the relationship between two variables as illustrated in Eq. (1). A positive correlation indicates that the variables move in the same direction, with a correlation value of +1.0 signifying a perfect positive relationship, meaning the variables are in complete sync. Conversely, a negative correlation implies that the variables move in opposite directions. In this case, the correlation coefficient ranges between 0 and -1.0, with -1.0 representing a perfect negative correlation. This measure is useful for determining how changes in one variable correspond to changes in another, providing insights into their relationship. Table 2: shows the final value for every correlation coefficient value between two distances.

$$r = \frac{n(\sum xy)-(\sum x)(\sum y)}{\sqrt{[n\sum x^2-(\sum x)^2][[n\sum x^2-(\sum y)^2)}} \quad (1)$$

**Table 2:** the final value for every correlation coefficient value between two distances

| Distance | Correlation Coefficient |
|---|---|
| 2cm,5cm | 0.999995 |
| 5cm,10cm | 0.99988 |
| 10cm,25cm | 0.999994 |
| 25cm,50cm | 0.99984 |
| 50cm,75cm | 0.99969 |
| 75cm,100cm | 0.99982 |

## 13. Results and Analysis

The experiments conducted yielded highly promising results. The statistical charts, as illustrated in Figure 8, and the corresponding data presented in Table 2, demonstrate the reliability of the system in transmitting and capturing data. The system consistently saved the transmitted data in the program, meeting the objective of the experiment. These results indicate that the VLC system can be effectively used for data communication over varying distances and data loads, confirming the system's potential for reliable data transmission. The analysis supports the conclusion that the system is a feasible and dependable solution for short-range communication using visible light.

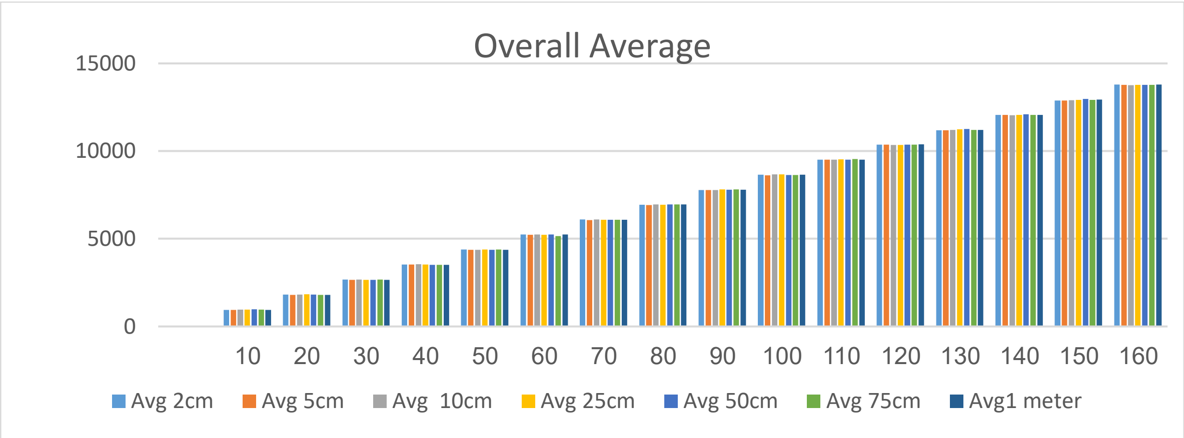


**Figure 8:** Lines coloration between different distance

## 14. Conclusion

In the practical phase of this research, we conducted a series of experiments to validate the reliability of a visible light communication (VLC) system, using correlation coefficient equations to analyze the connection performance. The setup involved transmitting data using two microcontrollers—one acting as the sender and the other as the receiver—while leveraging a Light Emitting Diode (LED) as the transmitting source and a solar panel as the receiving element. The communication was established through a serial data connection, with each character represented by 1 byte (8-bits). These bits were transmitted through the air, bit by bit, in the form of modulated light from the LED. The receiving side, equipped with a solar panel, detected the transmitted light signal and converted it into an electrical signal. This analog signal was processed by the receiver's microcontroller, which converted the electrical pulses back into binary data. The binary data was then reassembled into its original alphanumeric form and stored in a predetermined file location for further analysis. The average transmission time and the number of characters sent in each experiment were carefully measured and analyzed to assess the system's performance over varying distances and data sizes.

The experiments confirmed that the VLC system is a viable method for transmitting data wirelessly, demonstrating both accuracy and speed. The correlation coefficient analysis showed a strong positive relationship between the number of characters transmitted and the transmission time, proving the system's reliability. The results provided practical evidence that optical wireless communication systems using visible light are feasible for data transmission in short-range applications. Furthermore, this research explored the foundational concepts of optical communication technologies, including how visible light can be modulated and used as a medium for transmitting digital data. The system's components, such as LEDs and solar panels, were integrated to demonstrate how VLC systems can be implemented in real-world scenarios. Through this experimental approach, we gained insights into the structure of optical communication systems and their practical applications, showcasing how visible light can serve as an alternative to traditional radio-frequency-based wireless communication systems.

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