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THE EFFECT OF DIFFERENT COLOUR LEDS ON DATA TRANSMISSION

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Abstract:

Visible light communication (VLC) is a communication method where light is utilized as a medium of communication for data transmission. VLC is also regarded as a viable technique for indoor applications, assisting Wi-Fi to handle the spectrum crunch. This study aims to investigate the effect of different LED colours towards the distance and efficiency of data transmission with solar panels as a receiver. The experiment entailed gathering and inspecting components such as Arduino UNOs, solar panels, and LEDs, as well as replacing damaged or poorly kept ones to ensure correct operation and efficient debugging. A program was uploaded to the Arduino UNO boards to handle data transmission, including noise cancellation and ensuring synchronisation. Red, yellow and green LEDs are used as a transmitter light source. The experiment was conducted in a dark room as minimum ambient light noise is required to ensure accurate results. The study concluded that red colour LED could transmit the data at a longer distance than the other two colours but with low efficiency. It shows that light intensity and light sensitivity of the solar panel play a crucial role in data transmission performance.

Keywords:

Visible Light Communication (VLC); Solar Panel; LED Colour

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Introduction

Visible Light Communication (VLC) operates by emitting modulated light from a source, typically a Light Emitting Diode (LED), and receiving it with a photodetector or a similar device (Yu et al.,2021; Karunatilaka et al.,2015; Chavan et al.,2017). Data is processed through data modulation, which converts digital information into electrical signals suitable for controlling the LED. The LED driver uses these modulated signals to vary the light intensity in a way that encodes the data, allowing it to be transmitted to the receiver (Matheus et al.,2019; Wang et al.,2017). This technology was developed to solve the limitations of Radio Frequency (RF) communication, particularly the constrained bandwidth caused by the exponential growth of wireless devices. Rather than replacing RF technology, VLC complements it by addressing its shortcomings while adding unique advantages.

Researchers have extensively explored VLC, primarily focusing on its applications and capability to transmit data efficiently (Rehman et al.,2019; He & Chen, 2023). Other areas of interest include its environmental impact, emphasising its potential to reduce carbon footprints. In addition to environmental benefits, VLC offers several technical and practical advantages: it operates on an unregulated and license-free bandwidth, uses low-cost electronics, avoids RF interference, and poses no known health risks (Gancarz et al.,2013).

Many studies have concentrated on using primary colours (red, green, and blue) (Guzman & Dowhuszko, 2024; Singh, et al.,2023) or white-light LEDs (Salvador et al.,2023) in VLC. However, intermediate wavelengths like yellow light have received limited attention despite their potential significance in optimising data transmission. Moreover, while research on LED colour effects typically emphasises photodetectors as receivers, there is a comparative lack of focus on using solar panels as VLC receivers, particularly in analysing the performance of different LED wavelengths.

In theory, the colour of light affects data transmission performance due to variations in wavelength across the light spectrum. Shorter wavelengths like blue and green often provide higher modulation bandwidth. In comparison, longer wavelengths, such as red and yellow, might offer other benefits, such as better compatibility with solar panel spectral sensitivity (Saadi et al.,2019; Burchardt et al.,2014; Popoola et al.,2016). Therefore, this research aims to investigate the effects of various LED colours (red, yellow, and green) on data transmission performance and their efficiency when paired with solar panels as receivers.

Experimental Setup

This experimental study utilized off-the-shelf devices (Anwar & Srivastava, 2018), consisting of Arduino UNOs, solar panels, and LEDs. These components were meticulously collected and rigorously inspected to ensure their optimal condition prior to the experiment. Any damaged or poorly maintained components were promptly replaced to guarantee the proper functioning and efficiency of the VLC system. This proactive step also simplified debugging by eliminating the potential for faults caused by defective components. Following this, the system was meticulously assembled according to the circuit diagram shown in Figure 1. After assembly, the system underwent rigorous quality control tests to i0dentify and address any connection issues between components, ensuring reliable performance during the experiment. The program was subsequently uploaded to the Arduino UNO boards to provide the necessary functionality for the VLC system. This program managed all the logic involved in data transmission, including mitigating interference from ambient light through noise cancellation

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algorithms. It ensured that both Arduino UNO boards were synchronised during the transmission process. Before transmission, the program converted the input text message into binary numbers based on the ASCII format, preparing the data for modulation and light-based communication. On the receiver side, the binary data was decoded back into its corresponding alphabets or characters to reconstruct the original message accurately. To ensure reliable and precise results, the experiment was conducted in a controlled environment (a dark room) with minimal ambient light interference, reducing noise and enabling accurate measurement of the system's performance (Wang et al., 2024).

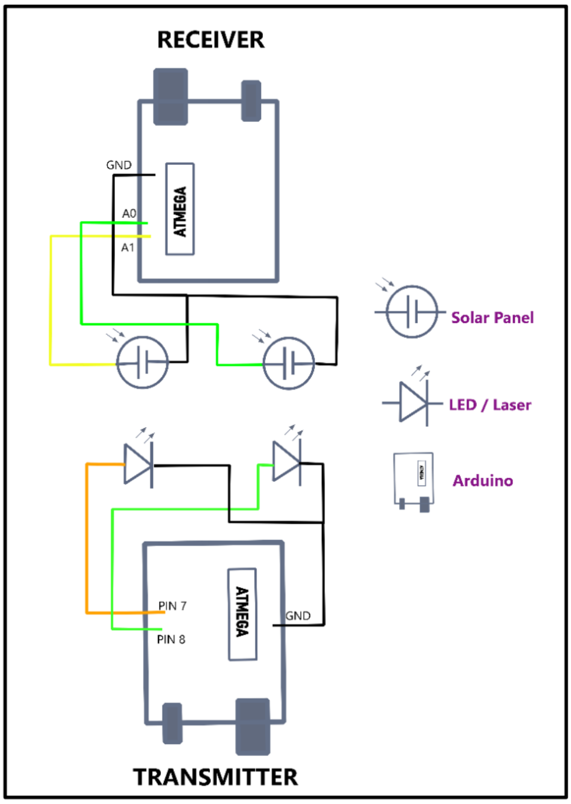

Figure 1: Circuit diagram of the VLC system

Data Measurement

Clock delay is the time required to transmit a single bit of data, measured in milliseconds. It indicates the transmission speed for individual bits when utilising a specific light source. To ensure accurate detection of incoming signals by the receiver, the clock delay was manually adjusted before and during the experiment. Adjustments were made as the distance between the transmitter and receiver increased, measured in centimetres, and when different light sources were employed. Similarly, transmission duration represents the total time needed to transmit an entire text message from the transmitter to the receiver, measured in seconds. The message "Hello World" was consistently used as the test message to maintain experimental uniformity. The receiver recorded the transmission duration by measuring the time at the start and end of the transmission process. This metric was systematically documented for varying distances between the transmitter and receiver and each light source tested. The code used to perform these two measurements is presented in Figure 2 and 3.

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```
//Transmitter
int DATAPIN = 8;
int CLOCKPIN = 7;
int tick = 50; //tick - 1- led     <---------------CLOCK DELAY
//unsigned int tick = 1000; //Laser 800
String message;

```

Figure 2: Coding for Clock Delay

```
}else{
  unsigned long fTime = millis();
  //Serial.print("Final Time: ");
  //Serial.println(fTime);
  double timePassed = (fTime - initTime)/1000.00;  // <-------- Handles the transmission duration
  Serial.print("Runtime: ");
  Serial.println(timePassed);
   isTimeSet = false;
}
```

Figure 3: Coding for Transmission Duration

Result And Discussion

Figure 4 illustrates that the red LED achieves the most significant transmission distance compared to the yellow and green LEDs. As shown in Table 1, the red LED can transmit data up to a maximum distance of 305 cm, whereas the yellow and green LEDs reach maximum distances of 175 cm and 55 cm, respectively. This variation in transmission distance can be attributed to differences in light intensity and the wavelength-specific sensitivity of the solar panel. According to a study by Bagher et al. (2015), a solar cell's performance and light-detecting capability are determined by the materials used in its construction, which influence its sensitivity to various wavelengths. Furthermore, Ogherohwo et al. (2015) discovered that solar panels detect red light better than yellow or green light. Furthermore, discrepancies in transmission distance may be caused by variations in light speed as it travels through a material, such as air.

Table 1: Summary Data Collection for Three Different Colour LED

LED Colour	Maximum Distance (cm)	Clock Delay (ms)	Duration (s)
Green	55	30	9.3
Yellow	175	45	13.9
Red	305	50	15.4

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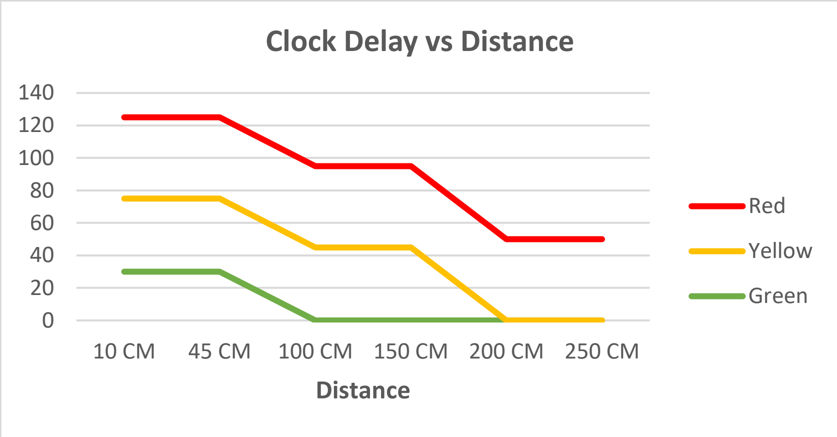

Figure 4: Clock Delay vs Distance

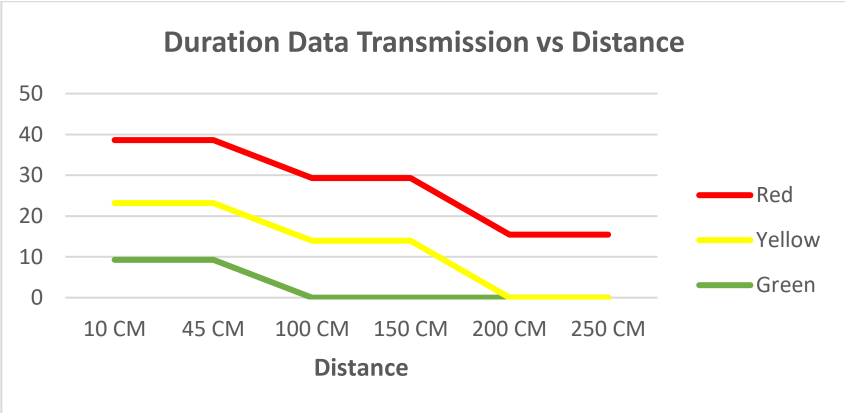

Figure 5: Duration Data Transmission vs Distance

Based on Equation 1, the longer the wavelength of the light spectrum, the faster the light travels through a medium such as air. This occurs because longer wavelengths, such as red light, experience less scattering and diffraction than shorter wavelengths, like yellow and green light (Chang et al.,2012; Flammer et al.,2013). As a result, the degree of light refraction decreases as the wavelength increases, allowing red light to maintain its intensity and coherence over greater distances. Consequently, red light retains its intensity and coherence over greater distances, enabling the red LED to achieve a longer transmission range. Additionally, the spectral sensitivity of solar panels further amplifies this effect, as red light falls within a range that is more efficiently detected by many solar cells, enhancing the overall transmission capability (Khaleda et al.,2021).

$$v = f\lambda \qquad \text{(Eq. 1)}$$

Further, clock delay is another critical parameter influenced by the properties of light. For the tested LEDs, the clock delays were 50 ms for red, 45 ms for yellow, and 30 ms for green, with these delays remaining constant. Based on Figure 5, the green LED transmitted the "Hello World" text message in the shortest amount of time (9.27 s), followed by the yellow LED (13.9 s) and the red LED (15.44 s). Importantly, the time taken to transmit data was not affected by the transmission distance but rather by the inherent properties of each LED and its emitted light. Light intensity also plays a vital role in determining the transmission range and the clock delay. According to the inverse square law, light intensity decreases as the distance from the source increases, reducing the energy delivered to the solar panel (Voudoukis & Oikonomidis,2017). This, combined with the inherent spectral sensitivity of the solar panel, results in green light having the shortest transmission distance. Equation 2 highlights the direct proportionality between photon energy and the frequency of light (Manojlović et al.,2020). This means that light with higher frequencies (shorter wavelengths) produces more tremendous photon energy, which reduces clock delay. Consequently, with their shorter wavelengths and higher frequencies, green LEDs exhibit lower clock delays compared to yellow and red LEDs.

$$E = hf \tag{Eq. 2}$$

Furthermore, light intensity also influences clock delay, defined as the energy of photons passing through a unit area per unit time. Higher light intensity leads to lower minimum clock delays required for data transmission. A combination of shorter wavelengths and higher light intensity results in faster data transmission. Thus, while green LEDs have the shortest transmission range due to lower light intensity at a distance, their shorter wavelength and higher frequency contribute to a reduced clock delay, enabling faster transmission of individual bits compared to yellow and red LEDs.

Conclusion

The performance of Visible Light Communication (VLC) systems is significantly influenced by the properties of the light source, including wavelength, intensity, and frequency. Among the tested LEDs, the red LED demonstrated the greatest transmission range (305 cm) due to its longer wavelength, which minimizes scattering and diffraction, and its better compatibility with the spectral sensitivity of solar panels. However, the green LED exhibited the shortest clock delay (30 ms) and fastest data transmission time (9.27 s for the “Hello World” message), attributed to its shorter wavelength, higher frequency, and greater photon energy, which enhances the efficiency of transmitting individual bits. The results highlight a trade-off between transmission distance and transmission speed, governed by the interplay of light intensity, wavelength-specific solar panel sensitivity, and the inverse square law. While the red LED is optimal for long-distance transmission, the green LED is more suitable for high-speed communication over shorter distances. These findings emphasize the importance of selecting LED colours based on application requirements, balancing transmission range and efficiency, and optimizing VLC system performance for specific use cases.

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