PARALLEL DATA TRANSMISSION USING MULTIPLE LDRS VIA VISIBLE LIGHT

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ABSTRACT

With the increasing number of objects connected in this Internet of Things era, the speed at which data is transferred is of utmost importance. With Light-Fidelity (Li-Fi), the rapid data transmission is due to the bit streams communication through high-speed flickering of a Light Emitting Diode (LED) bulb, occurring in ‘0’ and ‘1’ states. Thus, data is transferred at higher capacity but it is known that Li-Fi has limited distance capacity compared to Wi-Fi. Therefore, the aim of this paper investigates on parallel data transmission by making use of a combination of several LEDs and Light Dependent Resistors (LDRs). Audio as well as texts are used in different setups in order to check the effectiveness and efficiency of the parallel data transmission. Interestingly, results obtained showed that there is an increase of distance and data rate in both audio and text in such setups.

Keywords: *Li-Fi, LED, LDR, Arduino Uno, Audio Transmission, Text transmission, Parallel text transmission*

INTRODUCTION

With the advent of internet of things, research is focused towards reliable means for objects to communicate among themselves, instantly, reliably and securely (REF). As an alternative means to the exponentially increasing wireless traffic demand in Wi-Fi (Pawar, 2018; Vinnarasi, 2017), Light-Fidelity (Li-Fi) is promising (REF) means of communication. Li-Fi refers to light based communications technology which delivers a high-speed, bidirectional networked mobile communication, using light from LEDs as a communication medium (Hase, 2016). Li-Fi is offering a new era in wireless communication technology (Ekta, 2014) as its frequency is about 400 times greater than the Radio Frequency (RF), meaning that the data rate is higher in Li-Fi (Revathi, 2018). It also provides security as the Visible Light is unable to penetrate through the walls. Even though Li-Fi can be applied in various fields such as medical and healthcare, airlines and aviation, underwater explorations and communications, traffic, and has many advantages such as capacity, efficiency, availability and security, it however, demonstrates a number of limitations among which is data rate and transmission distance, and research is still underway on wireless system concepts (Kumawat, 2017).

Harald Haas’ group with researchers from Universities of Oxford, Cambridge, Strathclyde and St. Andrews, have researched on ultra-parallel Visible Light Communication (VLC), which make use of multiple colors to offer high-bandwidth linking over few meters (Sarkar, 2015). Furthermore, the Li-Fi Consortium recently demonstrated the use of red, green and blue LEDs as both emitters and photodiodes to detect light and achieved a rate of 155 Mbps with unidirectional transmission. In addition to this, a Mexican company Sisoft and researchers from the Autonomous Technological Institute of Mexico (ITAM) have achieved a transmission rate of 10 Gbps using LED lamps. More recently, researcher at the University of Oxford achieved bi-directional speeds of 224 Gbps, using specialized broadcast LEDs and receivers (Kumar, 2018).

Due to a lack of ways to increase the data transmission per second (Ekta, 2014), techniques need to be devised to provide an alternative way for better and reliable way for communication. Therefore, the aim of this paper focuses on the testing the impact of serial and parallel data transmission using Visible Light. The use of a single LED as transmitter and two LDRs at different distances from the transmitter is setup to achieve parallel text transmission.

LITERATURE REVIEW

With the aim of researching ways for transmitting parallel data using multiple LDRs via visible light, the literature review depicts that the main research conducted in Li-Fi, discusses on serial data transmission. Most of the papers, refer to different types of LEDs (Light Emitting Diodes) such as white and RGB (Red, Green, Blue), given its operating speed is less than 1 microsecond, thereby causing the light source to appear to be continuously on, enabling data transmission using binary codes (Sarkar, 2015). A. Khalid *et al*., (Khalid, 2012) used a phosphorescent white LED modulated by a DMT signal, demonstrating a VLC system achieving up to 1 Gb/s transmission rate while a 640 Mb/s transmission rate was obtained at a very low illuminance level of 10 lx. Ahmad Helmi Azhar *et al*., (Azhar, 2013) also made use of white LED sources, implementing a system consisting of a four-channel multiple input/output link, each transmitting signals at 250 Mb/s, achieving up to 1 Gb/s transmission rate. Giulio Cossu *et al*., (Cossu, 2013) used a single chip blue-phosphor LED achieving a transmission rate of 513 Mb/s at 1000 lux. A. Vinnarasi *et al*., (Vinnarasi, 2017) have not only made use of white LEDs, but also 10 mm LEDs under varying mediums such as plastic, water, glass and air achieving a maximum range of 50 cm, 50cm, 90 cm and 200 cm respectively.

Apart from white LED, other researchers have investigated on RGB LED and they achieved a far greater data rate using this type of LED. A. M. Khalid *et al*., (Khalid, 2012) adopted a DMT modulation based on an optimum bit-power loading allocation for optical wireless transmission based on a commercial RGB LED. They achieved 1.5 Gb/s transmission capacity in the single channel operation and 3.4 Gb/s transmission capacity in WDM operation. These results were achieved at brightness level of 410 lx. Further improvements may be expected by a suitable choice of the amplifier bandwidth (280 MHz instead of 130 MHz) and overcoming the focusing problem by increasing the distance between transmitter and receiver using several LEDs. Yiguang Wang *et al*., (Wang, 2015) experimentally demonstrated a high-speed RGB-LED based WDM VLC system employing CAP modulation and RLS based adaptive equalization. An aggregate data rate of 4.5 Gb/s was successfully achieved over 1.5 m indoor free space transmission. The RGB solution is more preferable than phosphorous-based white LED to improve the data rate, since, the slow response of the phosphors limit the modulation bandwidth whereas the power efficiency is reduced if combined with blue filter in order to reject the phosphorescent components (Cossu, 2013).

In visible light communication, a light detector is used as a receiver to detect pulsed light from LEDs to increase the signal-to-noise ratio, allowing a better definition of absorption peaks and bands (Rakesh, 2017). Researchers who have conducted their experiment by using LDR as their main light detector, concluded that it is the first choice in the construction of cheap homemade pulsed light spectroscopy systems and achieved a low bit error rate (BER). Derci Felix da Silva et al., (Silva, 2006) analyzed the use of a LDR and an electret microphone as a light sensor in an optical spectroscopy system using pulsed light. The results obtained showed that LDR could be used as a sensor of pulsed light in optical spectroscopy devices and the use of pulsed light (He-Ne laser) and lock-in amplifiers increases the signal-to-noise ratio, allowing a better definition of absorption peaks and bands. Amit Jaykumar Chinchawade *et al*., (Chinchawade, 2016) used voice as an input signal, a microphone to convert the signal to an electrical signal, which is then amplified and fed into a power LED, for audio transmission for a home/office automation system. The audio signals were successfully transmitted without any signal loss and the sound clarity was clear and the sound was loud. Wen-Yi Lin et al., (Lin, 2012) demonstrated a Wavelength-division multiplexing (WDM) Visible Light Communication (VLC) system employing red and green laser pointers with the assistance of preamplifier and adaptive filter, achieving a low bit error rate (BER) of 10m/500Mbps for each wavelength.

To allow digital data to be sent to a transmitting/receiving module, most papers have used microcontrollers. Himank Kumawat *et al*., (Kumawat, 2017) used a PIC16F877A, a CMOS flash-based 8-bit microcontroller to control an Audio Playback Recorder to achieve audio transmission within the range of about 15-20 m. However, the only drawback of this system is that it works on line of sight, but if more research is done in this field and this technology is put into full- fledged practical usage, every LED can be used like a Wi-Fi hotspot. Another paper by Kosuri Siva *et al*., (Kosuri, 2017) have also used the same model of microcontroller, along with a Universal Asynchronous Receiver Transmitter (UART) which provides serial data to a dual transmitter/receiver, Max232, from where it is sent to the microcontroller where serial data is framed and fed to a VLC transmitter end circuit. They achieved a maximum distance of 4 meters between the transmitter and receiver, and believed that the distance can be increased by using high capacity LEDs. Revathi *et al*., (Revathi, 2018) have also made use of the same model of microcontroller at receiving side where serial data from a UART converter is sent to an audio amplifier and then received by the speaker. As data transmission is done through LEDs, all screens which illuminate light can be served as a platform for data communication and be used in diverse fields.

To increase the strength (amplitude) of audio signals, researchers have used audio amplifiers in order to achieve a higher length communication. S. Poorna Pushkala *et al*., (Pushkala, 2017) have used an audio amplifier whereby the output signal from the amplifier is given to the speaker. The input audio signal transmitted is obtained as output in the speaker. The waveform diagrams of the corresponding input and output audio signals using MATLAB were plotted, to prove that the signal sent and received are almost the same. Based on their observations and the graphical results obtained, they concluded that the transfer of data and audio without the use of microcontrollers is much more efficient and powerful. Another paper by Himank Kumawat *et al.*, (Kumawat, 2017) used an audio amplifier IC TDA7052, to achieve a gain of approximately 40 dB. Additionally, Amit Jaykumar Chinchawade *etal*., (Chinchawade, 2016) have also made use of an audio power amplifier which amplifies low-power audio signals from audio jack or MIC. They have obtained a maximum length communication of 2 meters between transmitter and receiver and a maximum audio output of 85 to 95 dB from loudspeaker, without any signal loss. They concluded that this technology will be implemented for industrial equipment controls, internet communication and patient monitoring systems in the future.

To increase the VLC data rate, parallel data transmission which is still in its incipient stages, was implemented by few researchers, where separate streams of data were sent simultaneously. Xilu Yang *et al*., (Yang, 2017) demonstrated a design of ultra-thin optical sheets for parallel data transmission in the space dimension using flat optical components. The optical sheets are based on patterned quarter-wave stacks of 1D photonic crystals, and possess the property of angular selectivity by using a generalized Brewster angle. The Field of View (FoV) were able to reach down to 4° or less, and the cone-shape hexagonal array of the stacks were able to achieve a true unidirectional detection. Another paper by Asif Jilani Sheikh *et al*., (Jilani, 2018) successfully transferred text from PC to PC serially using a single LED and a phototransistor L14G2, MATLAB (R2017b) and Arduino Uno with no bit errors over a maximum transmission distance of two feet whereas for parallel text transmission, two LEDs and two phototransistors were used, achieving a maximum distance of 2-3 cm, and the error increases as the distance increases. Furthermore, Safawn Hafeedh Younus *et al*., (Younus, 2018) presented an indoor visible light communication (VLC) system in conjunction with an imaging receiver with parallel data transmission (spatial multiplexing) to reduce the effects of the inter-symbol interference (ISI). They achieved an aggregate data rate of 8 Gb/s with a bit error rate of 10^{-6} for each light unit, using simple on-off-keying (OOK). Additionally, Shuailong Zhang *et al*., (Zhang, 2012) demonstrated a multiple-channel visible light communication system which were realized through a CMOS-controlled micro LED array. Four typical micro LED pixels were modulated simultaneously with an array of custom complementary metal-oxide-semiconductor (CMOS) driver to achieve a total data transmission rate of 1.5 Gb/s.

IMPLEMENTATION AND RESULTS

As methodology, in order to experiment on parallel data transmission, a combination of LEDs, Light Dependent Resistors, amplifiers, Arduino were used to test how fast and reliable data transmission can be. Different setups were used to demonstrate and behaviour of audio and sound.

Audio Transmission in serial

To demonstrate parallel data transmission, as shown in Fig. 1, a Digital to Analog Converter (DAC) enabled audio device was used. To modulate the data by an analog signal transmitter (LED), a 220 Ohms resistor, a 12V battery and a 3.5 mm auxiliary cable were used at the transmitter side, to send the audio signal to the receiver side. At the receiver side, an analog signal receiver (solar panel) and an amplified speaker were used, to output the audio signal, as shown below in Figure 2.

Different colored LEDs were used to test the reliability and the data transmission. Distances of 0 to 40 cm were used

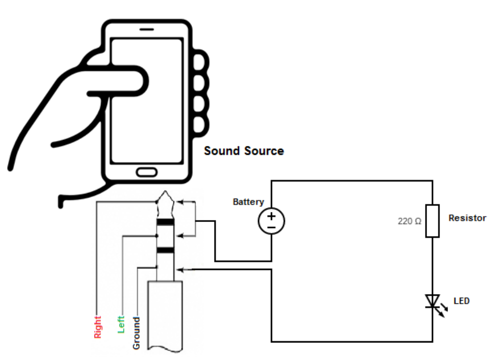


Figure 1: Audio Transmitter

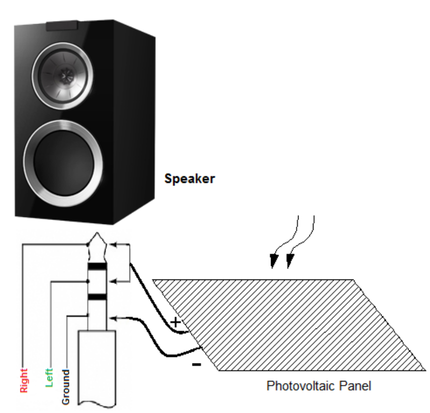


Figure 2: Audio Receiver

as shown in the table 1 below. The table also shows the results obtained when different LED colors were experimented by varying the distance between the LED and the solar panel. Two types of data were collected and recorded namely the sound level in decibel (dB)andtheoutputvoltage(V)oftwodifferenttypesofsolarpanel, a 4V and a12V.

Results

Experiment No.	LED color	Distance (cm)	Sound Level (dB)	S.Panel 12V (V)	Sound Level (dB)	S.Panel 4V (V)
1	White (10mm)	40	68.5	0.19	67.5	1.05
		30	70.5	0.28	70.5	1.31
		20	71.5	0.55	70.5	1.28
		10	71.5	0.57	70	1.11
		0	68.5	0.36	66.5	0.84
2	White (13mm)	40	68.5	0.24	66.5	0.82
		30	69.5	0.35	70.5	1.07
		20	71.5	0.54	70.5	1.26
		10	70.5	0.49	69.5	1.19
		0	68.5	0.34	67.5	0.8
3	Red (10mm)	40	67.5	0.25	66.5	0.75
		30	68.5	0.36	68.5	0.86
		20	69.5	0.47	68.5	0.99
		10	69.5	0.42	68.5	0.92
		0	66.5	0.18	65.5	0.11
4	Red (13mm)	40	67.5	0.25	66.5	1.19
		30	69.5	0.35	70.5	1.27
		20	70.5	0.49	69.5	1.2
		10	69.5	0.36	68.5	0.93
		0	68.5	0.34	67.5	0.9
5	Blue (10mm)	40	68.5	0.3	67.5	0.78
		30	69.5	0.37	68.5	0.85
		20	71.5	0.55	70.5	1.29
		10	72.5	0.62	72.5	1.32
		0	70.5	0.51	70.5	0.94
6	Blue (13mm)	40	70.5	0.66	68.5	3.11
		30	72.5	0.78	71.5	3.28
		20	73.5	0.88	72.5	3.57
		10	70.5	0.55	70.5	2.97
		0	67	0.26	67.5	0.41
7	Yellow (10mm)	40	60.5	0.02	60	0.07
		30	61.5	0.05	60.5	0.11
		20	62.5	0.06	62.5	0.14
		10	63.5	0.07	62.5	0.16
		0	61.5	0.04	60	0.09
8	Yellow (13mm)	40	59.5	0.03	58.5	0.1
		30	59.5	0.05	59.5	0.1
		20	60.5	0.06	60.5	0.15
		10	61.5	0.05	60.5	0.1
		0	62.5	0.05	62.5	0.1

Table 1: Table of Distance vs. Sound Level and Voltage

As the distance between the LED and solar panel increases, the sound level decreases. This is indeed expected as the increase in distance decreases the intensity of light from the LED that is incident on the solar panel. However, a higher sound level of 72.5 dB has been observed with the 12V solar panel and the 10 mm blue LED within a maximum distance of 40 cm, compared to 95 Db within a maximum distance of 200 cm obtained in (Vinnarasi, 2017).

Hence, from the results obtained, it was observed that there is a variation in the maximum distance that each colour of LEDs can achieve and the most effective LED in terms of maximum distance of transmission was found to be the Blue one.

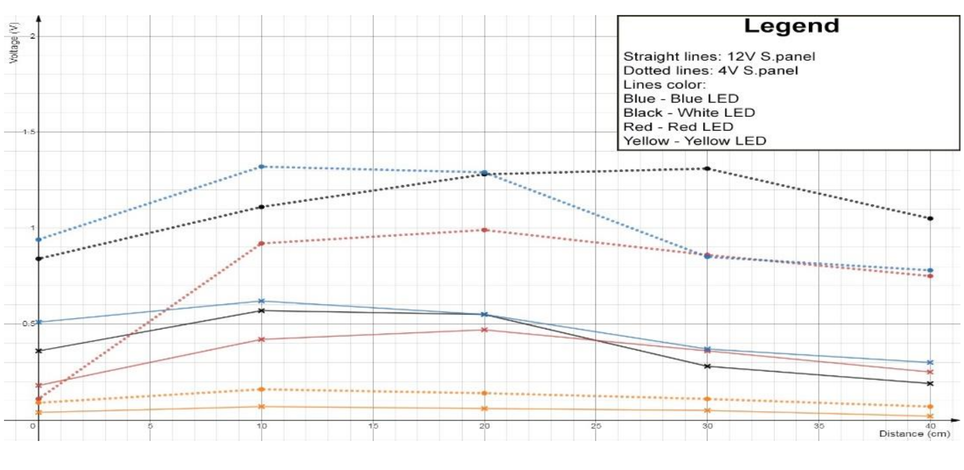


Figure 3: Graph of Voltage vs. Distance

The graph above was plotted and a higher voltage has been achieved within a short range of 0 to 10 cm with the blue LED. However, itis dominated by the white led for a longer range of 20 to 40 cm. Also, the optimum voltage of 1.3 V was recorded at 10 cm, compared to 3.6 V at a distance of 10 cm in (Kumar, 2018).

The lowest recorded values were that of the yellow light which can be explained by the yellowish nature of sunlight when it bounces on the walls of the room in which the experiment was carried out. The yellow light from the LED gets faded by the sunlight and hence it does not project onto the solar panel like the other three colors. However, the base voltages obtained with the 4V solar panel is higher than with the 12V one. This is due to the larger surface area of the 4V solar panel since more photocells is available for light capturing.

Text Transmission

For this experiment, text transmission was implemented using two Arduino Boards, a PC, a USB cable and five LEDs were used at the transmitter side to enable texts to be sent in the form of pulses, as shown below in Figure 4. The concept behind this text transmission is that the transmitter (Arduino Uno) converts individual text characters into a respective set of “1” and “0” array which represents the identity of that character and each LED is responsible for the transmission of a group if alphabetical characters. When the text is being emitted through the LED, the “1” represents the LED in its “ON” state, and the “0” is its “OFF” state, hence creating a pulsing like behavior of the LED transmitters.

At the receiver side, a breadboard, two Arduino boards, five LDRs, five resistors and a PC were used, to decodetheimpulsesreceivedtoreconstructthereceivedbinaryinformation, as shown below in Figure 5.

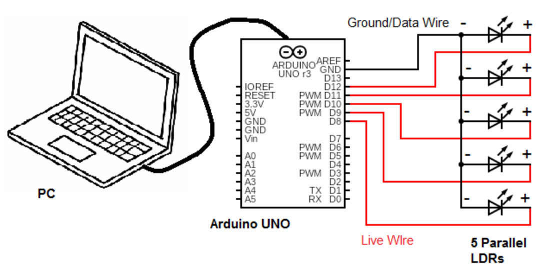


Figure 4: Text Transmitter

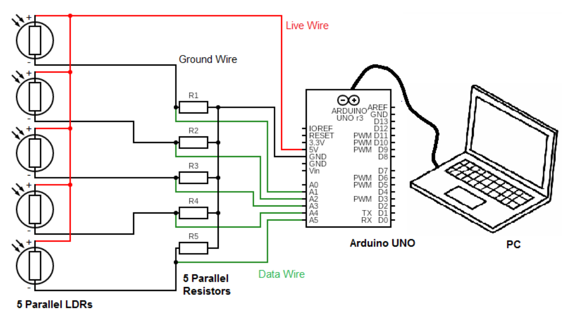


Figure 5: Text Receiver

As result, at transmitter side, at one instance, a “good morning” text was entered and sent successfully to the receiving side. However, at the receiving side, a “good forning” text was obtained, as shown in Figure 6. Hence, the transmission was not error-free. The transmission was tested with other text such as “hello”, “testing” and “good morning” those were successfully transmitted. Thus the reason for the error in the first “good morning” being interpreted at the receiver as “good forning” is due to external light contamination at the receiver hence causing the algorithm in the Arduino to interpret the “m” character in “morning” as an “f” character.

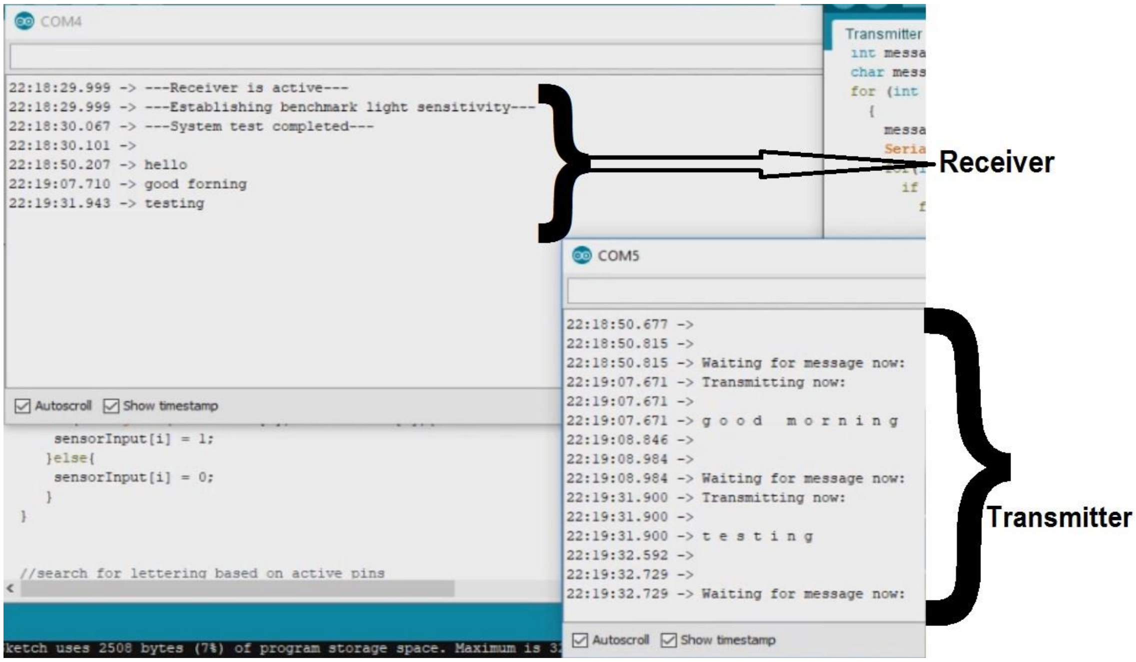
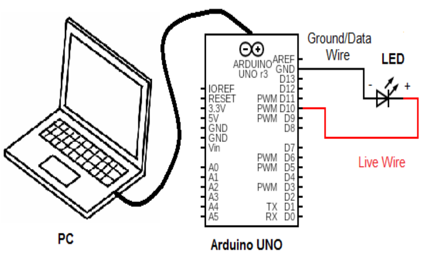


Figure 6: Transmitted text

Parallel Text Transmission

For this experiment,thesamerequirementswererequiredforthetransmissionofthetextinformation via Visible Light. However, in order to demonstrate the parallel transmission of the data, a single LED is required for the transmitter while two photosensitive sensors will act as the dual data receivers, as shown below in Figures 7 and 8.

Figure 7: Text Transmitter



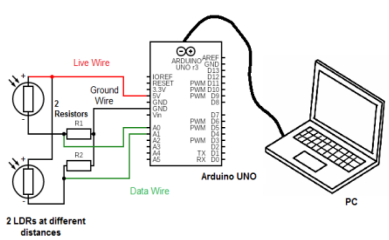


Figure 8: Parallel Text Receiver

Results

Distance (cm)	Sensor Value
Room light (Control)	15
0	810
5	440
10	275
15	170
20	125
25	90
30	60
35	50
40	30
45	20

Table 2: Table of Distance vs. Sensor Value

At a distance of 0 cm, that is when the LED is put into contact with the LDR, the sensor value that is read from the Arduino is 810, representing the maximum value obtainable from the LED. As the distance between the LED and the LDR approaches 45 cm, the sensor value nears the 15 obtained from the Room light control, hence making further distances readings not very accurate as it can get affected by the ambient light. Also, the optimum sensor value obtained was 440 at a distance of 5 cm.

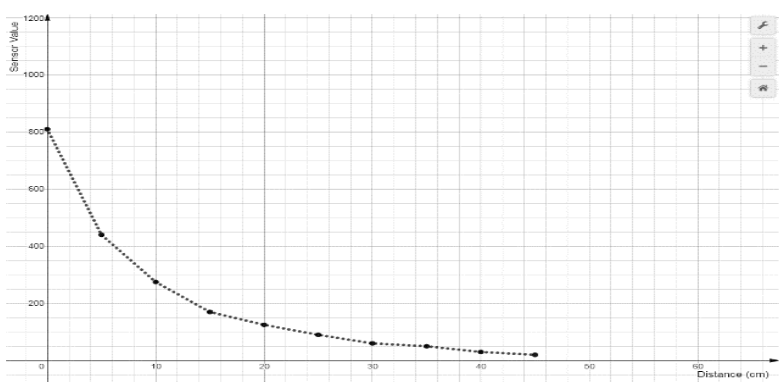


Figure 9: Graph of Sensor Value vs. Distance

The graph below shows the relationship of the sensor value of an LDR with an increasing distance, and a decrease in the sensor value which can be compared as the light intensity that is incident on the LDR, as shown in Figure 9. Interestingly, the maximum distance obtained in parallel data transmission in (Jilani, 2018) is 2-3 cm, while we obtained a maximum distance of 45 cm. Further than this, data transmission reliability can become an issue due to its proximity to the control sensor value. That is, if the distance is increased further, the sensor value will remain the same as the control as the LED light incident on the sensor is lower in intensity than the ambient light.

While a single LDR can receive this range of data according to the sensor value range, making use of two LDRs is able to receive twice the amount of data within the same timeframe. Since the amount of data received is doubled, the amount of characters received can be said to increase by a factor of two.

CONCLUSION

Parallel data transmission using LDR has been found to have an increase in data rate. The results obtained from the graphs of Voltage, Decibel and Sensor Value against distance matches that of what havedone.However,theexperimentweperformedwithdifferentLEDcolorsdiffersfromwhat(Kumar, 2018) have obtained in which they mentioned that no change in intensity were observed with different LED colors. A drawback of this system is that the receiver must be in the line of sight for successful retrieval of bits.

Observations

1. The closer the LED is to the Solar Panel, the less is the Intensity, dB (decibel) and the further the LEDfromtheSolarPanel,thelessisthedB.However,thereexistsanoptimumdistancerangebetween 20 cm to 25 cm within which the highest was recorded.
2. Mirrors can be used to increase the range of data transmission. However, the distance between the LED and mirror has to be adjusted when the distance between them and the solar panel is varied so as to obtain a focus.
3. External light such as sunlight, 'room light' affects the sound quality and noise can be heard due to these lights.
4. The LED color is a factor in the quality of transmitted sound.
5. Multiple LDR can be used to allow parallel data transmission.

Future Scope

1. Use of more LDRs with different ranges for parallel data transmission, instead of varying distance.
2. LDR sizes can be reduced to accommodate them into arrays for parallel data transmission and make its use in IoT (Internet of Things) even more prominent.
3. The transmission distance can be further increased by using more powerful LED source.

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