Li-Fi Transmission and Reception in Visible and IR Light in a Hospital Environment

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Li-Fi (Light Fidelity) is an important green technology being sought after these days. It is used in environments where Wi-Fi is a constraint, for example in hospitals, airplanes, schools, security installations, etc and areas where higher bandwidth and faster data speeds are required since Wi-Fi signals may interfere destructively with the existing signals generated by these environments. Li-Fi provides security by obeying the principle of the line of sight (LoS) and prevents the signals from leaking out of the room, hence preventing eavesdropping. The Li-Fi technique without modifications for optical communication, degrades and disables the transmitting signal to navigate far within the room. Various factors can be enhanced and adapted to improve the overall efficiency and efficacy, such as modulation, LED and Photodiode arrays in a particular geometrical pattern, alignment and synchronization, optical filters, and lenses to guide the transmitting signal onto the receiver for optimal output response. The paper proposes the improvement of Li-Fi transmission range using modulation techniques in an indoor environment. The authors have demonstrated experimentally, how the LED transmission of signal data through Li-Fi link is improved by implementing a simple OOK modulation. We have also demonstrated the transmission of the data packet of the patients by performing OOK with PWM modulation for transmission and sending a flicker free and constant light current. By doing this the transmission range was improved to 3mtrs, which is Quite acceptable.

Keywords: Light Fidelity (Li-Fi), Wireless Fidelity (Wi-Fi), Visible Light Communication (VLC), IR LED, Field of View (FoV), Line of sight (LoS).

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1 Introduction

The generation in which we are, cannot even be imagined, without possessing smart devices. Almost all these smart devices in some way or the other will have the data connected to the cloud, say may be through IoT's. Hence, it is the need of the hour to have high data speeds for transmission and reception to provide high-speed internet and network interconnectivity. Currently, for the Wi-Fi technology, the natural frequency spectrum that the Wi-Fi technology uses is exhausted, which means a spectrum crunch has taken place. Hence, we need to have a technology in place in which the communication system has an in exhaustive frequency spectrum or a spectrum larger than that of the Wi-Fi spectrum. Thus, the Li-Fi communication spectrum comes into play since it uses a frequency spectrum of 400 to 950 THz, which spans from visible light to IR light. Li-Fi supports multi-user access as well as provides user mobility. The Li-Fi system has a number of benefits such as a high level of security, high immunity to radio frequency destructive interference and has a lower price to pay since Li-Fi provides both illumination and communication as compared to using LED lights only for illumination. But, the LED's modulation bandwidth is not sufficient for the different wireless communication systems [1]. Currently, the LED's market share growth has been rising steadily. According to the analysis report of the LED market, which was released by the Chinese Industry research network, it was found that in 2014, India's growth in the usage of LED's for lighting and LED based systems is increasing very rapidly and almost to about 38% as compared to the world [2]. Presently, the world has also increased the usage of LED's in automobiles for lighting, in hospitals, aircrafts, wearable devices, light communications, smart lighting in houses, buildings, streets and cities. In the future, a huge number of mobile devices and network connections would be added to the global network. Thus, it is very important to ensure that the frequency spectrum is optimally utilized to support high-speed transmissions and receptions. Hence, Li-Fi technology serves as a saviour to this spectrum crunch in our existing network technology.

1.1 Modulation

The modulation bandwidth of a white LED is 3 MHz to 180 MHz hence, we have to design our modulation driver circuits appropriately based on the bandwidth limitations [1],[2]. There are three LED modulation schemes such as single Carrier Modulation (SCM), Multi-Carrier Modulation (MCM) and Color domain-based modulation (CBM). The output of these modulation schemes are often compared and measured in terms of selected VLC parameters namely Dimming factor, Bit Error Rate (BER), Signal to Noise Ratio (SNR), Optical Power requirement, Bandwidth efficiency and Data rate.

Single Carrier Modulation

Single Carrier Modulation employs only positive and real data signals to be transmitted to realize an IM/DD (Intensity-modulated/Direct detection) system [3][4][5]. So, the modulation techniques used here are OOK, PWM, PPM. Since the bandwidth of the LED's and the optical channel are limited, we require to employ multilevel schemes to achieve a higher throughput such as the Unipolar Pulse Amplitude Modulation (Unipolar PAM). As the data communication speeds increase, the Inter Symbol Interference (ISI) takes place due to the limited bandwidth. Hence, we need to adopt a better scheme that can take care of all these problems related to speed and Bandwidth. So, SCM includes OOK, PAM, PPM, PWM, OPPM, MPPM, DPPM, EPPM, VPPM, SPAM, DPWM.

OOK is the easiest of all and is an intensity-modulated direct detection scheme that is almost like the ASK modulation technique, but with a slight difference when it comes to the amplitude of the data signals. OOK transmits data by either sending a binary '1' or a binary '0' corresponding to the LED turning "ON" or "OFF" respectively [4]. OOK uses edge transition to perform its encoding as follows:

a) For a high to low transition, a logic 0 is represented
b) For a low to high transition, a logic 1 is represented

The serial encoding formats used in OOK modulations [6][7][8][9] are the:

a) Non-return to zero (NRZ)

b) Return to zero (RZ)

In the PAM, PPM, PWM modulation schemes, the digital data sequence can be converted into a pulse sequence either by changing the amplitude, position, or width of the pulse respectively [2].
PAM (Pulse Amplitude modulation) is an analog pulse modulation method in which the amplitude of the pulsed carrier signal is varied in accordance to the amplitude of the message signal. The pulses consist of a binary 1 or a binary 0 of different amplitudes. PAM requires a larger bandwidth and also draws more optical power.

PWM (Pulse Width Modulation) modulation is a technique that provides the ability to various different levels of power by varying the O/P from the Arduino or source input. We can vary the pulse width and control the light output from the LED. PWM is commonly used in VLC as a dimming control technique due to its low-intensity control [10].

PPM (Pulse position modulation) is a modulation technique that permits varying positions of the binary pulses in accordance with the amplitude of the sampled modulating signal. It has a low noise interference as compared to PAM [4]. PPM exhibits low spectral efficiency [11]. For higher speed data transmissions and also to control the brightness of the LED or dimming control, a combination of PWM and PPM is used.

Multiple pulses in any of the L chips are permitted in MPPM (Multiple Pulse Position Modulation). A Codeword is a one-of-a-kind combination of pulses inside a symbol time period.

MPPM is characterized by two values namely:

a) The number of chips per symbol, n and

b) The weight of the accepted codewords, w.

The weight, w is equal to the sum of the 1's in a given codeword and is a fixed value. It is meant for error detection [12].

OPPM (Overlapping Pulse position modulation) is just like MPPM, but with an additional constraint, that all the pulses must be consecutive, i.e., all the 1's must be contiguous in a codeword [13].

VPPM- Although PPM achieves Dimming Control without changing the light intensity. It is difficult to control the brightness of the LED, so VPPM which is a combination of PWM and 2-PPM is used to vary and control the brightness of the LED and improve the data transmission speeds. But, VPPM suffers from low spectral efficiency and a limited data rate [14], and a complex receiver structure [15]. In VPPM (Variable PPM), each symbol is divided into two slots or chips. In VPPM, for a fixed symbol duration, the pulses can shrink or expand in width to achieve the desired average power corresponding to the dimming set point, whereas in 2-PPM, a "0" bit is sent as a pulse in the first slot and a "1" bit is sent as a pulse in the second slot.

DPPM (Differential PPM) is a variation of the PPM modulation. DPPM transmits the data signal regardless of the clock. In DPPM, the delay between pulses is determined by the falling edge of the preceding pulse, rather than the rising edge of the clock. [16].

EPPM (Expurgated PPM) is a modulation technique in which the MPPM symbol is purged to maximize symbol distance. Thus, this scheme reduces flickering as compared to the PPM scheme and achieves the same spectral efficiency as PAM [17][18][19].

SPAM (Superimposed PAM) modulation is achieved by sending multiple optical pulses in parallel from different spatial positions inside the LED array, which overlap linearly in free space [20]. It has a low cost and it is immune to the non-linearity of an LED.

DPWM (Differential PWM) is implemented by the combination of the PWM and DPPM modulations. DPWM solves the narrow pulse problem in DPPM and also exhibits low power efficiency.

Multi-Carrier Modulation (MCM)

The modulation techniques used here are DCO-OFDM, ACO-OFDM, ADO-OFDM, PAM-DMT, RPO-OFDM, AHO-OFDM, and Flip-OFDM.

OFDM (Orthogonal Frequency division multiplexing) is a modulation technique used to compress huge amounts of data signals within a small bandwidth. It is a digital modulation technique in which we have multiple subcarriers within the same signal channel and the subcarriers are orthogonally separated from each other [21][22][23][24]. It also achieves very high data transmission speeds.

DCO-OFDM (DC biased Optical OFDM) – To transmit data signal through the DCO-OFDM, serial binary data is first converted to parallel and modulated with M-QAM (Multi-level Quadrature Amplitude Modulation) with a Hermitian symmetry [25]. The organized subcarriers are then passed via the IFFT block, resulting in a real-time discrete signal. When converting from parallel to serial, a CP (Cyclic Prefix) is applied [26].

ACO-OFDM (Asymmetrically Clipped Optical OFDM) – Here, the input stream of data bits is first mapped into complex symbols according to the order of QAM employed. The IFFT operation is applied to the complex symbols to generate the ACO-OFDM signal [27]. A real-valued ACO-OFDM signal is obtained by modulating only the odd subcarriers and even subcarriers are set to zero and ensuring that the Hermitian symmetry is imposed on the input of the IFFT module.

ADO-OFDM/AAD-OFDM (Asymmetrically Clipped and Direct Current biased Optical OFDM) is said to have the best performance in the modulation techniques for VLC communications, as it takes the benefits of both the DCO-OFDM as well as the ACO-OFDM [28][29][30].

PAM-DMT (Pulse Amplitude Modulated Discrete Multi-tone – In this modulation, the subcarriers are Pulse Amplitude modulated and this results in a PAM-DMT time signal which can be clipped asymmetrically to obtain a unipolar signal for transmission [31]. By loading purely imaginary PAM symbols onto all subcarriers while ensuring Hermitian symmetry and then clipping the negative samples of the time domain signal, the distortion caused by asymmetrically clipping is orthogonal to the data signal, causing no additional penalties and avoiding extra DC bias. This clipping introduces entirely real-valued noise in the frequency domain, which does not affect detecting or receiving purely imaginary symbols.

RPO-OFDM (Reverse Polarity Optical OFDM) – It's made up of two signals: a fast optical OFDM communication signal and a somewhat slow PWM dimming signal, both of which contribute to effective and efficient LED illumination levels [32][33].

AHO-OFDM/HACO-OFDM (Asymmetrically Hybrid Optical OFDM/Hybrid Asymmetrically Clipped Optical OFDM) – This is a hybrid method that modulates the imaginary component of the even subcarriers with ACO-OFDM and PAM-DMT signal modulation [34].

Flip-OFDM – In Flip OFDM, the negative and the positive halves are removed from the real bipolar OFDM symbol and all transmitted data symbols retain Hermitian symmetry [35]. Before transmitting both the negative and positive halves of two successive OFDM signals, the polarity of the negative portions is reversed. Flip OFDM is utilized for unipolar communications since the transmitted signal is positive. 50% savings in hardware design complexity at the receiver is achieved by Flip OFDM over ACO-OFDM. Flip ODM is also called U-OFDM (Unipolar OFDM) – This modulation is similar to the Flip OFDM in terms of performance and it is used to transmit only the real and positive signals [36].

Color Domain-based modulation

CSK (Color Shift Keying) is an intensity modulation system that conveys a signal by color intensities generated by RGB light LED's, comparable to FSK. In CSK, the bit patterns are encoded to color. The standard used in CSK supports multiple LED color combinations for communications by dividing the spectrum into seven color bands. The advantage of CSK is that the light will have a constant power since the average optical power is maintained to be the same. In CSK, the flickering and dimming control issues are taken care of in an efficient manner [37][38][39][40][41].

PWM

In PWM, which is a Single Carrier Modulation method, the LED current is switched at a high frequency in a range between zero and the rated O/P current in order to vary or adjust the LED brightness. The amount of PWM dimming depends upon the human eye's ability to understand that there is no flickering of light, although the data stream contains 1's and 0's and hence, a proper ratio of the duty cycle between ON time and OFF time must be maintained. The authors in this paper have kept 80% ON time and 20% OFF time duty cycle, to avoid flicker and still maintain proper data speeds for this application. A PWM driver circuit will only function the LED's at the zero level or the rated current value and thus, maintains the regulation of the current throughout the Dimming range. Another advantage of using PWM, in this application is that it is an energy efficient and also a current modulation technique, since it periodically switches between a zero current and the rated current value, thus ensuring that there is reduction in the running time of the LED's and thereby saving energy.

2 Li-Fi System Implementation

The Li-Fi system implemented block is shown in Figure.1, the authors have transmitted a set of data signals from source to destination, in an indoor environment using the Li-Fi technology. The source data signals should not interfere with the transmitting Li-Fi signal. The Li-Fi signal serves the dual purpose of lighting and communication simultaneously. The analog data signals from the source are first picked up and captured and then sent to an OOK modulator and are signal conditioned to be transmitted through light. This conditioned signal is then transmitted through light (White LED or IR-LED) without any modulation and with OOK modulation and is received by the OPT 101 Photodetector. The OPT101 Photodiode receives the transmitted light signal from the respective LED and is then filtered after passing through the trans-impedance circuit of the OPT101 itself. The signal is then received by the OOK demodulator to reconstruct the original source data signal. Thus, the receiver receives this data and signal conditions it and obtains the original form of the signal and is visualized on the DSO at the destination.

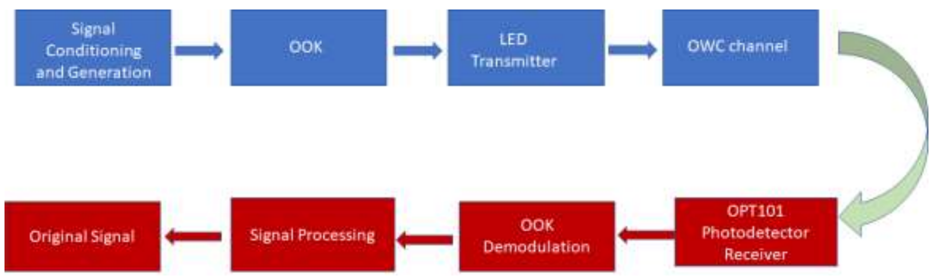

Figure 1. Li-Fi System with OOK technique.

Transmitter and Receiver for Experiment I

This experiment was conducted to analyze the performance of visible and IR light with and without modulation in an optical wireless communication system to transmit data reliably and to compare the response and measure the improvement in range as compared to the setup without modulation. Through this experiment, the authors have tried to verify the improvement in response and the range of the indoor optical link. The modulation used was the simple OOK technique. The transmitter was held fixed during the experiment, while the receiver was moved from 1 meter to 4 meters away, and data transmission accuracy was measured. The LED's used, provided us with an incoherent white light of around 400nm to 700nm and IR light of around 850 nm to 950 nm. It provides illumination or lighting as well as performs communication. The LED's come at a low cost and provides optimal ambience.

The experimental setup for Li-Fi has been shown in Figure2. The authors have performed this experimental setup to transmit patient data signals from one end of the hospital ward/ICU to a central monitoring unit, where all the signals are captured and monitored. The 555 timers are configured as an OOK light modulator, which continuously picks up the data i.e., the light signals coming from the individual patients are interleaved in the time domain for a fixed quantum of time for each patient. The nurses/doctors central control unit then, receives these transmitted signals from the individual patients interleaved in the time domain from the lighting panel to the OPT101 photodiode receiver. The OPT101 photodiode receiver has an in-built trans-impedance amplifier. This received signal is further filtered and OOK demodulated by using an op-amp and wave-shaped and post amplified at the output of the IC 386, which is a low voltage audio amplifier.

The experiment was performed under two conditions which are:
Without any modulations: Ambient lights are present and the data is transmitted, received and measured using a White LED and an IR LED separately without any modulations.

With OOK modulation: Ambient lights are present and the data is transmitted and measured using a White LED and an IR LED separately with OOK modulation and the signal is received and measured through OOK demodulation.

The data was generated using an Arduino. This experiment focuses on the successful transmission of data from the transmitter and its accurate reception at the receiver by using a simple modulation technique, OOK modulation.

The LED panel used, replaced the White and IR LED's functioning as a data transmitter with OOK modulation and gave better results due to the forming of the array of LED's and the improvement of the range because of the OOK technique. Signal information is sent through the Arduino board. LED panel followed by an OOK modulator was used as a transmitter and the readings were recorded by the receiver which consists of a photodiode, followed by the trans-impedance amplifier contained in the OPT 101. Synchronization between the transmitter and the receiver is a very challenging task and had to be taken care of, monitored, and adjusted at all times for a better response and improvement of range at the receiver end.

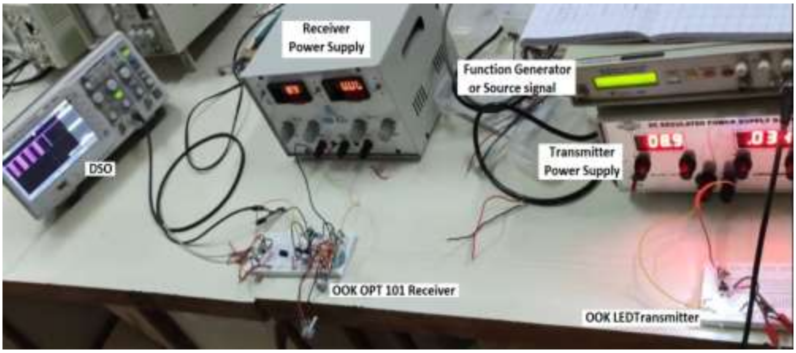

Figure2. Experimental setup I

Experiment II

The block diagram for Experiment II is shown in figure3, where there are 10 patients in a hospital room who have to be monitored 24x7. Each patient is connected with at least 5 data sensors and these bio signals (health parameters) from these data sensors are sent out via an infrared LED from an Arduino. In this scenario, the five health parameters of each patient are: a) Temperature b) Blood Pressure c) Heart Rate d) Patient moving detection sensor (Accelerometer) e) PIR sensor. The signal is transmitted by using an Arduino which modulates the LED light with a constant current to the receiver error free at a distance of 3metres.

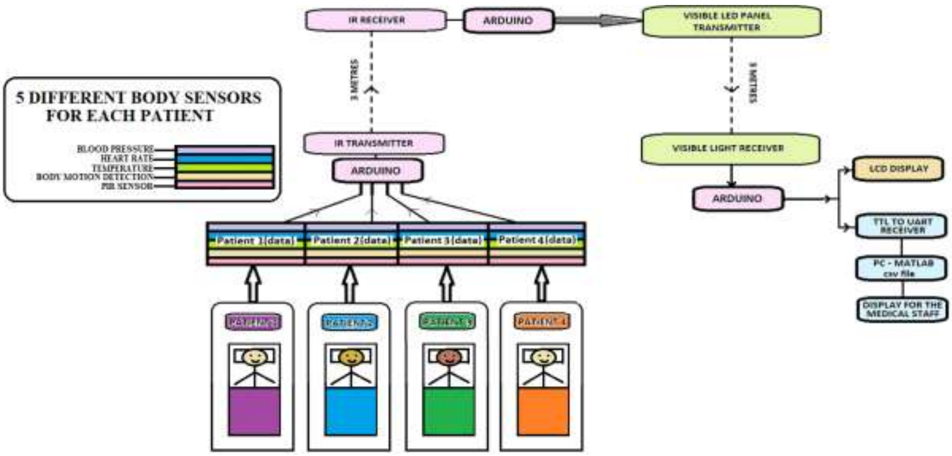

Figure 3. Block diagram for Experiment II with Arduino UNO.

Transmitter and Receiver for Experiment II

This experiment was conducted to remove the flicker from the transmitting LED, to maintain a steady LED current intensity during the transmission and to improve the range of the Li-Fi system with OOK modulation during the day and night time in a hospital room using visible and IR light in order to transmit data reliably and error free. Through this experiment II, the authors have tried to improve the response and the range of the indoor optical link. The modulation used was the OOK technique for transmission of 1's and 0's as digital data. The PWM technique with duty cycle of 80% ON time and 20% OFF time, was used to remove the flicker and maintain a steady LED current at all times.

The experimental setup for Li-Fi has been shown in figure4. The patients in a hospital room who have to be monitored 24x7 are connected with at least 5 data sensors and these bio signals (health parameters) from these data sensors are sent out via an infrared LED from an Arduino and the five health parameters of each patient are Temperature, Blood Pressure, Heart Rate, Patient moving (Accelerometer) and PIR sensor. The sync pulse is first initiated from the first bed connected to the Arduino and the five data signals from this first (patient) are IR transmitted out to the IR receiver connected to the second Arduino, then the next patient's data signals are IR transmitted out till we reach the last bed number 10 and finally transmit patient 10's data signals out. Again, we come back to the first patient's data signals (bed no. 1), to ensure that the signals are in sync and will be again reach the 10th bed and this process repeats. All the 10 patient's data is collected in a packet and this packet data which is transmitted out from each patient is transmitted out through IR light connected to the Transmitting Arduino UNO and is also received through an IR receiver connected to the Receiving Arduino UNO. This IR signal received from each patient is then transferred to the LED light panel to provide illumination in the room during the day time and simultaneously, also transmit the data signal packets to the receiver on the nurses/doctor's desk.

The distance from the bed to the ceiling and from the nurse's desk to the ceiling is at a minimum of 3 metres. During night time, the illumination from the Visible LED transmitter will be switched OFF, but the transmission and communication should continue through the IR LED transmitter which will be turned ON during the night time from the same illumination lighting panel. The signals from the patient's to the doctor's/nurses table should reach without any error. This is done to ensure that the transmission of each patient's data is done periodically 24x7 without any discomfort to the patient in the hospital room at night time too. The two transmitters are a) infrared light and b) visible light panel. The receivers, could be an array of photodiodes or LDR's followed by a transimpedance amplifier with multiple stage amplifiers, filters and signal conditioning stages and which should maintain a minimum communication range of 3 metres. The light from the LED panel should be able to illuminate the room. The LED panel light should serve dual purposes of illumination and communication during daytime as well as at night time without creating any flicker to the human eye and having the least bit error rate during transmission as well as reception. Alarms are placed at every critical values/limitations of each sensor connected to the patient to indicate to the nurses or medical personnel that the patient is in discomfort and thus, immediate and timely treatment could be given to the patient. Sometimes, the patient is not in a position to alert, complain or signal the nurses in the ICU about their discomfort since they might be hooked up to a ventilator or other medical gadgets etc, then these alarms from the respective sensors provide a huge help to the patient's as well as the doctors with regards to their timely treatment.

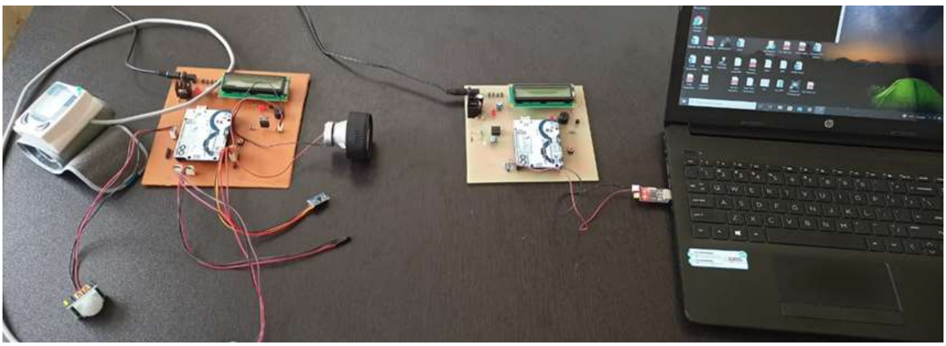

Figure4. Visible light Transmitter and Receiver modules.

3 RESULTS & DISCUSSION

The experiment I, was performed without any modulation and with OOK modulation and under ambient light conditions.

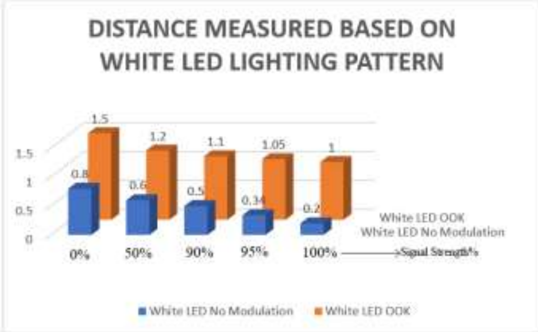

Figure 5. Measurement of distance in metres w.r.t without any modulation and with OOK modulation using White LED

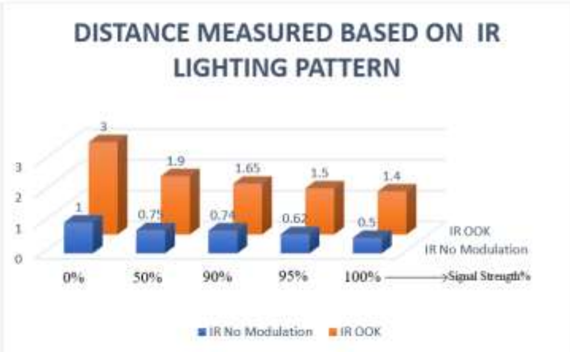

Figure 6. Measurement of distance in metres w.r.t without any modulation and with OOK modulation using IR LED

From the results seen in Figure 5 and Figure 6, the authors have obtained that, when the ambient lights are present and only LED's (White and IR) lights are ON, it is seen that after performing OOK modulation with the white and IR LED's individually which are participating in the communication, the system performance is the best. Thus, by implementing the OOK modulation, with IR LED, it shows a 100% reliable link, and the range is also improved at 1.40 meters and the signal dies out at 3.00 meters. Similarly, by implementing the OOK modulation, with White LED, it shows a 100% reliable link at 1.00 meter, and the range is slightly degraded as compared to the IR setup and the signal dies out at 1.50 meters.

However, the performance was not satisfactory, especially while using the white LED alone and also without any modulations. The system performance degrades to 0.80 meters when the signal dies out and 100% successful transmission at 0.20 meters with the ambient lights present. But by using IR LED, without modulation, it improves by giving a 100% response at a distance of 0.50 meters, which was better than for a white light LED alone with no modulation but showed a lower range of distance as compared to with OOK modulation. The OPT101 was moved to a distance of 4.00 meters and the experiment was performed and the readings were recorded.

From this experiment, it was evident that there was an improvement in the output response at the receiver of the photodiode, OPT101 followed by an OOK demodulator, for the transmission of the signal during communication for an OOK modulated wave as compared to un-modulated data transmission. The factors responsible were:

1) If the ambient lights are removed and only if the LED array is used as the lighting panel as well as the communication link, the receiver would be able to capture, demodulate and get a higher output response signal.
2) The single White and IR LED's must be well synchronized to improve the linking issues from the transmitter to the receiver, which hinders the performance at the output.
3) The geometrical arrangement of the lighting and transmitting panel in a circular geometrical pattern would improve the performance to an optimal value.
4) If a convex lens was used to converge the LED array beam onto the receiver, the synchronization and linking problems would have marginally improved.

Experiment II

In the Experiment II, we were able to achieve a better output using OOK modulation, with respect to removal of flicker, PWM modulation was used to always maintain a constant LED current intensity with a duty cycle of 80% ON time and 20% OFF time and obtain a better distance range, accurately up to 3 metres at the receiver end.

If the medical data of each patient has to be streamed to the adjacent rooms or to the cloud, then, we need to use a software to understand, what data is being received and which patient's data is being received in the file's database. But, if the same file is used, the one which was uploaded on the cloud, then we need not just stream but rather send them to the other room as an individual patient's .csv file format, which contains all the medical data (health parameters) about that patient only. So, the concerned authority or doctors can pick up only their patient's file and do the needful or take necessary action immediately. Also, all these files will remain in the hospital's repository. Whenever there is a recurring health problem with the concerned patient, the earlier admission files could be viewed for faster and efficient processing of the patient's file and health concerns and thus providing immediate and timely treatment. When the doctor's receive the patient's file well in advance or rather in real time, and even before visiting the patient in the hospital, and since the doctor knows about his patient's real time health parameters through this file, it gives the doctor, a better idea regarding the patient's health and also helps with regards to the treatment of the patient better. There will not be any delay in case of an emergency, as the doctor is fully aware at all times of his patient's health, as it is monitored periodically in real time and stored on the cloud also periodically. This happens, as the health parameters of each patient's file gets appended, updated, plotted and tabularized periodically in the excel file uploaded on to the Cloud. The important task after this is to ensure that the data correction algorithms and security algorithms are in place to protect the patient's privacy.

4 CONCLUSION

In this paper, the authors were able to review the various modulation schemes adopted by VLC and OWC. The authors were able to demonstrate and make a comparison study of using the OOK technique in an OWC link model, for indoor communications. In the first experiment, the authors were able to demonstrate the improvement in the range and the overall efficiency using modulation. It was observed that for OOK modulation with white LED, the improvement in range or distance covered without any errors was increased by 5 times as compared to without any modulations. Also, it was observed that for OOK modulation with IR LED, the improvement in range was increased by 2.8 times as compared to without any modulations. In the second experiment, the different modulations were used at the Arduino's transmitter side. For the transmission of the patient's data through the LED light, the authors have used OOK modulation and for removing the flicker and maintaining a constant current or constant light intensity from the LED, the authors have used PWM modulation with a duty cycle of 80% ON time and 20% OFF time. At the receiver end, the signals are demodulated and processed by the Arduino to receive each patient's data, which is then displayed on the LCD display unit and also the data will be transferred into a .csv file into the computer periodically and further the file will be uploaded onto the Cloud for storage and retrieval by the concerned authorities. Through this experiment, the authors were able to achieve and serve the dual purpose of Transmission and Illumination of the health parameter data of 10 patients within the room respectively error free. Further investigations to improve the range by adopting the best modulation for an indoor link environment will be studied and undertaken to increase the speed, gain and obtain the optimal output response in such an environment.

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