Implementation of Optical Camera Communication with Novel Image Processing Algorithm and webcam as Receiver

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Abstract

Over the last few decades, network-connected devices have grown exponentially and the radio frequency (RF) used for this massive connectivity is getting saturated. Exposure to RF is also harmful to health. So, visible light communication (VLC) is becoming a pledging technology. In VLC, light is encoded into the digital data then it is modulated and transmitted to the receiver. This paper demonstrates and implements the OCC system in real time. In this paper, we have designed efficient transmitter and used low budget webcam for video capturing. We have designed flicker free modulation scheme and effective novel image processing algorithm to implement real time communication. We have used Manchester modulation technique for its inherent synchronization and error detection capability enabling robust communication, even in ambient light interference and varying distance. Experimental results showcase the performance of the proposed OCC system under different lighting conditions and distances, highlighting its potential for practical applications in secure indoor communication, localization, and data transfer. The data rate achieved in this experiment is 14.285 kbits/s for 4 cm communication distance and 1.0 kbits/s in 23 cm communication distance. The highest achievable bit rate in this setup is 57.142 kbits/s in 4 cm communication distance and 3.076 kbits per second in 24 cm communication distance. In this designed setup, communication distance can be increased by using the cameras which have long focusing distance.

Keywords: Optical Camera Communication (OCC); Webcam; inherent synchronization; robust communication

1.Introduction

In recent decades, there is an exponential increase in demand for wireless communication. A new wireless communication system, the sixth-generation (6G) system, with the full support of artificial intelligence, is expected to be implemented between 2027 and 2030 [1]. Wireless systems using radio frequencies (RFs) are extensively used in communication networks. High demand for communication connections leading to congestion in RF has created the need for a supplementary, license-free method of transmitting data. To increase the data rate, the communication bandwidth must be increased. Many research groups and organizations have tried to find ways to improve sixth-generation (6G) cellular networks in the sub-THz waveband, which promises a data rate of up to 1–10 Tbps [2]. The most important technologies that will be the driving force for 6G are the THz band, which is an optical wireless communication (OWC), and visible light communication (VLC). In future smart transportation systems, such as vehicle-to-vehicle and vehicle-to-everything (V2X) communication, the need for communications networks that can connect many devices or sensors and the end-users will be increased [3].

Several technologies have been proposed to increase wireless transmission resources (i.e., bandwidth) [4]. The use of OCC technology shows potential, especially in applications that need to improve data transmission in situations with RF limitation. It has advantages like low energy use, high data rates, and using existing systems like LED lights and smart phone cameras. OCC is the visible light communication that can provide the indoor navigation, secure communication, and the applications for Internet of Things (IoT) because it is an interference free service with RF signals. Despite these, there are a number of obstacles OCC needs to overcome before mainstream adoption of this technology is to be expected. OCC is line-of-sight dependent. Line-of-sight dependent means that it can only communicate when the transmitting and receiving ends are visible to each other, which can restrict its range and reliability in dynamic environment.

OCC offers some challenges that affect the performance of the link to be both efficient and reliable in practice. A major problem is its reliance on LOS scenario because having obstacles or misaligned transmitter and receiver, can dramatically disfigure the very essence of commutation. Then, interference from ambient light from natural and artificial sources, e.g. sunlight or indoor lighting, can introduce noise, making it difficult to extract the transmitted data. In addition, the frame rate and exposure time of conventional cameras are limited, limiting the data rate that can be reached and making real-time communication a challenge. Additionally, the inconsistencies arising from hardware variants like lens quality and sensor sensitivity result in the cameras performing differently from one device to the other. To mitigate such challenges, advanced modulation schemes, reliable error correction algorithms, and adaptive techniques ought to be employed to improve robustness and practicality of OCC systems.

Real time color-intensity modulation technique for OCC have been designed using 192 data caring 3 color RGB LED achieving data rate of 126.72 kbps [5]. OCC was implemented by using 4 level light intensity achieving data rate more than 10 kbps with 2 m communication distance [6]. Sensor data was continuously monitored by using neural network incorporated OCC [7]. A series of techniques have been developed to solve the challenges associated with Optical Camera Communication (OCC) and to improve its performance. In [8], a rolling-shutter (RS) based OCC (RS-OCC) using a red, green, and blue (RGB) LED transmitter and using a combination of UPSOOK, wavelength-division multiplexing, and Multiple input multiple outputs (MIMO) to improve space efficiency of 3 bits/Hz/LED. Data fusion technique is demonstrated in [9] to extend the communication distance to two times the original value, and the frame rate variation and also discussed in the operation to link OCC to 5G technology. To mitigate the dependency on line-of-sight (LOS) conditions and enhance reliability, advanced modulation schemes such as Frequency Shift On-Off Keying (FSOOK) and Hybrid Frequency Shift Pulse Width Modulation (HFSPDM) are employed in [10], offering improved bit error rates (BER) under varying conditions. Non line of sight OCC was achieved by using multiple input multiple output (MIMO) and time division multiple access which achieved 10 m link distance and used significant low power transmitter [11]. Short range underwater OCC was implemented achieving range of 1 m and BER in 10^{-3} range [12]. Neural network-based equalizers have been introduced in [13] to enhance data throughput by effectively compensating for noise and distortions, achieving up to 12 kbps data rate. The integration of error correction algorithms and adaptive techniques helps to stabilize the performance across different environments and hardware variations, facilitating robust and practical OCC systems. These advancements collectively contribute to overcoming the inherent limitations of OCC, enabling more reliable and efficient communication systems. A detailed experimental study on the effect of temperature on transmitter efficiency to increase the data rate while using Wavelength Division Multiplexing (WDM) or Color Shift Keying (CSK) modulation has been shown in [14].

We have developed a prototype for real-time communication utilizing Optical Camera Communication (OCC) technology. Our design includes an efficient transmitter and a sophisticated algorithm, enabling robust and seamless real-time data transmission. This prototype demonstrates significant improvements in communication efficiency and reliability, showcasing the potential for OCC to support various applications requiring rapid and dependable data exchange. In this study, we have incorporated advanced coding technique with Manchester modulation technique to encode date. We have also used multi thread decoding algorithm for real time communication. The significant contributions of this research are summed up as follows:

- To discuss the requirements for designing transmitter and receiver to implement OCC,
- To design a flicker free transmitter and necessary modulation and encoding schemes for the implementation,

- To understand the implementation challenges in real-time communication and overcome the challenges,
- To design a multi thread decoding algorithm for real time communication,
- To study the performance of the proposed OCC system, analyze bit loss and find BER,
- analyze the performance of the system, measure strip width, detect Error in strip width, determine data rate in different communication distance in different frame rate.

The remainder of the paper is structured as follows: section 2 provides an overview of OCC principle and related works. Section 3 presents the methodology and performance comparison among different modulation techniques. Section 4 includes transmitter and receiver design, encoding algorithm, decoding algorithm, experimental results and performance evaluation. This work is finally concluded in section 5, which also offers further research suggestions.

2. System Overview

A. Architecture

The generalized block diagram of OCC system is depicted in the Fig. 1, illustrating the complete process from data input to output. The architecture has mainly two sections: OCC Transmitter and OCC Receiver.

In transmitter section, the transmission process starts with taking input messages from user. The input text message is then converted in ASCII code and then converted to equivalent binary bit sequence. In the next step, the binary bit sequence is encoded by using Manchester coding, a modulation technique that helps in maintain synchronization and helps to detect errors during transmission. The encoded binary bit pattern is then given to LED driver circuit which drives the LED panel according to the encoded binary bit pattern. LED panel gets turned on for “1” and turned off for “0”.

At the receiving end, the camera captures the images. Then frame sampling is performed. Because of the rolling shutter effect, white and black strip pattern is formed according to the transmitter bit patters. The frames then go through the process called image processing where the embedded binary bit pattern in captured frames is extracted. The extracted bit patterns is demodulated where Manchester coding is reversed and coverts the binary sequence to original form. The output binary bit pattern is then converted into output text messages, successfully completing the data transmission process.

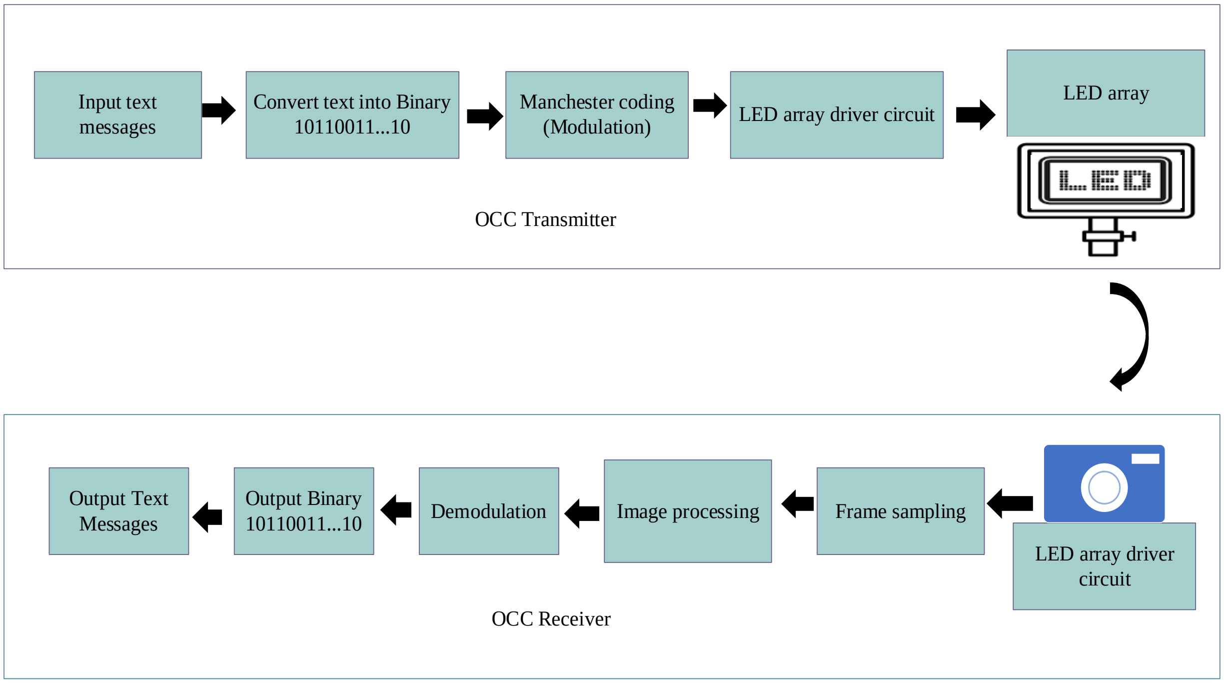

Fig. 1. The generalized block diagram of OCC system.

B. Research Activities on OCC

OCC implementation faces several types of problem because of some technological limitations and ambient light interference. However, in coming future, meeting those limitations and solving the problems associated with interference, OCC can provide tremendous contributions in future IoT. Researchers are trying to solve limited data rate and low distance problem by presenting new ideas and incorporating novel technologies. Table 1 represents the recent studies conducted on OCC with achievements and limitations. Multiple color intensity level was used to modulate data by W. Huang et al. [5], where 126.72 kbps and 1.4 m communication distance was achieved by using 16x16 LED array and 330 fps camera. Multilevel light intensity was used by V. P. Rachim, and W. Chung [6], where data rate up to 10 kbps was achieved but distance was limited due to high sensitivity of ambient light interference. According to another experiment, data rate 10.32 kb/s was achieved by using beacon joint packet reconstruction by W. Wang et al. [15] but limited by cm range distance. A new sampling technique called line sampling which is a high-speed sampling technique and modulation technique was proposed by Hideki Aoyama and Mitsuaki Oshima, where the sampling rate is thousand time faster than the conventional image frame-based sampling [16]. Van Linh Nguyen et al. have introduced MIMO C-OOK (Multiple-Input Multiple-Output Camera On–Off Keying) scheme that uses neural network to predict threshold and provided mobility support up-to 2 m/s in [17] . In [18] Plastic Optical fiber Coupled light emitting diode and commercial camera have been used for flicker free communication in off-axis camera rotation upto 45 degree by Shivani Rajendra Teli et al.

Table 1. Overview of previous work on OCC with their achievements and limitations.

Reference	Authors	Year	Research direction and contribution	Limitations
[1]	M.Z. Chowdhury et al.	2020	Basic architecture of VLC and OCC has been described. Requirements, future application, limitations have been described.	Detailed architecture and implementation procedure is not described.
[2]	M. Shahjala et al.	2019	A broad discussion on OCC system, requirements for OCC, advantages and future possibility has been discussed.	Challenges include low data rates, short distance communication, multilateral communication, visual flickering, and user mobility support
[5]	W. Huang et al.	2016	A mobile phone of 330fps was used and data rate of 126.72 kbps was achieved in 1.4m communication distance by using 16x16 RGB LED array.	Long distance transmission was not achieved. Bit error rate was high.
[6]	V.P. Rachim et al.	2018	Multilevel light intensity was used to modulate data bit and more bit was infused within one strip.	Problem in detecting different level of light intensity due to ambient light interference.
[7]	M.F. Ahmed	2020	Dedicated neural network was developed for enhancing bit rate and flicker free communication was achieved in different modulating frequency by using a small LED and LED array.	Communication distance is very low as compared to other experiment.
[13]	O. I. Younus et al.	2020	Artificial neural network was developed to reduce inter symbol interference and increased data rate.	System architecture is complex and communication distance is not increased significantly.
[14]	Daniel Moreno et al.	2021	Effect of temperature on Image sensor channel while using Wavelength Division Multiplexing (WDM) or Color Shift Keying (CSK) modulation schemes.	Temperature effect has been considered only for Bayer and Foveon filtering schemes.

[15]	W.-C. Wang et al.	2017	Beacon joint packet reconstruction scheme was used to enhance data rate for mobile phone based visible light communication.	Communication distance is in cm range. Data rate is not so good.
[17]	Van Linh Nguyen et al.	2022	MIMO C-OOK modulation scheme based neural network has been used in this paper and up-to 2 m/s mobility with 22 m communication distance in low bit error rate have been achieved.	The system is complex and bit rate is limited to 3.71 kbps.
[18]	Shivani Rajendra Teli et al.	2021	LED couple optical fiber has been used to achieve flicker free, rotation of camera up-to 45 degree and low error rate communication.	Data rate is too low, limited to 500 Hz.
[19]	T. Nguyen et al.	2015	Asynchronous communication using frame and super-frame.	Not flicker free communication and data rate is less.
[20]	N.B. Hasan et al.	2019	In this article non line of sight MIMO and space and time division multiple access for optical camera communication is used. It shows that zooming and defocusing of camera does not have impact on the system performances.	Bit error rate is higher than standard limit.
[21]	Ke Dong et al.	2025	Effect of image sensor exposure on bit error rate OCC has been discussed here.	The effect is considered in up-to 1 m communication distance only.
This paper			This paper discusses the requirement for designing transmitter and receiver and describe how flicker free transmitter and necessary encoding and decoding scheme is designed for real time communication. It also describes the implementation challenges for real time communication and overcome some problems. In this experiment we incorporated advanced coding Manchester Modulation technique to transmit data at high rate. We used multi thread decoding algorithm for real time communication and studied the performances of our designed OCC.	

3. Methodology

3.1 Rolling Shutter Effect

Most of the modern camera uses CMOS sensor that include rolling shutter effect to capture image. Like global shutter camera, the image sensor of rolling shutter camera does not open at a time for charge collection. Rather it opens the image sensor row and perform read out operation in sequential manner. This unique feature of rolling shutter camera allows to capture the fast ON and OFF state of a LED array in frames. ON states of LED array produce bright strip and OFF state produce dark strip. Figure 2 shows how this strip pattern is produced. ON and OFF describes the state of LED along time. Row n, n+1, n+2…X defines the exposure time and read out time of consecutive rows of image sensor. In ON state of LED from Row n to Row n+4 of image sensor will get light and in image frame they appear as bright strip. From Row n+5 to Row n+8 image sensors row will gradually get less light and in image frame there would be a gradient of white and black. From Row n+9 to Row n+14 the image sensors row will not get any light so they appear as dark strip. In this was white and black strip will appear in image frames. By setting a range of illumination value for 0 and 1 we can decode the message captured by image frame. To increase data rate, there are two parameter we can change, increasing modulation frequency and decreasing exposure time. If modulation frequency is increased, exposure time must be decreased. There would be no defined strip pattern because of the gradient of black and white, if exposure is not decreased.

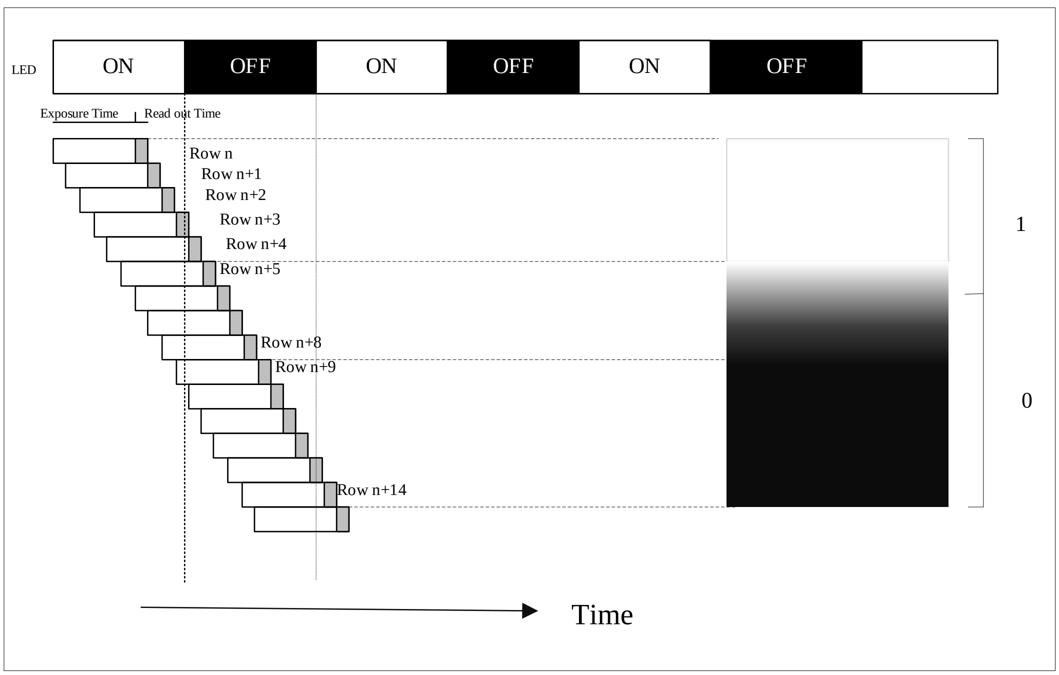

Fig. 2. Illustration of strip formation in rolling shutter camera with exposure and read-out process.

3.2 Transmitter characteristics and design

OCC transmitter is much simpler compared to radio frequency transmitter. It consists of existing LED array for illumination purpose, power supply and signal modulator. There should be suitable modulation scheme and encoding technique for minimizing error and flicker-free communication. Infrared (IR) or usually used visible light emitting LED for illumination purpose can be used for transmission. For flicker free communication IR-LED can a suitable choice. But if we want illumination and transmission of data at a time then visible light-based LED is the choice. In that case, flickering effect can be mitigated by selecting suitable modulation technique. LED panel size and light intensity are also determining factor for communication distance and data rate.

The LEDs used in this experiment need to be turned on and off at certain frequency to transmit data. In this experiment a LED array of 236 low power LED was used. The LEDs are arranged in a barro board of 6 cm width and 32 cm length was used. The LEDs are connected in a circuit such a manner that each LED can get 3 volts. As the supply was a 12.0V adapter, 4 LEDs was connected in series and 59 such series connected LEDs was connected in parallel. In such way, a 4 LED group got 12 volt and 12 V is distributed among 4 LED, each one got 3V supply according to Kirchhoff's voltage law. The LED array was driven by using a transistor (TIP122). LED array was turned on and off by using Arduino Mega 2560. Using Arduino program, the character data stream which intended to send was at first converted to ASCII code then ASCII code was converted in 8 bit binary bit stream. Then the binary bit stream was coded by using Manchester coding scheme to simplify the processing algorithm. The Manchester coded binary bit stream is used to drive the LED. LED array was turned ON when the coded bit was 1 and turned OFF when the coded bit was 0. Fig. 3 represents how the LEDs was arranged into barro board and Fig. 4.2 represents the LED array with shedding. Fig. 5 represents the transmitter setup and Fig. 6 represent the transmitter when the power supply is given. In this experiment, we have aligned the receiving camera in line with transmitter LED array.

Each coded bit is sent for certain time duration for achieving certain data rate. The less time is set for one coded bit, the more data rate is achievable. But there is a limitation in this case. As we lower the time set for one bit, the lower number of pixel will be used to represent one bit in image frame. In this circumstances, “blooming” effect is appeared. The blooming effect is the main hindrance to represent a bit by low number of pixel value. Blooming effect vary from camera to camera as a consequence of image sensor construction and read out technique

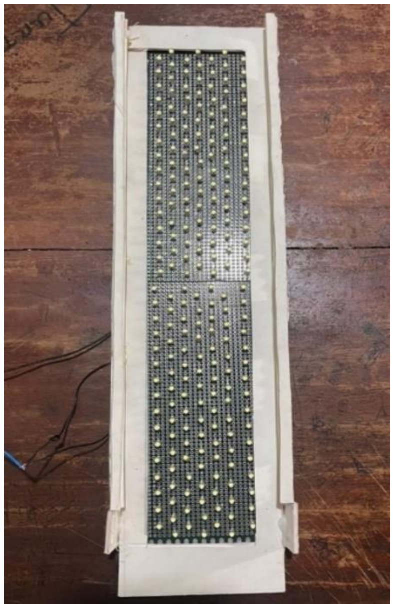

Fig. 3. Transmitter LED array.

Fig. 4. Transmitter LED array with shedding.

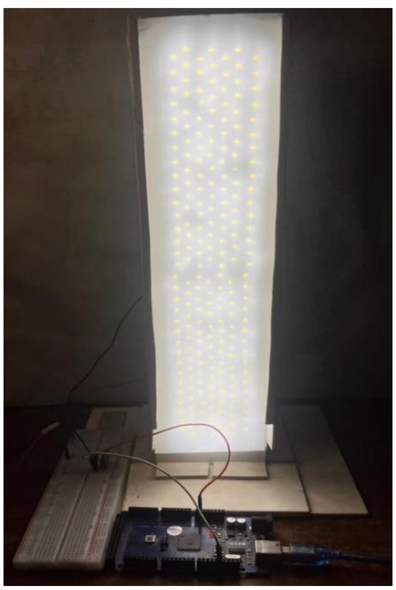

Fig. 5. LED transmitter.

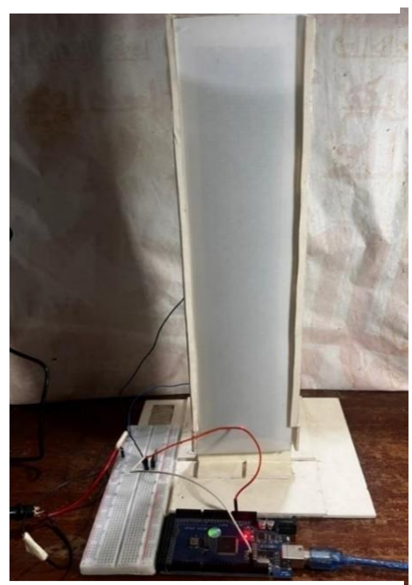

Fig. 6. LED transmitter with power supply.

3.3 Receiver

On receiving side, a Logitech C922 webcam is used to feed the signal. By using OpenCV Python the video is online processed to demodulate the signal. To assess the effectiveness oof the proposed Manchester modulation scheme-based OCC system, several tests were conducted using different distances (d) and frequencies (f). The camera's frames per second (fps) were configured at 30 fps and the resolution is set to 1080p (full HD). Before decoding the video each frame of the video down-sample to 432x768 pixels. Camera parameters are shown in Table 4.1. Those parameters are needed to be set accurately before recording the video of the transmitted signal. As camera setting cannot be changed in this webcam, we used Samsung S24 to record video in higher frame per second and tested the feasibility of processing higher frame rate using the same architecture and program.

Table 2. Logitech C922 webcam.

Parameter	Value
Resolution	1080x1920 pixels
Brightness	128
Contrast	128
Saturation	138
Sharpness	164
White Balance	6500
Zoom	100
Focus	85
Exposure Time	488.28 µs
Frame rate	30 fps

Fig. 7 shows the experimental setup for this experiment. The experimental setup includes transmitter section on the left and receiver section on the right side of Fig. 4.5. Transmitter section includes a LED array transmitter which is driven by a transistor and Arduino mega 2560. The receiver section includes a Logitech C922 webcam and laptop where python and Arduino was installed.

Fig. 7. Experimental setup.

3.4 Image Processing Algorithm

We developed an image processing algorithm where we used a parallel, Produced-Consumer pipeline to process the video containing strip pattern and decode the messages infused in image frames. The system has two main components: a Frame Acquisition process (The Producer) and a Frame Processing Process (The Consumer) which communicate asynchronously via a queue.

A frame can be represented by the following 3D tensor equation,

$$F \in \Re^{H \times W \times C} \tag{1}$$

where H, W and C represent height, width and number of color channel respectively.

At first a queue is created to stack the frames containing strip pattern. The queue, Q we used here is a first-in, first-out (FIFO) system. The frame acquisition process is a continuous loop which acts like the producer, generating a stream of frames. When the camera connected to the USB port of computer is opened, a sequence of frame $\{F_1, F_2, F_3, ...\}$ is provided by camera to queue. It requires some time to open the webcam. In a time step t, a continuous stream of frame F_t is acquired. By enqueuing operation, the selected frames are put into the queue Q. The enqueue operation can be represented by the following mathematical explanation.

$$Q \leftarrow Q \cup \{F_t\} \tag{2}$$

If the camera is opened then the program starts to read the frame. When we start to transmit data, due to the rolling shutter effect white and black strip is appeared according to the coded binary bit by which LED array transmitter is driven. The strip containing frame are continuously put into queue as long as data is transmitted. Fig. 8 shows the step by step processing of frames before going to sub processing thread.

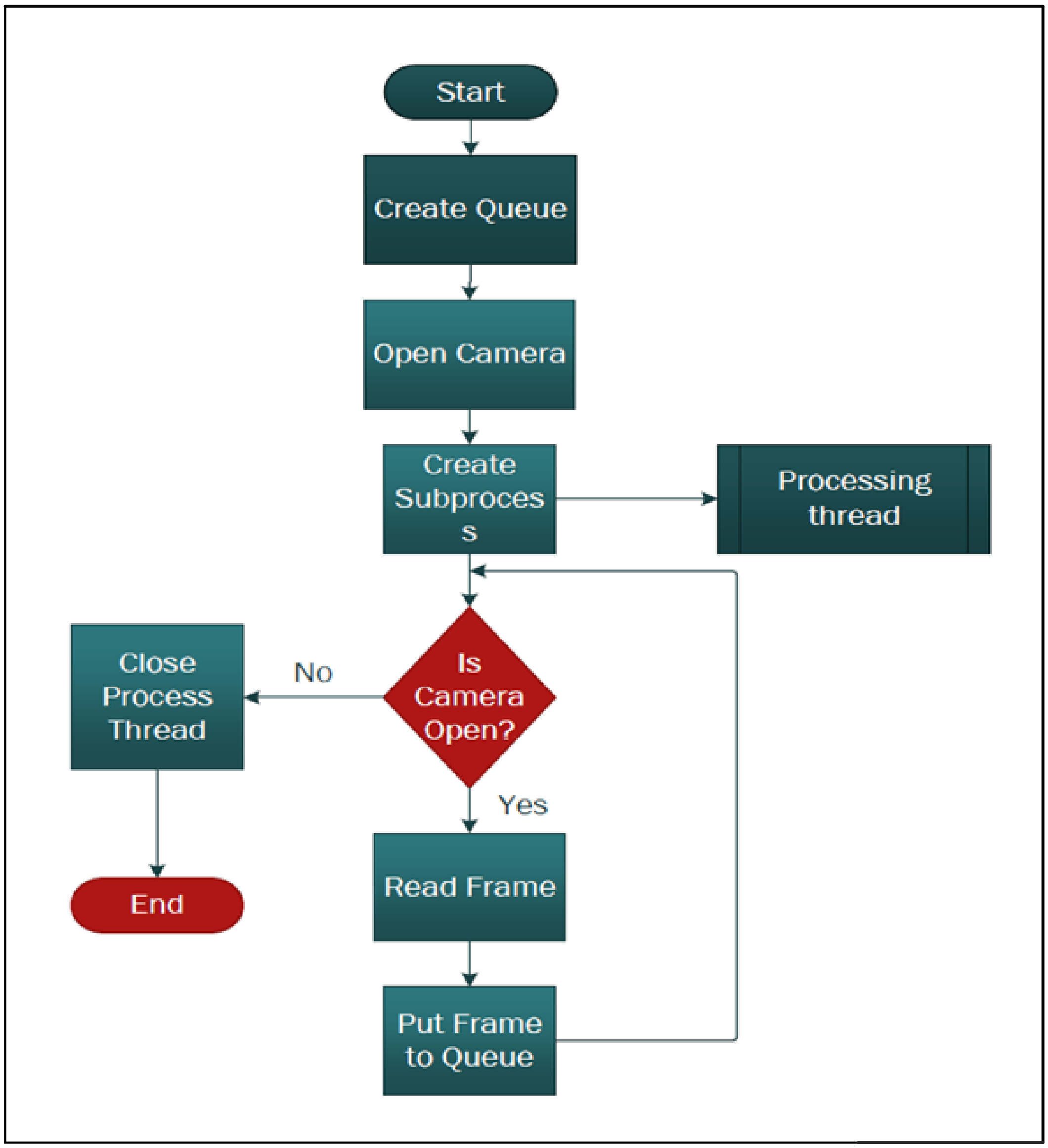

Fig. 8. Image processing algorithm.

A sub-processing thread called frame processing process is created, which does the consumer operation to process the stacked frame in the queue. The thread was created for parallel computing such that computation time is minimized and fast processing of the stacked frame can be implemented in real time. The Sub processing thread algorithm is shown in Fig. 9. In sub processing thread the image is collected one by one and go through a series of sequential transformations in different processing phase. At first the image is resized in new dimension $H^{'} \times W^{'}$ by down sampling to reduce the image size and increase processing efficiency. The transformation function for resizing is given by following equation.

$$F_{resize} = T_{resize}(F) \tag{3}$$

The image is then cropped in region of interest (ROI) to again increase the processing efficiency. The new dimension of the cropped images is $h \times w$ and the cropped frames can be represented as follows.

$$F_{cropped} = T_{crop}(F_{resized}) \tag{4}$$

The cropped frames which is colored image is then converted into single channel grayscale image. The RGB pixel values (r, g and b) are converted into grayscale using weighted sum. The following equation represents the grayscale converted pixels.

$$l = \omega_r .r + \omega_g .g + \omega_b .b \tag{5}$$

Where ω_r, ω_g and ω_b are represented as weight of red, green and blue color respectively. The red, green and blue color intensity of pixels are represented as r, g and b respectively.

So, he transformed gray scale frames can be represented as follows.

$$F_{gray} = T_{gray}(F_{cropped}) \tag{6}$$

After the grayscale transformation the frames F_{gray} go into logical transformation function Ω which checks for strip pattern. The particular frames are stacked vertically if $\Omega(F_{gray})$ = true (The frame is stripped). The frame which does not contain strip pattern is rejected and check is made whether the stack is available or not. The stack here is last-in, last-out (LIFO) system, that stores the processed frame. The stacking operation can be represented by the following push function.

$$S \leftarrow S \cup \{F_{gray}\} \tag{7}$$

Where S represent stacked frames. The next step is implemented only if there is a non-stripped frame and the stack contains frames. The sequence of frames $\{F_{s1}, F_{s2,} F_{s3}, ..., F_{sk}\}$ are extracted from the stack and mage is extracted from the stack and converted to binary stream by using decoding function Π_{bin}. The binary bit stream β is achieved by following function.

$$\beta = \prod_{bin}(\{F_{s1}, F_{s2,} F_{s3}, ..., F_{sk}\}) \tag{8}$$

In decoding algorithm, two threshold values are set. One for detecting 1 and one for 0. Any threshold light intensity value lower than low threshold is considered as 0 and any value higher than high threshold value is considered as 1. The binary bit sequence is then converted to original character by using Manchester demodulation algorithm. The stack is then cleared and new loop will begin to process next frame.

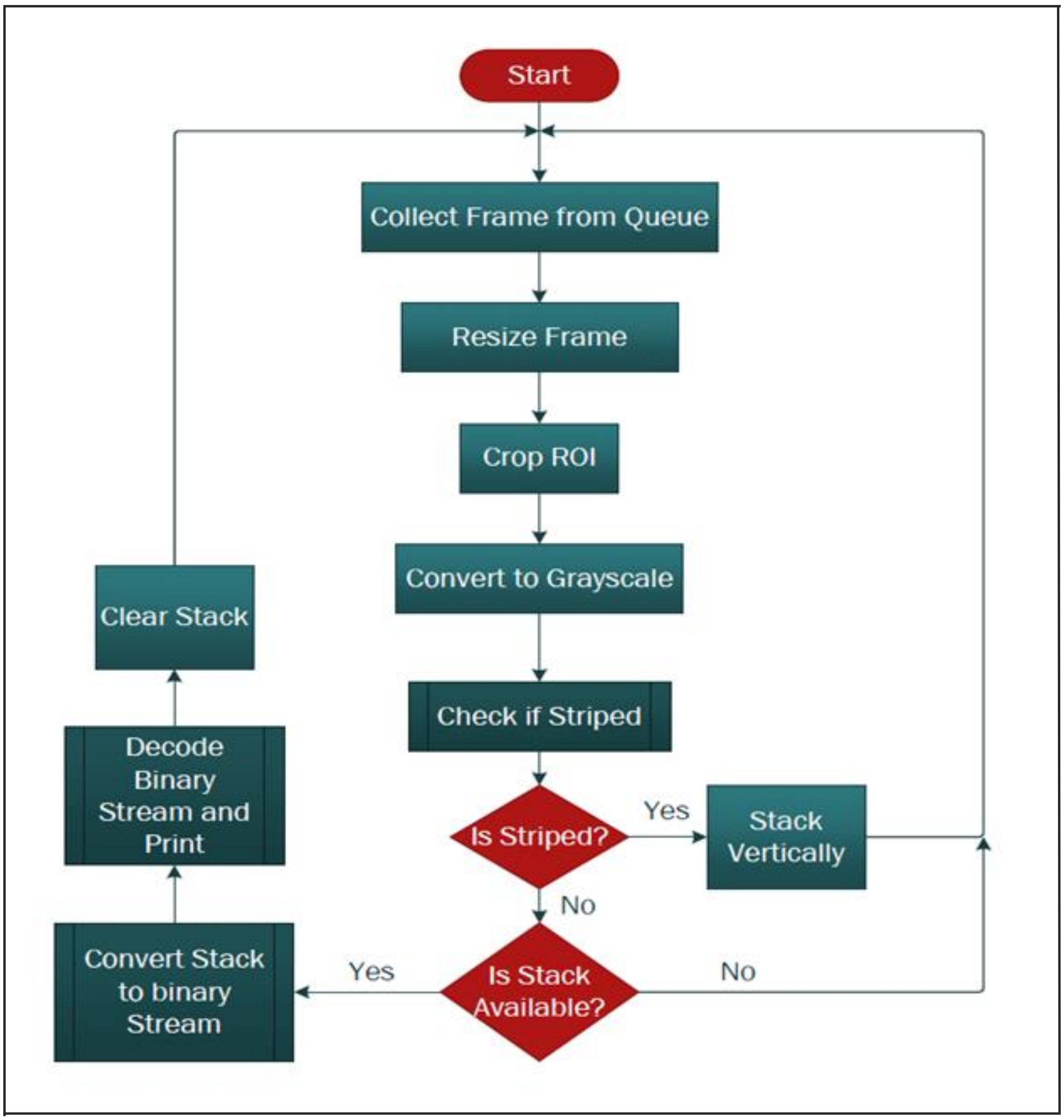

Fig. 9. Sub processing thread algorithm.

Figure 4.8 shows the step by step decoding process from captured image to decoded bit pattern from an image frame. At first the captured image is converted into gray scale image then the image is binarized. Then the binarized image in converted to eroded image from that image bit pattern is detected and at last data is decoded.

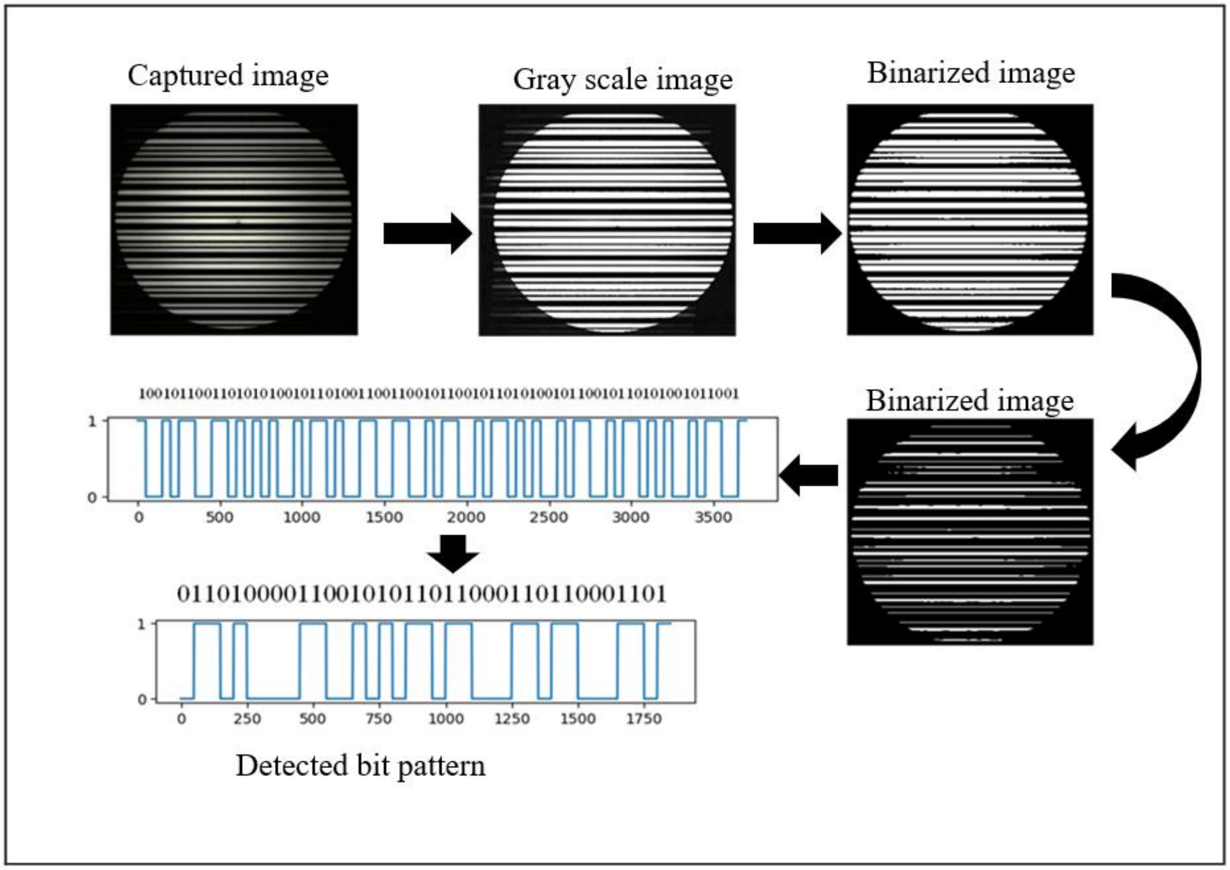

Fig. 10. Step by Step image decoding process.

4. Experimental Result

In this experiment, data is received from several distance in different bit rate and maximum possible distance in certain bit rate is noted and plotted in graph. From 4 cm to 24 cm distance is taken into count and in each two cm interval data is noted. 3 different frame rate is being used 30fps, 60fps and 120 fps. As we increased the fps the bit rate is increases accordingly. Lowest bit rate was achieved in 30fps and highest bit rate is achieved in 120fps.

In different bit rate white and black strip appeared in image frame is different because of the steady frame rate of camera. Fig. 11 shows the strip pattern at different frequency. At 12.5 kbits/s the strip pattern is shown in (a). At 10 kbits/s the strip pattern is shown at (b). And at 1kbits/s and 500 bits/s the strip pattern is shown at (c) and (d) respectively. As we increase the bit rate the strip width decreases. In such way, greater number of bits are fit into one image frame. But there is a limitation between strip width and communication distance due to blooming effect. In different bit rate white and black strip appeared in image frame is different because of the steady frame rate of camera.

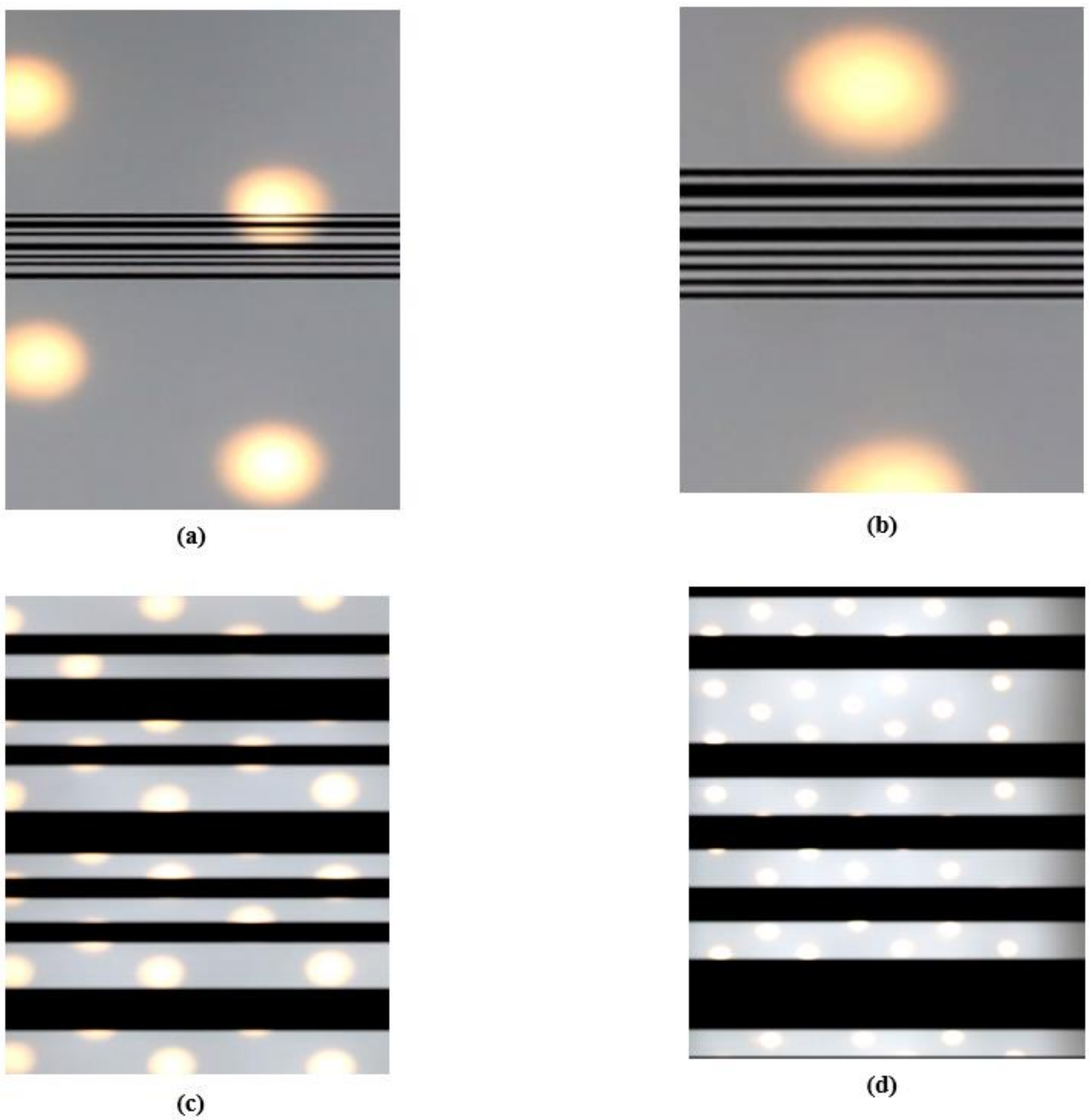

Fig. 11. Strip pattern in image frame in different bit rate (a) Strip pattern in 12.5 kHz (b) Strip pattern in 10 kHz (c) Strip pattern in 1 kHz (d) Strip pattern in 500Hz.

Fig. 12 shows the distance vs bit rate in 30, 60 and 120 frame per second. When the camera captures the frames in 30 frame per second the highest achievable bit rate is 14285 bits per second which is at distance 4 cm. With the increase of distance, the blooming effect increased, that is why we needed to decrease the transmitted bit rate in order to retrieve bits in low loss mode. The highest possible distance in low loss was achieved at distance 24 cm. The distance limitation is due to camera focus limitation. After 24 cm distance, the LED array was out of focus, that is why the camera couldn't detect the strip and no bit pattern was received. The lowest bit rate is at highest communication distance which is at 24 cm and bit rate is 769 bits per second

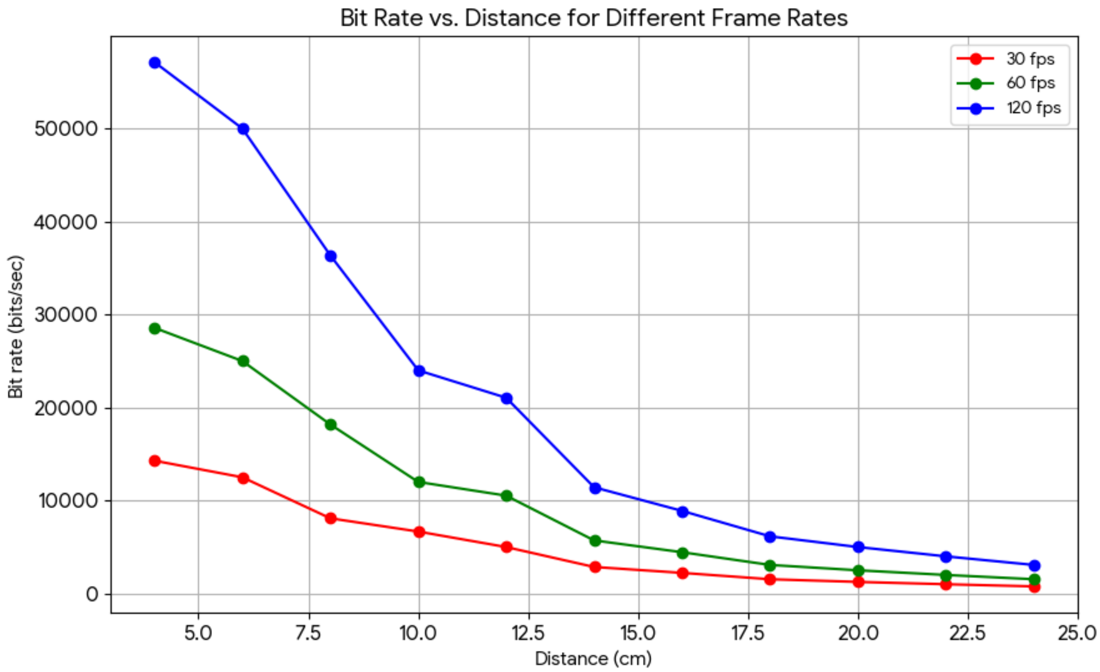

Fig. 12. Distance vs Bit Rate graph in 30, 60 and 120 frame per second.

When we increased the frame rate, the bit rate increased significantly. The reason behind this is more strip can fit into one frame. The highest bit rate is 28571 bits per second which is at distance 4cm. With further increase of frame rate to 120 fps, the bit rate increased as expected. At this frame rate we achieved highest 57142 bits per second at 4cm communication distance. The lowest bit rate at this frame rate was 3076 bits per second at 24 cm distance. For the both three cases the bit rate decrease because of the blooming effect of camera sensor. We observed that the communication distance was limited due to the focusing limit of our webcam. If we use different type of camera which has long focusing distance and also have reduced blooming effect in camera sensor, both communication distance and bit rate can be increased using the same architecture that we implemented in this paper.

Character Error Rate (CER) in OCC is an important parameter for performance evaluation of the system. CER is calculated by the percentage of character that are incorrectly decoded by the receiver. It can be calculated by the following formula.

$$CER = \frac{S + D + I}{N} \times 100\% \quad (8)$$

Where, S, D and I Represent number of substituted, deleted and wrongly inserted character in output. Total number of original characters sent by transmitter is represented by N. CER is the quantification of quality of data link in OCC. The less is the percentage, the better is the quality of the data link. The CER is affected by various factors like distance, ambient light, camera setting decoding algorithm etc. Fig. 13 shows CER vs distance in different fps setting, 30 fps, 60 fps and 120 fps. In our experiment we observed that with the increase of distance character loss increased for three fps settings. Though increased fps had less effect on CER, the increase was almost linear with distance for three settings. We experimented the performance in different ambient light condition and we observed that with the increase of ambient light data loss increased significantly. We have been able to decrease the CER in this designed system because we have used a robust image processing algorithm in our receiving end. The error we recorded can be decrease significantly using the same architecture and algorithm if we use better camera with access in camera settings like exposure, shutter speed, resolution, low blooming effect in image sensor of the camera.

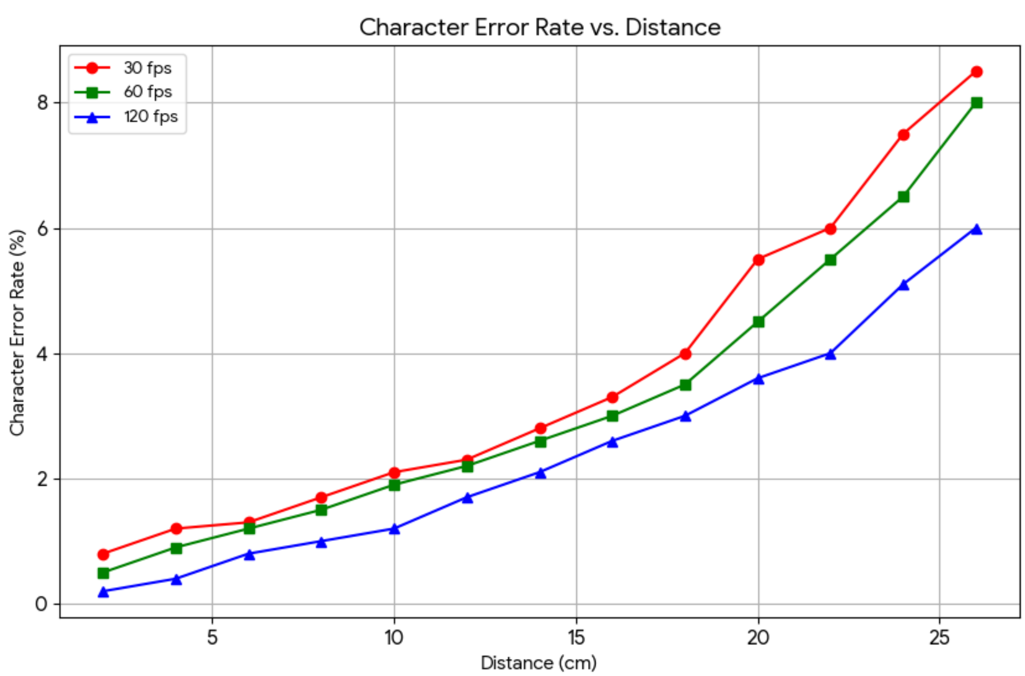

Fig. 13. Character Error Rate vs Distance graph in 30 fps, 60 fps and 120 fps.

Conclusion

The experiment was implementation of an OCC system using Logitech C922 webcam based on Manchester modulation technique. The main objective of this work is to transmit and receive data in real time and enhance the data transmission rate. In this experiment, data is transmitted and received in different bit rate and for every bit rate strip with is measured and calibrated and demodulated. Using the Manchester modulation technique, maximum 476 bits per frame can be transmitted using 30 fps setup. But about 2 frames are required to transmit the same amount of data. The image processing algorithm using Python software is described to interpret the captured image. We analyze data rates for various distances. We show the relationship between distance and bit rate. We can transmit data up to 24 cm at a frequency of 3076 Hz by using this system. The highest possible bit rate is 57142 bits per second at a distance of 4cm. But due to camera limitation we could not verify the result experimentally. This work will enable us to use new frequency band communication called optical band. However, data rate and communication distance could be enhanced by increasing the size of the LED transmitter and by using high resolution camera. High speed camera has high frame rate which can be used to transmit data even higher bit rate at high distance. As the frame rate increases more bits can be fit into the one second duration frames. Thus increases the data rate. Large size LED array increases the focus distance of camera and thus increases the distance and bit rate. The blooming effect of image sensor can be reduced by reducing LED intensity, controlling the exposure time and shutter speed of camera. Natural density filter and lens with narrower aperture can also reduce blooming effect, thus increasing data transmission rate.

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