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Wireless EEG Signal Transmission using Visible Light Optical Camera Communication

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Abstract. Electroencephalogram (EEG) has been widely adopted for the brain monitoring. The transmission of the EEG signals captured from the scalp using electrodes to a displayed screen is often performed through wires utilizing Radio Frequency (RF) communication technology. The wired EEG transmission restricts the patient movement during the entire EEG recordings. However, patient movement is necessary during EEG recordings in certain medical scenario. Towards this end, wireless transmission of the EEG signals enables patient movements during the recordings. In this context, this paper proposes a Visible Light Optical Camera Communication (VL-OCC) system for wireless transmission of EEG signal. The signal transmission under the LOS, line of sight is conducted modulation scheme namely On-Off-Keying (OOK), Non-Return-to-Zero (NRZ). Specifically, organic light emitting diode, and optical camera are used as sender and receiver in the system, respectively. The performance of VL-OCC system is evaluated by developing an experimental prototype under realistic medical scenario.

Keywords: EEG, Biomedical Data, Visible light Communication, Organic Light Emitting Diode, Optical Camera communication.

1. INTRODUCTION

Monitoring the brain electrical activity has great possibility to perceive the brain functionality and to diagnose the brain abnormalities. The traditional Electroencephalogram (EEG) monitoring systems deploy several scalp electrodes, physically connected to the EEG recording machine however recently the wearable EEG devices have gained wide popularity due to lesser number of electrodes, ease and comfort [1]. Some of the EEG machines deploy wireless Radio Frequency communication protocols alike Bluetooth and ZigBee to transmit signal information wirelessly; however, both Bluetooth and ZigBee dependent EEG machines emit radio frequency signal that may interfere to other medical equipment. Radio Frequency (RF) communication plays an important role in daily life such as TV, radio, Wi-Fi and so on. Furthermore, the RF signal transmitted is susceptible to contamination by other RF signals in the neighboring environment [2].

As RF spectrum is immensely crowded, therefore to meet the requirements of the increasing bandwidth is possibly one of the biggest challenges or drawbacks of RF. In healthcare, the RF radiation may cause interference with the operation of some equipment to hospital equipment, therefore owing to shortcomings of RF, the Visible Light Communications (VLC) technology is an alternative solution since VLC uses the license free light spectrum ($380 - 780nm$) and free from electromagnetic interference with enhanced security [3]. Recent reports showed that VLC communication systems employing Light Emitting Diodes (LEDs) have been widely adopted and have reached gigabit transmission speed [4], however the Organic Light Emitting Diode (OLED) is promising area for research due to easy integration and fabrication, wide beam angle, rich colors and flexibility. As the latest development of VLC, Optical Camera Communication (OCC) has shown its existence in several applications [5], hence due to advances in imaging technology and an extension of IEEE 802.15.7 standard for VLC, OCC presents a promising vision of optical communications [6]. The eruption in the usage of smart and advancement in technology over the decade unfolds the capacity of VLC implementation for the smart devices or camera with no hardware modifications [7], hence the proposed research in this paper comprises of visible light and optical camera communication between the OLED screen and image sensor of the camera.

Over the years, there has been an increase in improvement in healthcare quality at several hospitals and nursing homes thereby bringing the wireless technology due to high mobility and flexibility [8]. However, the most important thing for the wireless technology to be adapted and used in hospitals is that it should be free from invisible Electromagnetic Interference (EMI) which tends to affect the medical equipment's and their functionality thus posing a threat to both patient's health and medical equipment. Hence, the Optical wireless communication such as Visible Light Communication (VLC) is most suited for the environment such as hospitals as VLC is free from electromagnetic inference, highly reliable and low cost [9]. In [10], it has been stated that the usage of communication technology such as RF in medical applications, mainly EEG is flustered because of EMI hence affecting the reliability and accuracy of the transmitted data.

This paper proposes a new optical/electrical front-end and experimental system for VLC-OCC system thus achieving data rate of $2kbps$ over free space at camera frame rate of 30 frames per second. Organic Light Emitting diode, OLED screen acting as transmitter converts the EEG signal into two dimensional images by displaying the images. The camera operates as the receiver and detects the images shown on the OLED screen and thereafter a computer to demodulate the EEG signal from image further processes the image received by the camera. This paper suggests a novel scheme for wireless transmission of EEG signals deploying OOK_NRZ modulation scheme employing OLED screen at the transmitter and camera at the receiver. The paper is divides into four different sections. Section 2 presents the proposed system for EEG use case. Section 3 discusses experiments and analysis of results followed by conclusion presented in section 4.

2. VISIBLE LIGHT OPTICAL CAMERA COMMUNICATION (VL-OCC) SYSTEM

This section illustrates the system modelling of the optical wireless communication link as shown in Fig.1. In this system, the transmitted bits in the form of OOK-NRZ is represented by b_n. The system has three major operational components including EEG data processing, microcontroller, and offline processing module. The EEG signal module is responsible for generating raw data from the signal. The microcontroller takes raw EEG data as input and perform Serial-to-Parallel (S/P) operation on data. The offline processing module is responsible for generating final EEG output focusing on image processing, decision processing, and parallel to serial operation. The OLED screen is divided into rows and columns. The number of bits transmitted simultaneously in parallel using OOK-NRZ modulation scheme in each frame can be computed by $N = R_1 \times C_1$. Thereafter, following serial to parallel conversion the signal is transmitted in dimensional form and can be written as $s^{(t)} = [n_1, n_2\,]$, with n_1 and n_2 representing the discrete spatial coordinates of the OLED Display pixels and t denotes t^{th} frame.

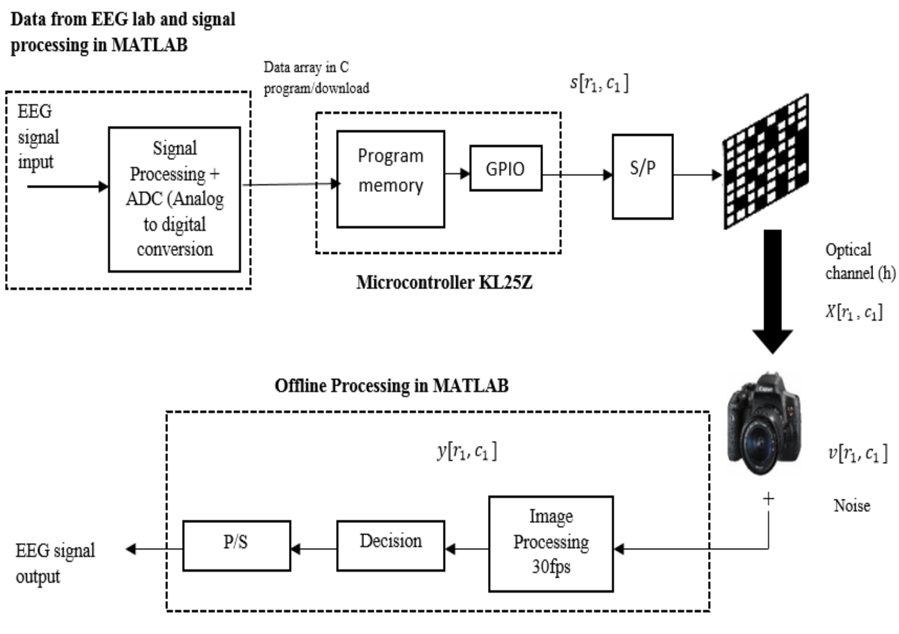


Fig.1. Overall system model of the proposed VL-OCC framework

The information bits consist of square of pixels of size D. Hence, the number of bits effectively transmitted per frame changes with the value of D, thus number of transmitted bits per frame N given by Eq. (1).

$$(S_{z_{row}}/D) \times (S_{z_{column}}/D) = R_1 \times C_1 \quad (1)$$

Where, $S_{z_{row}}$ and $S_{z_{column}}$ is number of rows and number of columns respectively. Following the transit from the optical, channel the signal can be computed as given by Eq. (2).

$$x^{(t)}[r_1, c_1] = (s * h)^{(t)}[r_1, c_1] \quad (2)$$

Where, h is impulse response. Hence, at receiver the signal can be represented by Eq. (3).

$$y^{(t)}[r_1, c_1] = (x)^{(t)}[r_1, c_1] + (v)^{(t)}[r_1, c_1] \quad (3)$$

Representing the signal received at the camera in the form of pixels of matrix. Also, $(v)^{(t)}[r_1, c_1]$ is a realization of White Gaussian Noise (WGN) with mean value equal to zero, variance $\sigma^2{}_v$ and is independent of the pixels. Table 1. Shown below provides the description of the symbols and notations used in system model.

Table 1. Nomenclature

Notation	Description
N	Number of bits transmitted by formation of rows and columns on OLED screen
D	Size of Pixel
R_1	Number of rows per frame
C_1	Number of columns per frame
b_n	Transmitted bits from Microcontroller
$s^{(t)}$	dimensional signal transmitted after S/P in t-the time frame
$y^{(t)}$	Received dimensional signal
$v^{(t)}$	Noise realization which is known by
$x^{(t)}$	Signal at optical channel
S/P	Serial to Parallel
P/S	Parallel to Serial
fps	Frames per second

The EEG signal extracted from EEG lab toolbox is downloaded to MATLAB, thereafter signal processing and Analogue to Digital Conversion (ADC) is done before uploading the data to the program memory of microcontroller thus forming patterns on OLED screen which are captured by camera in the video form and finally the offline processing in MATLAB. The number of frames or the length of the video depends upon the pixel size and the data rate transmitted. For example: if the pixel size is 16 and the number of bits transmitted are 256 at a data rate of $256bps$ then the number of frames needed to transmit $256\ bits$ will be $256/16\ = 16$.

3. EXPERIMENTS AND RESULTS ANALYSIS

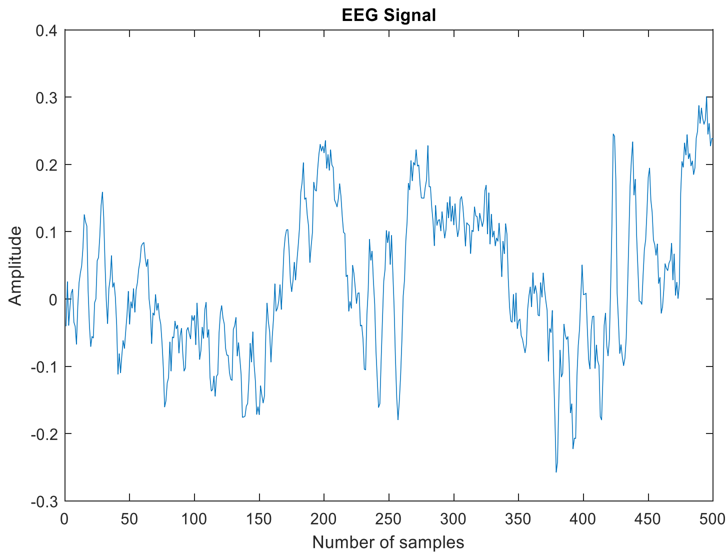
3.1 Experimental Setup and Hardware

EEG signal is of low amplitude of the order of some micro volts and a mixture of different frequencies or EEG bands comprising of waves divided into category of delta (δ, 0.7Hz- 5 Hz), theta (θ,5Hz -9Hz,) alpha (α, 9Hz-15 Hz) and beta (β,15Hz-35 Hz) [11]. Table 2. Illustrates the equipment and the model used for experimental set-up.

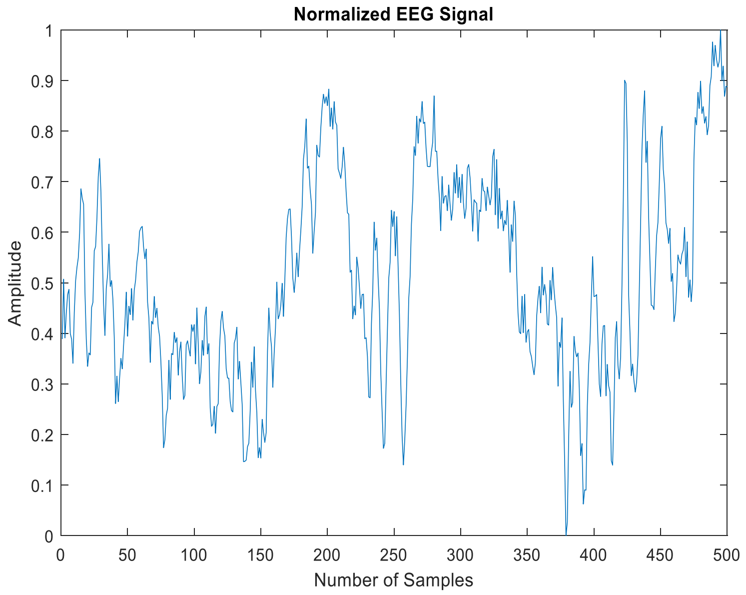
Table 2. Experimental Equipment

Equipment	Model
OLED Display Module	DD-160128FC with EVK board with a resolution of 160RGB ×128 dots
Microprocessor	ARM Processor FRDM KL25Z
Thorlabs Camera	DCC 1645C
Language/Software used for coding	C, MATLAB
Power Supply	EL302D Dual Power Supply 13.3 V which is regulated to 3.3 V using Voltage regulator

In the experiment testbed, the EEG signal transmitted shown in Fig. 2(a) and 2(b) was obtained from EEG toolbox [12] using MATLAB.
The normalized EEG signal obtained is then amplified to a desirable voltage level with the help of amplifiers and filtered by making use of a low pass filter ranging between $0.5Hz$ to $40Hz$ to remove the noise and artifacts. For the analogue to digital conversion, a $16bit$ ADC was chosen to allow for higher resolution and low quantization error. The selected microprocessor was FRDM-KL25Z, because of high speed and low power consumption.



(a)



(b)

Fig. 2 (a) EEG signal from EEG tool box, (b) Normalized EEG signal for VLC-OCC

DD-160128FC OLED [13] screen is preferred as the transmitter with an active area of 28.78 mm into 23.024 mm and a weight of $3.6g$. The evaluation board of OLED screen required a voltage of $2.8V$ to switch on the OLED screen hence, switching board designed using KICAD software having resistors forming a potential divider thus reducing the voltage level of power of the microcontroller from $3.3V$ to the voltage level of $2.8V$ required to switch on the OLED screen. The optical camera is tested at the receiver section to capture the video of the OLED screen at several distances in Line of Sight (LOS). Fig.3 represents the experimental hardware where microprocessor connected to the OLED screen through the switching board and the 741 op-amp designed as voltage regulator in order to regulate the dual power supply.

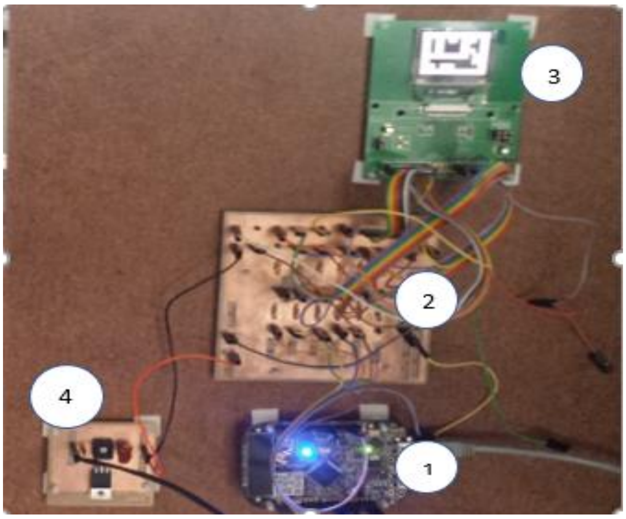


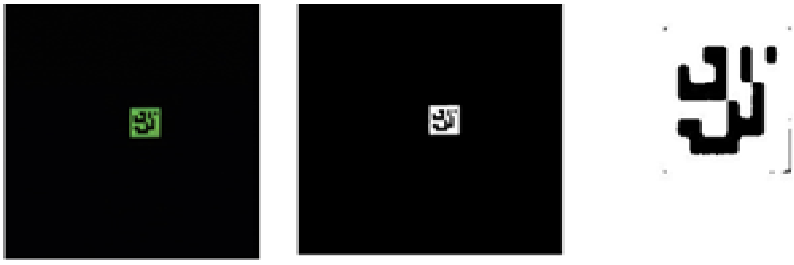
Fig 3. Experimental set-up: 1-microcontroller, 2-switching board, 3-OLED screen, 4-voltage regulator

The OLED screen is a power efficient operating at 2.8V hence switching board drops down the voltage coming from microcontroller to 2.8V. The bits in the form of OOK_NRZ uploaded to the microcontroller through software written in the C language. With the help of switching board, the patterns based on transmitted bits formed on OLED display module, which then recorded by the camera in video form followed up by image processing to calculate the Bit Error Rate (BER).

3.2 Result and Discussion

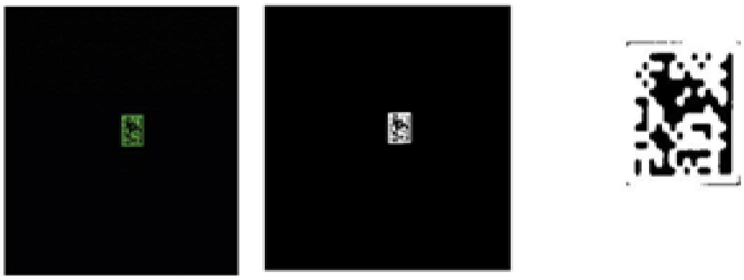
During the lab work, several measurements were taken in different distances at pixel sizes of 8 and 16. The OLED screen had a library where OLED screen divided into pixel sizes of 32, 16, 8, 4, 2 and 1. In our experiments, we considered the pixel sizes 8 and 16 to accept the challenge of complexity in calculating the Bit Error Rate (BER) with decrease in size of pixels thus enabling to transmit more information bits per frame. Additionally, the experiments carried out with the pixel size of 32 of the OLED screen thus dividing the OLED screen into 5 rows and 4 columns resulting in lesser number of bits transmitted, hence was an optimum choice. On the other hand, to increase the data rate and the number of bits transmitted per frame OLED screen divided into pixel sizes such as 4, 2 and 1 could be considered. However, due to reduction in BER using pixel size of 4, we restricted to the experiments with OLED screen divided into pixel size 8 and 16, respectively.

The number of frames required for the entire length of the video calculated by total no of bits transmitted divided by no. of bits per frame. Fig. 4 (a) and (b) show the image processing at pixel size 16 and 8, respectively. It illustrates the transmitted information per frame captured, and the gray image conversion after the border detection and then the cropped image taking the background off.



Transmitted information Image converted to gray scale Cropped

(a)



Transmitted information Image converted to gray scale Cropped

(b)

Fig. 4. Image Processing, (a) at pixel size 16, (b) at pixel size 8

As shown in Fig.3.3 the cropped image is identical to the transmitted information hence illustrating the successful optical transmission of electroencephalogram signals. After the video capture the image processing is performed for BER calculation by comparing the bits obtained per frame and the entire video. The BER obtained at pixel size 16 was lower or better than BER obtained at pixel size as shown in Fig. 5. Though the number of bits transmitted using 8-pixel size are increased in comparison to number of bits transmitted using the pixel size 16. It is a trade-off between BER and symbol size. The increase in pixel size results in increase bit number possibly transmitted per frame hence, the information capacity or data rate improves significantly however, processing speed increases and possibly increases the BER too. After demodulation and digital to analogue converter the received original transmitted EEG signal in shown in Fig. 6. The received EEG signal is same as that of transmitted EEG signal, hence implicates the successful and error free optical transmission of EEG signal. Furthermore, the detection of transmitted bits is clearly possible for images and videos however, the BER changes with increase in distance.

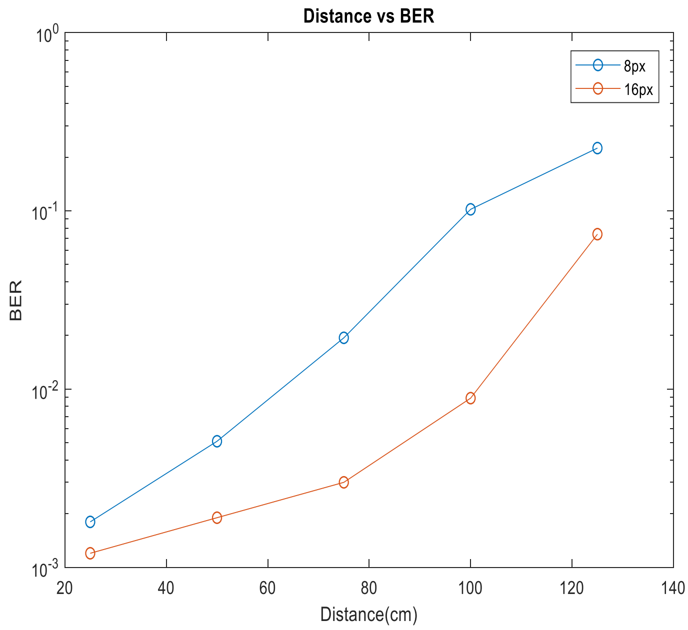


Fig.5. BER vs Distance

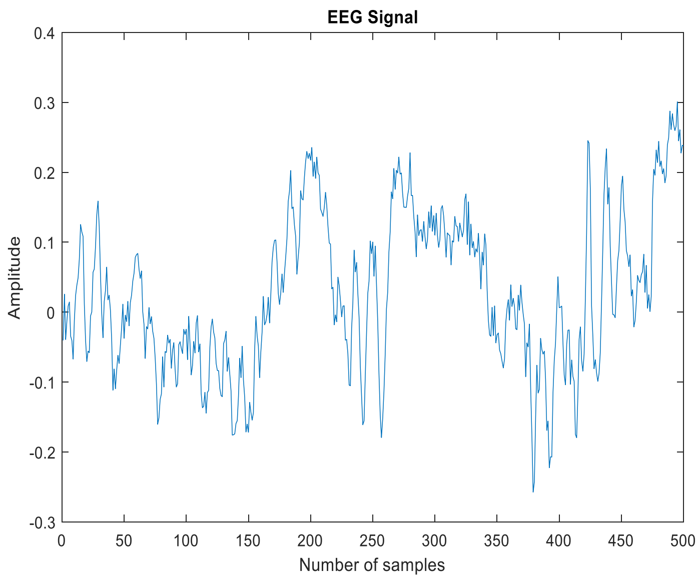


Fig.6. Amplitude of received EEG signal Vs number of samples

4. CONCLUSION

This paper suggested a novel technique to transmit EEG signals using VL-OCC system. The system proposed deployed in healthcare without generating any RF radiation in the sensitive areas such as hospitals. Furthermore, we successfully proposed a technique that could replace current EEG systems deployed in clinical applications based on RF, which suffer from electromagnetic interference and signal loss. The BER obtained from the pixel sizes of 8 and 16 respectively at $25cm$ is of the order of 10e-3. However, with the increase in distance, the BER for 8-pixel size drops considerably after $50cm$ unlike 16-pixel size where the BER obtained is of the order of 10e-3 up to $75cm$ and the data rate achieved was $2kbps$ at a camera frame rate of 30 frames per second.

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