

# Northumbria Research Link

Citation: Aggarwal, Geetika, Dai, Xuewu, Binns, Richard and Saatchi, Reza (2019) Real-time Wireless Healthcare system for Angular Transmission of EEG signal using VL-OCC. Procedia Computer Science, 152. pp. 28-35. ISSN 1877-0509

Published by: Elsevier

URL: <http://dx.doi.org/10.1016/j.procs.2019.05.023>  
<<http://dx.doi.org/10.1016/j.procs.2019.05.023>>

This version was downloaded from Northumbria Research Link:  
<http://nrl.northumbria.ac.uk/id/eprint/39438/>

Northumbria University has developed Northumbria Research Link (NRL) to enable users to access the University's research output. Copyright © and moral rights for items on NRL are retained by the individual author(s) and/or other copyright owners. Single copies of full items can be reproduced, displayed or performed, and given to third parties in any format or medium for personal research or study, educational, or not-for-profit purposes without prior permission or charge, provided the authors, title and full bibliographic details are given, as well as a hyperlink and/or URL to the original metadata page. The content must not be changed in any way. Full items must not be sold commercially in any format or medium without formal permission of the copyright holder. The full policy is available online: <http://nrl.northumbria.ac.uk/policies.html>

This document may differ from the final, published version of the research and has been made available online in accordance with publisher policies. To read and/or cite from the published version of the research, please visit the publisher's website (a subscription may be required.)



International Conference on Pervasive Computing Advances and Applications – PerCAA 2019

# Real-time Wireless Healthcare system for Angular Transmission of EEG signal using VL-OCC

Geetika Aggarwal<sup>a,\*</sup>, Xuewu Dai<sup>a</sup>, Richard Binns<sup>a</sup> and Reza Saatchi<sup>b</sup>

<sup>a</sup>Department of Mathematics, Physics and Electrical Engineering, Northumbria University, Newcastle Upon Tyne, UK, NE1 8ST

<sup>b</sup>Department of Engineering and Mathematics, Sheffield Hallam University, UK, S1 1WB

## Abstract

Examining the brain activity has immense scope in diagnosing specific diseases such as epilepsy and comma. The electrical activity of the brain read from the scalp is known as Electroencephalography (EEG). The traditional EEG systems deploy RF protocols suffering from electromagnetic interference (EMI) which might have harmful effect on health of patient especially in RF restricted zones such as hospitals, hence VLC is preferred due to free from EMI, reliability and enhanced security. Also, the advancement in technology in smartphones and cameras have led to the use of camera or smartphone as receiver in VLC systems rather than using photodiode as receiver unlike traditional VLC systems. Hence, this paper proposes a new novel technique and the system reliability for angular transmission of biomedical EEG data VL-OCC system at data rate of 2kbps with 30 fps camera frame rate deploying modulation namely, On-Off Keying Non- Return to Zero (OOK\_NRZ).

© 2019 The Authors. Published by Elsevier Ltd.

This is an open access article under the CC BY-NC-ND license (<https://creativecommons.org/licenses/by-nc-nd/4.0/>)

Peer-review under responsibility of the scientific committee of the International Conference on Pervasive Computing Advances and Applications – PerCAA 2019.

**Keywords:** Visible light Communication (VLC); Radio Frequency (RF); Optical camera communication (OCC); Organic light emitting diode (OLED); Electroencephalography (EEG)

## 1. Introduction

Epilepsy is the most prevalent brain disorder and in 2015, in UK there were 0.6 million cases of epilepsy and about 60 million worldwide out of which 75% cases have been reported in developing countries [1,2]. People with epilepsy have high risks of personal injury, such as premature and sudden unexpected death, and the impact of epilepsy extends to unemployment, depression and anxiety [3]. Monitoring the human brain has great potential in helping us to understand how it functions and ultimately be able detect early signs of disease and thus prevent mental disorders

\* Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000 .

E-mail address: [geetika.aggarwal@northumbria.ac.uk](mailto:geetika.aggarwal@northumbria.ac.uk)

and cognitive decline [4]. Electroencephalography (EEG), discovered by Hans Berger (1873–1941), is widely used in the healthcare in analysing the brain activity through the scalp using electrodes in order to diagnose several diseases such as epilepsy, brain death etc; thus, examining the brain disease [5]. Evolution in the radio frequency (RF) based wireless technology has not only minimized the requirement of wired EEG solutions but has also moved to the current wireless EEG devices, which are more adjustable and flexible to patients and the medical staff [6].

The authors in [7] reported that in dissimilarity to the traditional EEG monitoring where wet electrodes were used, current wireless EEG devices or systems make use of dry electrodes, however hair affects the immediate connection between scalp and the electrodes, thus ensuring in an obtrusive path in measuring EEG signals. Predominantly, the conventional silver/silver chloride electrodes with conductive gels were used to record EEG, however due to long-term monitoring the conductive gel dries and thus affecting the recording of EEG [8]. Yan-Jun Huang et al [9] proposed an active comb shaped dry electrode to separate the layer of hair to minimize the attenuation of the signal and phase shift, however the device was designed only for brain computer applications [9]. Yi-Hsin et al [10] used metal pogo probes in the design of dry sensors which could be used for EEG monitoring. However, even with high precision and quality the dry sensors produced discomfort. Valentin Goverdovsky et al [11] used in-ear sensors, which provided a low input impedance and immunity to several motion artifacts. Even with their ability to measure several responses, the device failed to provide comprehensive study of the human brain [11].

Healthcare Wireless systems should be light weight thus offering intelligent communication system ideal for both patients and mass market [12]. Presently, the RF based wireless is the only technology used in EEG or clinical applications, which suffers from lack of the frequency spectrum and electromagnetic interference [13], which the latter also has adverse effects on patient's health and the medical equipment especially in RF restricted zones like ICUs. It is well known that RF signal do suffer from multipath induced fading and distortions, which might affect the system performance and the extensive usage of mobiles and electronic devices in RF restricted areas such as ICU might have abnormal have harmful effect on brain signals too[14]. In healthcare applications, due to shortcomings of RF, VLC technology is optimum solution as it is free from electromagnetic interference, eco-friendly, highly secure and reliable [15,16]. Such a green technology could be used for patient monitoring, patient's data collection and transmission within hospitals as well as at home, and other places without using RF based technologies.

Optical camera communication (OCC) has gain interest due to popularity of smartphones with embedded cameras where data is transmitted in the form of binary bits through a screen and is captured by camera through video followed by image processing in MATLAB [17,18]. Furthermore, EEG recording from scalp electrodes is done from electrodes situated at different angles and distances on the scalp for the comprehensive study of the brain, Optical Camera Communication (OCC) is the recent development of VLC and an extension of VLC IEEE standard 802.15.7, first proposed due to advances in imaging [18,19]. The rise in smart devices usage and improvement in technology over the last decade opens a possibility of Visible Light Optical Camera Communication (VL-OCC) without any need of hardware modifications [19,20].

Hence, this research work experimentally demonstrates the real-time system for wireless angular transmission of EEG signals based on OOK-NRZ modulation using VL-OCC deploying OLED screen as transmitter and camera as receiver, thus illustrating the BER performance at different angles at several distances achieving the data rate of 2kbps with camera frame rate of 30fps. The remaining paper is set as; Section 2 describes the proposed system model of VL-OCC for EEG. Section 3 experimental set up and hardware description. Section 4 lists the results and discussions and the Section 5 concludes the paper.

## 2. Proposed VL-OCC System model for EEG

EEG Lab toolbox [21] was used to obtain the EEG signals shown in Fig. 1 and 2 using MATLAB and thereafter the signal processing was followed comprising of amplification as EEG signal is of low amplitude, filtering to remove the artefacts and Analogue to digital conversion of 16 bit was used to reduce the quantization error. A preamble of 400 bits comprising of all 1s was used to distinguish between the first and last frames during image processing and video capture.

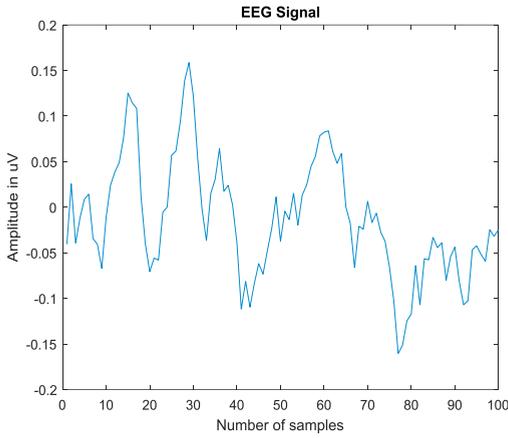


Fig.1. EEG signal captured from EEGlab using Matlab

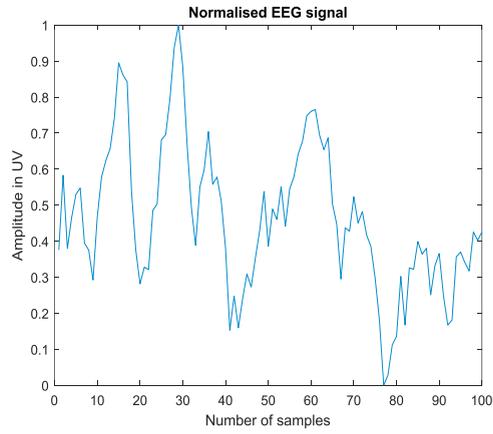


Fig.2. Normalised EEG signal

Figure 2. shows the Normalised EEG signal i.e EEG signal has values between 0 and 1. AWGN is the dominant noise, the data stream was received by a receiver unit comprising of Camera followed up by offline processing. In Figure 3, proposed system model is illustrated where  $b_n$  represents the useful data bits to be transmitted following modulation OOK-NRZ. The transmitter used is OLED (Organic light emitting diode) which is represented by rows and columns, hence information bits transmitted are in the form of rows and columns given by  $N = R_1 \times C_1$ .

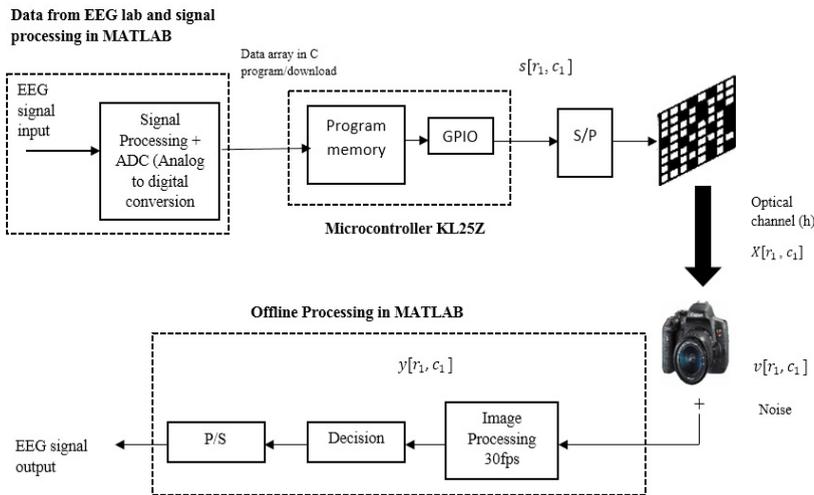


Fig. 3: Proposed System model [17]

Furthermore,  $s^{(t)} = [r_1, c_1]$  is the signal obtained after serial to parallel conversion with  $r_1$  and  $c_1$  represents the spatial coordinates of the OLED screen formed by rows and columns. D represents the square pixel where consisting of information bits, where the number of data bits transmitted per frame of OLED screen that changes with change in value of D is given by

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

Where,  $S_{z_{row}}$  and  $S_{z_{column}}$  is rows and columns number respectively. Thereafter, the optical channel signal becomes

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

In equation (2), h represents the impulse response. The signal received is given in equation (3).

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

Representing received signal by camera which is the matrix formed by pixels. Also,  $(v)^{(t)}[r_1, c_1]$  represents White

Gaussian noise (WGN) which is independent of the pixels. The video captured using camera is followed by image processing in MATLAB for BER calculation at different angles and several distances for the reliability of the proposed system.

### 3. Experimental setup and Hardware Description

Figure 4(a) Shows the experimental set up hardware design consisting of Microprocessor, switching board, OLED (Organic Light emitting diode) and voltage regulator. Voltage regulator LM series used to regulate the power voltage from dual power supply. The equipment used for experimental work along with model description listed below in Table 1.

Table 1. Experimental Equipment

| Equipment Required   | Model Description     |
|----------------------|-----------------------|
| OLED Screen          | DD-160128FC           |
| ARM processor        | KL25Z                 |
| Thorlabs Camera      | DCC 1645C             |
| Coding language used | C language and MATLAB |
| Voltage Power        | 2.8V                  |

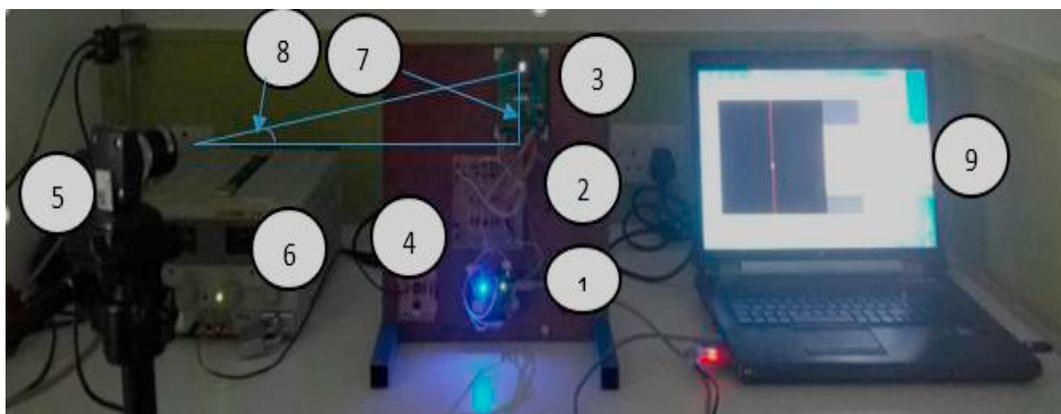


Fig.4. Experimental set up

Figure 4. shows the experimental set up where: 1. Microprocessor; 2. Switching Board; 3. OLED screen; 4. Voltage Regulator; 5. Camera as Receiver; 6. Power supply; 7. Normal at 0 -degree angle; 8. Angle deviation ( $\theta$ ); 9. Laptop

After the signal processing of EEG signal obtained from EEGlab, the EEG signal in the form of bits uploaded to ARM processor from laptop with the help of cable USB cable wire from PC connecting the ARM processor. The OLED screen works on a voltage of 2.8 V and the ARM processor on 3.3 V, so the switching PCB board used between the OLED screen and processor, which reduces the voltage to 2.8 V from 3.3 V.

Table 2. Description of OLED screen per pixel size and transmitted bit information

| S.No | Size of each block (in pixel) | Number of Rows * Columns as per size of block | Number of data bits can be transmitted per image/frame |
|------|-------------------------------|---|--|
| 1    | 32                            | 5*4   | 20   |
| 2    | 16                            | 10*8  | 80   |

|   |   |         |       |
|---|---|---------|-------|
| 3 | 8 | 20*16   | 320   |
| 4 | 4 | 40*32   | 1280  |
| 5 | 2 | 80*64   | 5120  |
| 6 | 1 | 160*128 | 20480 |

Table 2 lists the description of OLED screen per pixel size and transmitted bit data information. Depending upon the pattern of bits and the bits that single frame can transmit an OLED screen is represented as shown in Figure 5(a) and 5(b) respectively. The white section represents the transmission of '1' and the black section represent the transmission of '0' following the modulation scheme OOK-NRZ. At the receiver, side camera used followed by with image processing to detect the bits and to calculate the BER at different distances at different angles.

#### 4. Results and Discussion



Fig. 5(a) Image Processing at an angle deviation of pixel size 16

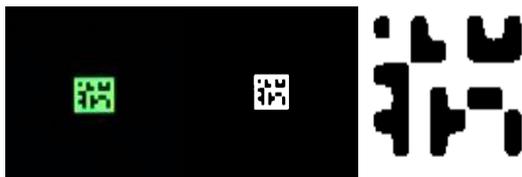


Fig. 5(b) Image Processing at an angle of 0-degree pixel size 16

At angle deviation the image received in Figure 5(a) is tilted depending upon the angle between the normal, transmitter and receiver. As shown in Figure 5(b). Larger angle deviation increases the image tilt thus resulting in an increase in BER as shown in Fig 6 at 50cm. Figure 7 shows the BER performance with distance and clearly states that with increase in distance the BER increases significantly. Thus, the BER increases significantly with increase in both distance and angle deviation respectively.

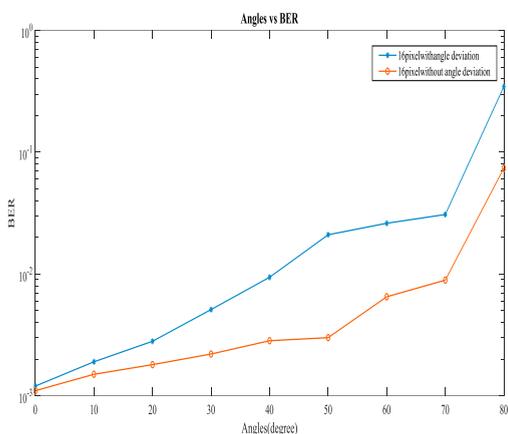


Fig. 6. Angles vs BER

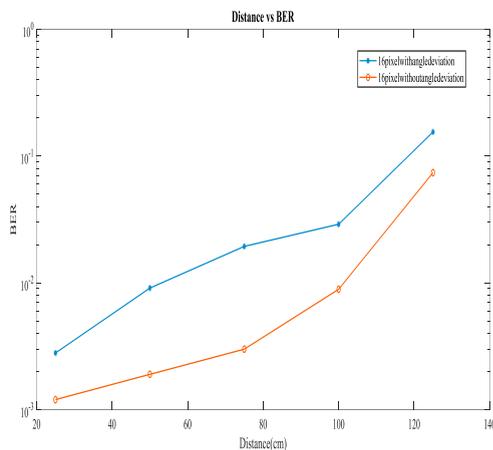


Fig. 7. Distance vs BER

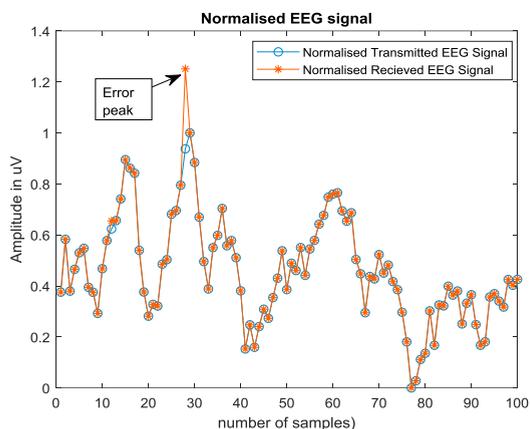


Fig. 8. Received EEG signal in Normalised form

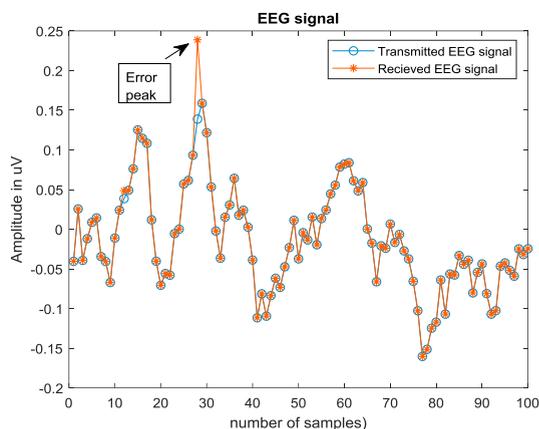


Fig. 9. Received EEG signal

The increase in distance and the higher angle deviation enhanced the BER significantly; however, during the EEG monitoring most of the electrodes placed on the scalp follow the 10-20 system [22]. Therefore, the ideal distance between two electrodes placed on scalp is of few millimetres and the maximum angle deviation range is from 0 to 30 degree [22]. As, using the VL-OCC system, the EEG signal was successfully recovered as shown in Figure 8 and Figure 9 thus implicates the reliability of the proposed system. Figure 8 shows the normalised transmitted and received signal while Figure 9 shows the received and transmitted EEG signal without any normalization, hence implicates the successful transmission of EEG signal using VL-OCC. There is one error peak which can be clearly seen in Figure 8 and Figure 9 when comparing the transmitted and received EEG signal at 50cm illustrating the BER increases significantly when angle deviation and distance between the transmitter and receiver is considerably increased.

## 5. Conclusion

The work in this paper suggested and experimentally proven novel technique to be deployed in hospitals for angular transmission of EEG signals using wireless VL-OCC system with achievable data rate of 2kbps using the camera frame rate of 30 fps. The BER obtained from the size of block of OLED screen in pixel size 16 irrespective of angle deviation is  $10e^{-3}$  at 50 cm. thus demonstrating a successful transmission of EEG signal using VL-OCC system. The achievable data rate is enough to detect EEG signal in applications where instant recording is required from couple of seconds to few minutes to detect the brain activity. This research work could be helpful in healthcare applications especially brain monitoring as presently the brain monitoring is done though traditional wired systems which is tedious using RF based technology suffering from EMI.

## Acknowledgement

The author would like to acknowledge the entire supervisory team from Northumbria University, UK and Sheffield Hallam University, UK for the dynamic guidance throughout the research work. The author also expresses gratitude towards the family especially Dad and younger sister for the endless support and encouragement during the study abroad. The author would also like to express gratitude to the anonymous reviewers for their comments and valuable suggestions.

## References

- [1] Ahmad, R.F.; Malik, A.S.; Kamel, N.; Reza, F., "A proposed frame work for real time epileptic seizure prediction using scalp EEG," in *IEEE International Conference on Control System, Computing and Engineering (ICCSCE), 2013*, vol., no., pp.284-289, Nov. 29 2013-Dec. 1 2013
- [2] Biswas, B.C.; Bhalerao, S.V., "A real time based wireless wearable EEG device for epilepsy seizure control," in *International Conference on Communications and Signal Processing (ICCSPP), 2015*, vol., no., pp.0149-0153, 2-4 April 2015
- [3] Jian Xu; Baitong Wang; Mclaughlin, B.; Schachther, S.; Zhi Yang, "An integrated sub-scalp EEG sensor for diagnosis in epilepsy," in *Biomedical Circuits and Systems Conference (BioCAS), 2015 IEEE*, vol., no., pp.1-4, 22-24 Oct. 2015
- [4] Mihajlovic, V.; Grundlehner, B.; Vullers, R.; Penders, J., "Wearable, Wireless EEG Solutions in Daily Life Applications: What are we Missing?" in *IEEE Journal of Biomedical and Health Informatics*, vol.19, no.1, pp.6-21, Jan. 2015
- [5] Peker, M.; Sen, B.; Delen, D., "A Novel Method for Automated Diagnosis of Epilepsy siUng Complex-Valued Classifiers," in *Biomedical and Health Informatics, IEEE Journal of*, vol.20, no.1, pp.108-118, Jan. 2016
- [6] Nezhad, M.H, Subari, K.S., Yahyavi, M, "Improvement of wireless transmission system performance for EEG signals based on development of scalar quantization", *Journal of Electrical Bioimpedance*, vol. 4, pp. 62-72, Dec 2013
- [7] Chin-Teng Lin; Chun-Hsiang Chuang; Chih-Sheng Huang; Shu-Fang Tsai; Shao-Wei Lu; Yen-Hsuan Chen; Li-Wei Ko, "Wireless and Wearable EEG System for Evaluating Driver Vigilance," in *IEEE Transactions on Biomedical Circuits and Systems*, vol.8, no.2, pp.165-176, April 2014
- [8] Lee, S.M.; Kim, J.H.; Park, C.; Hwang, J.; Hong, J.S.; Lee, K.H.; Lee, S.H., "Self-Adhesive and Capacitive Carbon Nanotube-Based Electrode to Record Electroencephalograph Signals From the Hairy Scalp," in *IEEE Transactions on Biomedical Engineering*, vol.63, no.1, pp.138-147, Jan. 2016
- [9] Yan-Jun Huang; Chung-Yu Wu; Wong, A.M.-K.; Bor-Shyh Lin, "Novel Active Comb-Shaped Dry Electrode for EEG Measurement in Hairy Site," in *IEEE Transactions on Biomedical Engineering*, vol.62, no.1, pp.256-263, Jan. 2015
- [10] Yu, Yi-Hsin; Lu, Shao-Wei; Chuang, Chun-Hsiang; King, Jung-Tai; Chang, Che-Lun; Chen, S.; Chen, Sheng-Fu; Lin, Chin-Teng, "An Inflatable and Wearable Wireless System for Making 32-Channel Electroencephalogram Measurements," in *Neural Systems and Rehabilitation Engineering, IEEE Transactions on*, vol. PP, no.99, pp.1-1
- [11] Goverdovsky, V.; Looney, D.; Kidmose, P.; Mandic, D.P., "In-Ear EEG From Viscoelastic Generic Earpieces: Robust and Unobtrusive 24/7 Monitoring," in *Sensors Journal, IEEE*, vol.16, no.1, pp.271-277, Jan.1, 2016
- [12] Dey, N., Ashour, A. S., Shi, F., Fong, S. J., & Sherratt, R. S. (2017). Developing residential wireless sensor networks for ECG healthcare monitoring. *IEEE Transactions on Consumer Electronics*, 63(4), 442-449.
- [13] Dhatchayeny, D.R.; Sewaiwar, A.; Tiwari, S.V.; Yeon Ho Chung, "Experimental Biomedical EEG Signal Transmission Using VLC," in *Sensors Journal, IEEE*, vol.15, no.10, pp.5386-5387, Oct. 2015
- [14] Yew-Kiat Cheong; Xiao-Wei Ng; Wan-Young Chung, "Hazardless Biomedical Sensing Data Transmission Using VLC," in *Sensors Journal, IEEE*, vol.13, no.9, pp.3347-3348, Sept. 2013
- [15] Prasad, R.; Mihovska, A.; Cianca, E.; Mukherjee, S., "Comparative overview of UWB and VLC for data-intensive and security-sensitive applications," in *IEEE International Conference on Ultra-Wideband (ICUWB), 2012* vol., no., pp.41-45, 17-20 Sept. 2012
- [16] Al-Qahtani, A.; Nasir, A.; Shakir, M.Z.; Qaraqa, K.A., "Cognitive impairments in human brain due to wireless signals and systems: An experimental study using EEG signal analysis," in *e-Health Networking, Applications & Services (Healthcom), 2013 IEEE 15th International Conference on*, vol., no., pp.1-3, 9-12 Oct. 2013

- [17] G. Aggarwal, X. Dai, R. Binns, R. Saatchi, K. Busawon, E. Bentley (2018) Wireless EEG Signal Transmission Using Visible Light Optical Camera Communication. In: Deka G., Kaiwartya O., Vashisth P., Rathee P. (eds) *Applications of Computing and Communication Technologies. ICACCT 2018*. Communications in Computer and Information Science, vol 899. Springer, Singapore
- [18] J. Deguchi, T. Yamagishi and H. Majima, "A 1.4Mpixel CMOS image sensor with multiple row-rescan based data sampling for optical camera communication," in *Solid-State Circuits Conference (A-SSCC), 2014 IEEE Asian, 2015*.
- [19] Roberts, R.D., "A MIMO protocol for camera communications (CamCom) using under sampled frequency shift ON-OFF keying (UFSOOK)," in *Globecom Workshops (GC Wkshps), 2013 IEEE*, vol., no., pp.1052-1057, 9-13 Dec. 2013.
- [20] Roberts, R.D., "Space-time forward error correction for dimmable under sampled frequency shift ON-OFF keying camera communications (CamCom)," in *Fifth International Conference on Ubiquitous and Future Networks (ICUFN), 2013* vol., no., pp.459-464, 2-5 July 2013.
- [21] Etoolbox. Bioelectromagnetism MATLAB Toolbox. [Online]. Available at: <http://eeg.sourceforge.net>
- [22] S. Mantri, et al, 'A Survey: Fundamental of EEG' *International Journal of Advance Research in Computer Science and Management Studies*, vol 1, Sept 2013.