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Free-Space Optical Communication with an Optimized Lipschitz Exponent for Biosignal Telemetry

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Abstract: Healthcare monitoring is a rapidly developing network in the field of advanced medical treatment. The network combines the ideology of wireless communication, signal processing, medical information and real-time processing units to support the medical monitoring system. The proposed work focuses on the development of a Free-Space Optical (FSO) system to transmit the biosignals from a remote distance to the physician. Generally, the data transmitted over the FSO system is affected by various atmospheric conditions such as air medium, O_2, and H_2O molecules. To tackle these problems, the Biosignals Electrocardiogram (ECG) and Electroencephalogram (EEG) are processed in the Optimized Lipschitz Exponent (OLE) function before transmission over the FSO medium. In this novel technique, the OLE function measures the informative data from the biosignals by calculating the local regularities and singularity. This collects the most informative signals and transmits them in the signal over the FSO medium. This particular hybridization helps to transmit the required data without distortion. The Bit Error Rate (BER) of 10^{-9} is obtained, which satisfies the healthcare monitoring condition. The result section shows that the proposed model has minimum losses compared to the original signal.

Keywords: Biosignals, optimized Lipschitz function, free-space optics medium, Line-of-Sight (LOS), diffusion channel.

1. Introduction

The emerging field of health monitoring systems has inspired great innovation in the technology world. Especially, the remote healthcare system, which enables remote monitoring in urban areas, biotelemetry, real-time monitoring, and fast action for the detection of diseases [1]. In general, remote monitoring is the observation of patients in rural or remote areas without direct contact. The advantages of remote monitoring include biosignal transmission, continuous monitoring of the incapacitated person, and immediate and rapid treatment of fatal conditions [2]. Transmission of biosignals from the remote area is possible through a Radio Frequency (RF) medium and optical wireless communication [3]. Herein, the Free-Space Optical (FSO) is an advanced field of optical communication that transmits information using propagation of light sources through free space [4]. Recently, FSO has played a significant role in healthcare monitoring systems for the transmission of biosignals, such as wireless RF devices for monitoring human skin, gigabit data telemetry using bidirectional FSO, transmission of multiple patient biosignals using an optical area network, and high-speed FSO communication link for biomedical signals [5].

Biosignals or bioelectrical signals are generated by the electrical potential in body tissues and measured by electrical devices such as Electroencephalogram (EEG), Electrocardiogram (ECG), Electrooculogram (EOG), Electromyogram (EMG), and Electroretinogram (ERG) [6]. The EEG and ECG signals are chosen for the transmission process in the proposed work. The electrical signals are measured in analog waveform and converted to digital or light signals for transmission over free space [7]. The FSO system has a high-frequency space, which is a great advantage for the transmission of biosignals. However, the FSO communication system faces spreading loss and atmospheric loss due to O_2 and H_2O molecules in the air [8], [9].

Similarly, the free-space medium is constructed in the following step [10], [11]. First, the electrical signal is converted to the light source using the Light-Emitting Diode (LED). The signal is multiplexed in Frequency Division Multiplexing (FDM) to separate the carry signal. Then the Lithium Niobate Modulator (LNM) is used to control the amplitude of the optical waves. The waves are processed in the optical filter and the information is recovered using the FDM demodulator [12], [13]. The metal semiconductor metal

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photodetector is used at the receiver end of the free-space medium to convert the photon energy of the light into electrical form. Finally, the signal is filtered in a low-pass filter and visualized to the analyzed biosignal [14]. Transmission of biosignals is a revolutionary development of the medical monitoring system. Free-space optics is a major source of optical communication that facilitates the biosignal transmission process. Here are some brief retrospective studies on FSO and biosignal communication. In 2015, Vazquez-Lopez, Rodriguez-Aleman, and Romo-Cardenas [15] developed a FSO system to transmit the ECG signal for telemedicine approaches. Studies were intended to model the transmission optical effects in the environment through absorption experiments, and beam polarization was used to better understand its functioning, benefits, and limitations. In 2017, Alyan and Aljunid [16] developed a Code Division Multiple Access (CDMA) optical system for monitoring biosignals using infrared technology. This system states that the model achieves high power efficiency in a health monitoring system using RF infrared technology.

In 2020, Guiomar et al. [18] presented adaptive probabilistic modulation for FSO links. They also demonstrated a time-adaptive modulation scheme to increase bit rate flexibility and adjust the transmission rate and reliability. Ahmed et al. [19] discussed the concept of wireless communication and Hospital of Future (HoF) connectivity. The paper focused on the hybridization of the radio and optical networks to transmit both types of signals. Llorente et al. [20] developed a deep learning technique to classify the EEG biosignal. The technique implements the Lyapunov analysis method to analyze the local convergence of the weight in the network model and the convergence error. Noel et al. [21] developed an optimization technique based on the firebug swarm behavior. This technique showed that the optimization technique extends the performance of FSO for multi-dimensional problems.

The aforementioned works investigate the performance of existing models for wireless communication, biosignal telemetry, FSO communications, and optimization techniques. The review shows that mathematical models have a great impact on biosignal processing. Similarly, FSO faces various atmospheric losses when transmitting and receiving biosignals from remote regions. To address this problem, the proposed work focuses on developing an Optimized Lipschitz Exponent (OLE) function that computes the informative data from the biosignal and binds the signal to control the loss of biosignals during transmission.

The proposed work was developed with the idea of developing an optimized mathematical model to combat atmospheric loss in the FSO system. The proposed OLE is a sophisticated mathematical feature that can characterize the signal's local regularity or smoothness. Singularity is the mathematical aspect that measures the sharpness of random variables in signals. The biosignal acquired from the patient is first processed with an optimized Lipschitz exponent to collect the informative data from the acquired biosignals. Then the signal is packed with the raw biosignal and transmitted through the free-space medium.

The remainder of this paper is organized as follows. Section 2 contains a detailed explanation of the proposed method for shine cancer detection, section 3 comprises the experimental results, section 4 contains the discussion of the proposed model, and finally section 5 presents the conclusion and future work.

2. PROPOSED METHODOLOGY

Remote monitoring system is an advanced technology of medicine that helps in early detection and monitoring of remote patients in real time through a wireless medium. The current work focuses on the development of an optical wireless communication system to monitor the health condition of patients remotely.

A. Free-Space Optics (FSO) medium

FSO communications is an optical communication that transmits visible and infrared (IR) beams through the atmosphere. This technique uses lasers and LEDs to transmit data through the air instead of streaming in optical fiber. This method is very efficient for high bit rates and short distances and can satisfy the broadband requirements. FSO is a Line-of-Sight (LOS) technology that allows for full-duplex (bidirectional) data, voice and video communications at a maximum data rate of 10 Gbps. FSO systems have several advantages, including low-cost setup and operation, bandwidth comparable to fiber optic cables, transmission at the speed of light, signal interception resistance, and license- and regulation-free operation.

FSO is an optical communication medium that usually transmits high-frequency signals from one point to another at incredible speeds. FSO uses narrow optical beams and relies on point-to-point transmission. Unlike a dedicated optical fiber link, the FSO technology uses unlicensed bandwidth above 300 GHz and can be easily set up or uninstalled. FSO systems first gained attention as a solution to the last-mile problem by bridging the gap between the end user and the existing optical fiber and RF network infrastructure.

Representation of the FSO System

Transmitter: The modulator receives the information-carrying biosignal (EEG and ECG) in electrical form and an electrical carrier or subcarrier with coherent and non-coherent modulation. The modulated carrier then modifies the intensity of an optical source, such as a LED, which produces optical beams suitable for optical transmission in the spectral windows of 780-850 nm and 1520-1600 nm. The LED was used as a broadband source at the transmitter and was presumed to relate to the medical sensor, then the signal is multiplexed using FDM to separate the carrier signal. It divides the spectrum into tiny 0.6 - 1.0 nm spectrum widths. Then the lithium niobate modulator fabricated with 8.5 mm and 14 mm length measures the directly transmitted current. The LNM is proficient in encoding the biosignals transmitted by an optical medium. It uses quadrature amplitude modulation and quadrature phase-shift keying signals to encode biosignals. These factors reduce optical loss during transmission. Then, the nodes are combined and transmitted to the FSO channel medium. The schematic block diagram of the transmitter and receiver of the FSO-OLE system is depicted in Fig. 1 and Fig. 2.

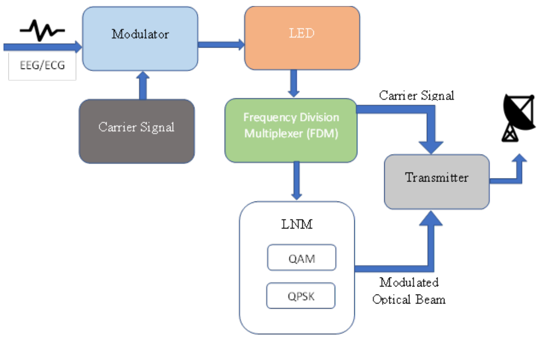


Fig. 1. Transmission Unit of an FSO system.

Receiver: The information beam transmitted through the atmospheric channel is restored using the FDM demodulator. The FDM DEMUX has a group of bandpass filters to decode all the information without any distortion. It removes the carrier signal and retrieves the original biosignal. The metal semiconductor metal photodetector is used at the receiver end of the free-space medium to convert the photon energy of light into electrical form. In the proposed work, the Metal Semiconductor Metal (MSM) photodetector is used especially because of its high-speed communication. Finally, the signal is filtered in a Low-Pass Filter (LPF) and visualized in the biosignal analyzer.

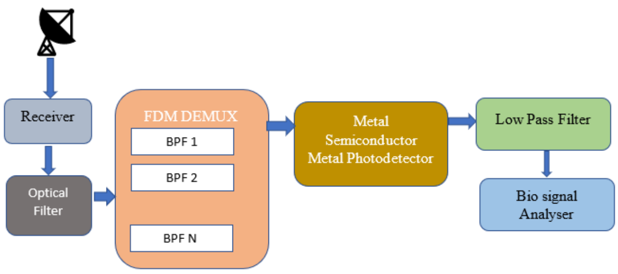
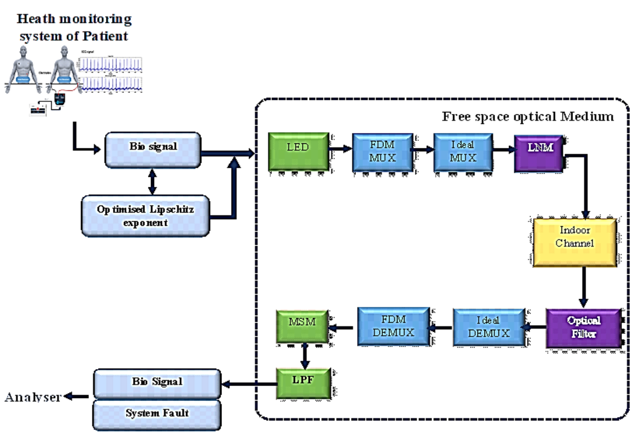


Fig. 2. Receiver unit of an FSO system.



LED - Light-Emitting Diode
FDM - Frequency Division Multiplexing
LNM - Lithium Niobate Modulator
MSM - Metal Semiconductor Metal photodetector
LPF - Low-Pass Filter

Fig. 3. Overall workflow of enhanced free space medium for biosignal telemetry.

FSO communication provides a high data rate to meet the constantly increasing need for broadband traffic, fueled primarily by Internet access and HDTV transmission. Meteorological factors impede the FSO transmission, reducing vulnerability and data rates with acceptable Bit Error Rate (BER). Turbulence, absorption, and scattering are some of these degradations, and a number of mitigation approaches exist to ensure reliable and efficient data transmission and improve communication performance.

The proposed system developed a modified free-space optics (FSO) medium for transmitting biosignals from a remote area to the health analyzer. However, the FSO medium faces some problems such as spreading loss and atmospheric loss due to O_2 and H_2O molecules in the air. To address this problem and prevent the loss of signal, an OLE is added to the biosignal monitor. OLE is a mathematical derivative that measures the singularity and dynamic behavior of the ECG and EEG signals. Fig. 3 describes the overall workflow of the proposed OLE-FSO system.

B. *Optimized Lipchitz Exponent (OLE)*

The Lipschitz exponent is a continuous function that is important for a smooth deformation function. In biosignals, the local regularity, singularity variation, and dynamic behavior of biosignals are often calculated by the Lipschitz Exponent (LE). In the Lipschitz function, important information about the signal is calculated by taking the modulus maxima of the signal and that data is bound together and transmitted through FSO. In the proposed work, the Lipschitz function is optimized with a discrete harmonic wavelet function. First, the singularity character of the biosignal is detected using the modulus maxima of the EEG and ECG wavelets. The Discrete Harmonic Wavelet (DHW), a complex wavelet, is considered to detect the weak singularities in the given biosignal. DHW is sensitive to susceptible singularity features and handles the multi-wavelet frames.

Lipschitz is a strong form of uniform continuity for functions, while DHW is sensitive to small variations in the signal. Thus, the combination of Lipschitz and DHW helps to accurately determine the singularity of the biosignal. Even the weak singularities are estimated using the DHW function. This novel method helps to identify the minor changes in the biosignal and transmits them without any corruption by transmission noise.

Lipschitz exponent

The function F(x) is a Lipschitz l_z, for $0 \leq \alpha \leq 1$, if and only if a constant C exists at the point x_0.

$$|f(x) - f(x_0)| \leq C|x - x_0|^{\alpha} \tag{1}$$

Therefore, $f(x)$ is uniformly Lipschitz for all x. The neighborhood of x_0 in (1), $f(x_0)$ is continuous when $\alpha > 0$ and singular when $\alpha \neq 1$.

Suppose, the function $f(x)$ is n times differentiable in $[x_n - c, x_n + c]$; then, the neighborhood of x_n in Taylor form is,

$$f_{x_0}(x) = \sum_{C=0}^{n-1} \frac{f^{c}(x_n)}{C!}(x - x_0)^c \tag{2}$$

Approximate error,

$$e(x) = f(x) - f_{x_0}(x) \tag{3}$$

When x goes to x_0, the n^{th} time differentiability of $f(x)$ in the neighborhood x_0 offers an upper bound on the error $e(x)$.

Discrete harmonic wavelet algorithm

The discrete harmonic wavelets are expressed by,

$$\omega_j^n(2^m x - j) \stackrel{\text{def}}{=} \frac{\exp(4\pi i(2^m x-j)-\exp(2\pi i(2^m x-j))}{2\pi i(2^m x-j)} \tag{4}$$

where n = -1, 0, 1, 2, 3, … N, n is different scale and j is different time

Modulus maxima of wavelet

The $f(x)$ modulus maximum function of wavelet at the pt. $(2^m, x_0)$ is given as,

$$|\omega f(2^m, x)| < |\omega f(2^m, x_0)| \tag{5}$$

Here x is the nearby element of x_0. A modulus maximum in the space m = -1, 0, 1, 2, …. N. These multiscale modulus maxima are utilized to find discontinuities, and if $f(2^m, x)$ has no modulus maxima at tiny scales. $f(x)$ is locally regular. Modulus maximum helps to identify a singular point.

Optimized Lipschitz function based on discrete wavelet transform

The Lipschitz exponent of local regularities and singularity was determined based on the characteristics of their local modulus maxima at each scale. By using a Lipschitz exponent and a quantitative analysis of the signal singularities, the modulus maxima of the harmonic wavelet transform exploited the singularities. By looking at the asymptotic drop of the wavelet modulus maxima from coarser to finer scales, the Lipschitz exponent is used to characterize the strength of the singularity.

Let $v = 2^m$ and m = -1, 0, 1, 2, …. N in terms of the optimized Lipschitz function $f(x), x\,\epsilon(p,q)$. The *m*th derivative of Rl $(\omega f(v,x)$ and Img $(\omega f(v,x)$ is defined for each level *v*. If a level $v_0 > 0$ and the constants C and E exist for $x\,\epsilon\,(v,x)$ and $v > v_0$, the modulus maxima of $\omega f(v,x)$ belonging to a cone is expressed by,

$$|v - v_0| \leq Cv \tag{6}$$

Therefore, the maximum module (v,x) in the cone is given as;

$$|\omega f(v,x)| \leq E v^{\alpha} \tag{7}$$

When $x \neq x_0$, $f(x)$ is uniformly Lipschitz (α) at x and when $l_z < m, f(x)$ is Lipschitz at x_0. Here α is a non-integer.

Taking logarithm on both sides of (7);

$$\log|\omega f(v,x)| \leq \log_2 E + \alpha \log_2 v \tag{8}$$

Computation of E and α,

$$\min_{A,\alpha} \textstyle\sum_v [\log_2|\omega f(v,x)| - \log_2 E - \alpha * \log_2 v]^2 \tag{9}$$

The estimation of alpha changes is based on nonlinear least squared optimization. With the minimization of (9) at all levels, the A and Lipschitz function are obtained.

Substituting the value $v = 2^m$, the following equation is obtained

$$\alpha(x) = \left(\textstyle\sum_{m=-1}^{N} \sum_{m=-1}^{N} (\log_2|\omega f(2^m, x)| * \log_2 2^m) - \frac{(\sum_{m=-1}^{N} \log_2|\omega f(2^m,x)|)(\sum_{m=-1}^{N} \log_2 2^m)}{N}\right) \tag{10}$$

The derived $\alpha(x)$ is the function of the optimized Lipschitz exponent. The change of the Lipschitz exponent value along the (*x*) plane describes the ECG and EEG signal information during the biosignal monitoring process.

C. Channel model

The proposed FSO system has three major channels, namely a transmitter, an atmospheric channel, and a receiver. The channel is classified based on the transmission and reception path, the transmitter's degree and the receivers' field of view. The LOS channel and the indoor diffusion channel are discussed in the following section.

LOS channel

Due to absorption and scattering, a LOS channel has a relatively short length and very low attenuation. A generalized Lambertian radiant intensity is used to quantitatively describe the LED output. The direct path between the transmitter and the receiver is represented by the indoor LOS link. The channel gain of the receiver at a distance L_0 and an angle φ_0 in accordance with the transmitter is given in (11),

$$Ch_{LOS} = \begin{cases} \frac{n+1}{2\pi L_0^2} P_A T_{fc}(\Psi_0) T_{cn}(\Psi_0) cos^n(\varphi_0)\cos(\Psi_0), \\ \qquad 0 \leq \Psi_0 \leq \Psi_c \\ 0, \ \Psi_0 \geq \Psi_c \end{cases} \tag{11}$$

Here P_A indicates the physical area of the photodetector, $T_{fc}(\Psi_0)$ refers to the transmission factor of the optical filter, (Ψcn) – semi angle concentrator of the field of view, and *n* – Lambertian order of emission with half power semi-angle.

$$n = \frac{\ln(2)}{\ln(\cos{\varphi_0}^{1/2})} \tag{12}$$

Indoor diffusion channel

The loss in optical links for non-directed LOS and diffuse connections is more difficult to predict because it is affected by numerous factors. The power received at the detector is given by the expression,

$$Pw_{Los} = Ch_{LOS}(0) + Ch_{LOS}(0)Pw_{tx} = Ch_{LOS}(0)_{-} + \textstyle\sum_{reft} Ch_{LOS}(0)Pw_{tx} \tag{13}$$

The transmitter is attached to the medical sensor on the patient's body, and the receiver is installed on the ceiling with the field of vision (FOV) directed down to the floor. The light reflected from whole wall surfaces can be analytically approximated by breaking the reflecting surfaces into small reflecting components dA. As a result, for first-order reflection, the channel Dark Current (DC) gain is given by

$$Ch_{diff} = \begin{cases} \frac{(n+1)(n_{element}+1)}{4\pi^2 L_1^2 L_2^2} P_A dP\rho T_{fc}(\Psi_1) T_{cn}(\Psi_1) cos^n(\varphi_1), \\ \cos(\delta_1)\, cos^{n_{element}}(\gamma_1)\cos(\Psi_1), 0 \le \Psi_1 \le \Psi_c \\ 0,\ \Psi_1 \ge \Psi_c \end{cases} \quad (14)$$

Here $L_1 \& L_2$ is the reflective wall separation between the transmitter and the receiver point and receiver and target point, respectively. γ_1 – the angle between the irradiance element and the reflection coefficient (ρ), Table 1.

Table 1. Parameters of the FSO monitoring system.

Component	Parameter
Optical Filter	Bandwidth = 1550 nm
Room Dimension	12' x 14'
MSM	0.11 A/W
Fluorescent lamp power	36 W
Frequency	50 Hz
Dark current	4.55×10^4 mW^{-1}

Performance analysis

Certain metrics are measured and compared with existing methods in order to estimate the system's performance. Transmitted optical power refers to the output optical power of the light source on the optical module's transmitting end, while received optical power refers to the input optical power of the light source on the optical module's receiving end. This is the signal's strength, often known as its power level. 1 mW (milliwatt) of power in a power meter is equivalent to 0 dBm. Negative signals are small signals. For example, typical LED power sources have a -20 dBm output power, while laser and VCSEL sources for fiber optic testing have a -10 dBm output power. An ECPR, or electrically calibrated pyroelectric radiometer, is the NIST standard for all power measurements. It compares the heating power of light to the well-known heating power of a resistor to determine the optical power. Calibration is performed at 850, 1300, and 1550 nm. The BER is strongly influenced by the transmitter power level.

Bit Error Rate (BER)

The BER is the proportion of bits with errors compared with the total number of bits received in a transmission, often expressed as ten to a negative power. The BER is measured by finding the ratio between the total number of bits transmitted in the same period and the number of bits received in error. A BER of 10^{-9} is typically considered acceptable in telecommunications, although 10^{-13} is a more appropriate minimum for data transmission BER. The BER is calculated by comparing the transmitted and received bit sequences and calculating the number of errors. The BER is the ratio between the total number of bits received and the number of bits received by mistake. When sending data from one location to another, the most important consideration is how many errors will appear in the data at the other end.

Optical Signal-to-Noise Ratio (OSNR)

The Optical Signal-to-Noise Ratio (OSNR) is a significant indicator of signal quality for long-distance fiber-optic communications. OSNR values represent the signal degradation due to Amplified Spontaneous Emission (ASE) noise introduced by optical components such as amplifiers along the transmission path. When an optical signal is transmitted over an optical transmission system with optical amplifiers, OSNR is crucial because it indicates the degree of degradation. It can be thought of as the Quality of Service (QoS) at the physical layer of optical networks. The noise power received at the receiver is summed by the noise sent from each amplifier across the link to the receiver. The value of OSNR can be calculated by subtracting the noise power from the signal power, according to the definition.

Q-Factor

A Q-factor is a comprehensive measure of an optical channel's signal quality that accounts for noise, filtering, and linear/non-linear distortions of the pulse form, which cannot be determined with simple optical characteristics alone. Receiver performance is qualitatively described by the Q-factor, which is a function of OSNR. The Q-factor is the minimal SNR required to obtain a given BER. For high bit rate, high OSNR ratio is required.

3. EXPERIMENTAL RESULTS

The evaluation of the optimized Lipschitz exponent and the free-space optic section for monitoring the ECG and EEG signals is implemented by the MATLAB 2019b stimulation platform. The following section illustrates the performance and effect of the OLE function on biosignal transmitting power, error rate, and OSNR.

A. System model

The system will be housed in 12 x 14 rooms in remote areas about 7 km from the hospital. Medical devices such as ECG and EEG electrodes are placed on the patient's body [22]. The signal is continuously monitored with a multiparamonitor. In this work, we recorded various EEG and ECG signals from 20 patients from different aspects. The six sample images of the patients are shown in Fig. 4.

In this model, informative features of the biosignal are measured by the optimized Lipschitz function [23]. OLE measures the information such as singularities, dynamic behavior, and local regularities from the EEG and ECG signals. The processed real-time signals are transmitted to the target receiver via the free space medium [24]. The transmission and reception process are managed through the line-of-sight and indoor optical channels. At the receiver end, the optical filter receives the source signal and the noise signal [25].

The optical filter removes the background noise and converts the optical signal into an electrical signal using the photodiode [26]. The LPF is placed on the receiver end to remove unwanted frequency signals, and finally the output is calculated by the signal analyzer.

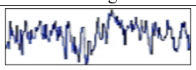
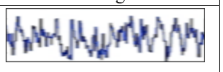
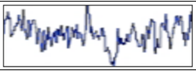
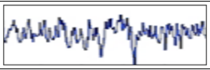
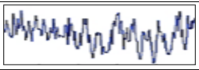
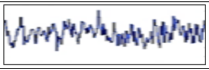
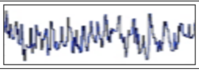
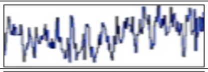
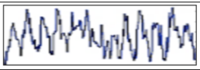
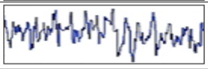
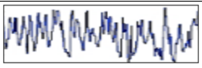
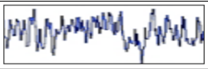
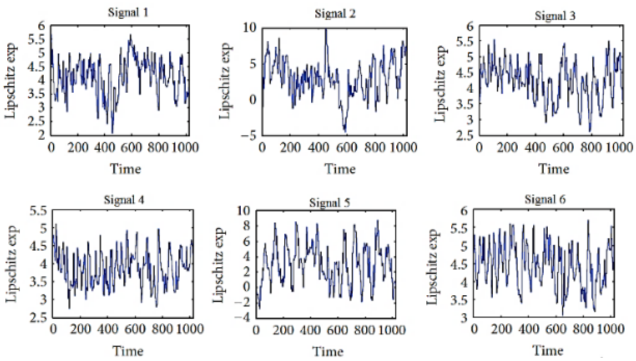
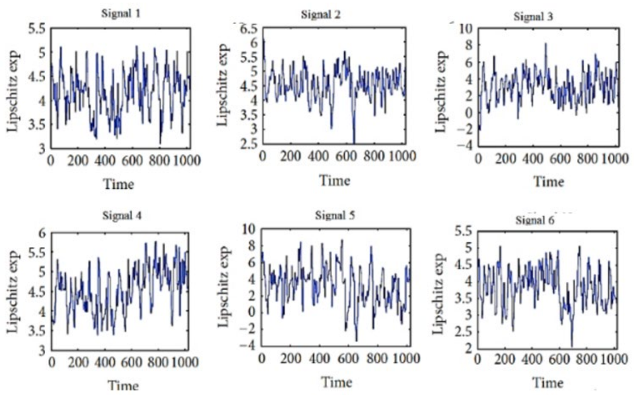
Patient details	Biosignal Telemetry	
	EEG signal	ECG signal
Gender: Male Physical: Fat Age: 56		
Gender: Female Physical: Skinny Age: 22		
Gender: Male Physical: Normal Age: 26		
Gender: Male Physical: Skinny Age: 35		
Gender: Female Physical: Fat Age: 36		
Gender: Female Physical: Normal Age: 20		

Fig. 4. Samples of biosignal telemetry.

Fig. 5 shows the ability to detect local irregularities and singularities of EEG and ECG biosignals with optimized Lipschitz function. The obtained biosignals are transmitted to the hospitals about 7 km from the remote area via a FSO medium. The biosignals of the patients are improved by the OLE function and the optimized signal is transmitted to the hospital.



(a) EEG signal



(b) ECG signal

Fig. 5. Optimized Lipschitz function of the EEG and the ECG biosignal data.

B. *Performance of transmitted power signals on FSO power system*

For performance analysis, the bit error rate estimation for the LOS channel and the indoor diffusion channel are illustrated in Fig. 6 and Fig. 7. The bit error rate of LOS scenario 1 and scenario 2 for 100 kbps, 1 Mbps, and 10 Mbps data is shown in Fig. 6. The bit error rate of diffusion channel scenario 1 and scenario 2 for 100 kbps, 1 Mbps, and 10 Mbps data is shown in Fig. 7.

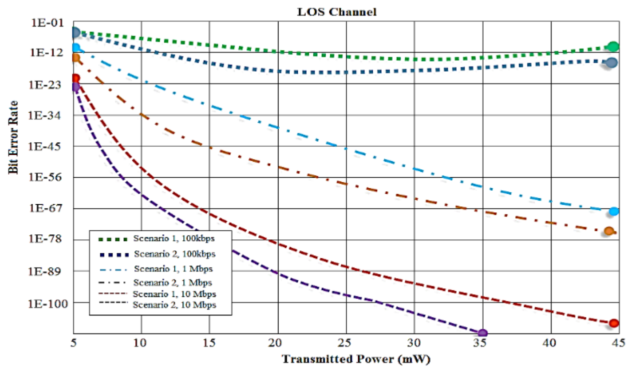


Fig. 6. Bit error rate and transmitted power for LOS channel of scenario 1 and scenario 2.

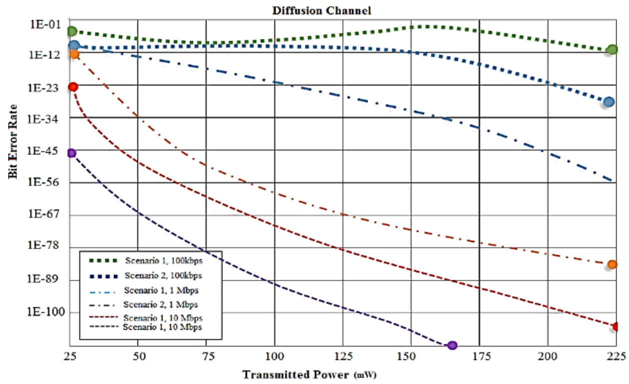


Fig. 7. Bit error rate and transmitted power for diffusion channel of scenario 1 and scenario 2.

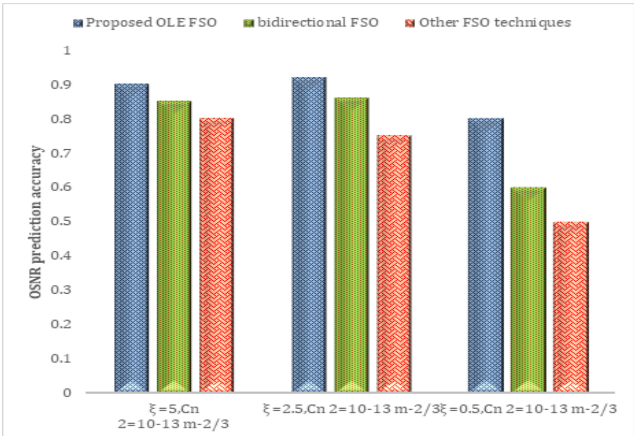


Fig. 8. OSNR performance accuracy of OLE-FSO model and the existing models.

From Fig. 6 and Fig. 7, it is clear that the optimized biosignal has a lower BER than the raw biosignal in all frequencies of 100 kbps, 1 Mbps, and 10 Mbps. This proves that the proposed FSO-OLE method is better than the conventional methods and the error rate is lower [29].

The OSNR value is determined to measure the performance of the OLE-FSO system and the result is compared with existing methods. For the comparison, the system selects the Q-factor-based parameter in the existing FSO techniques and the proposed OLE-FSO model to predict the OSNR performance accuracy. Fig. 6 shows the OSNR performance of the proposed OLE-FSO model, bidirectional FSO and other FSO techniques.

The OSNR is calculated for the proposed FSO-OLE method, the bidirectional FSO system, and other FSO systems for different carrier signal frequencies. Fig. 8 shows that the OSNR value of the proposed FSO-OLE method is high for all different carrier signal frequencies. Thus, the efficiency of the FSO-OLE method is proved.

4. Discussion

The performance evaluation of the proposed model was calculated using certain parameters such as transmitted power, bit error rate, and optical signal-to-noise ratio. To understand the efficiency of the optimized Lipschitz exponent function, the BER of the normal biosignal and the optimized biosignal are calculated separately in two different channels (LOS and Diffusion) and compared for analysis [27]. We consider two scenarios in the comparison stage. In scenario 1, the regular biosignals (ECG and EEG) of the 20 patients are collected, transmitted through the FSO system, and received at the hospital [28]. In scenario 2, the biosignals of the same 20 patients are improved by the OLE function and the optimized signal is transmitted to the hospital. Moreover, the optimized biosignal has a lower BER than the raw biosignal in all frequencies of 100 kbps, 1 Mbps, and 10 Mbps, as shown in Fig. 6 and Fig. 7. This demonstrates that the proposed FSO-OLE method is superior to the established methods and has a lower error rate. From Fig. 8, it can be seen that the proposed OLE-FSO model has the best performance in terms of OSNR compared to the existing methods. The bit error rate of 10^{-9} is obtained, which satisfies the healthcare monitoring condition.

5. Conclusion

The present work focuses on the processing and transmission of biosignals over the free-space medium. The system is developed with an optimized Lipschitz function and an improved free-space medium for signal transmission. The transmitter end of the FSO system has a LED source, FDM, and lithium niobate modulator to convert the electrical source into a convenient transmission signal. On the receiver end, the signal consists of an optical filter, an FDM demultiplexer, and a metal semiconductor metal photo detector to obtain the biosignal in electrical form. The performance of the proposed OLE and FSO systems is examined through the graphical output of the biosignal and the transmitted power and bit rate error in the LOS and diffusion channel. The bit error rate of 10^{-9} is obtained for scenario 1 and scenario 2, which satisfies the healthcare monitoring condition. The result section shows that the proposed model has minimum loss compared to the original signal. The proposed system allows the analyzer to detect the fault or error and prevent the loss of the signal. In the future, the system can be enhanced with advanced deep learning techniques to increase the robustness of the free-space medium.

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References

[1] Malasinghe, L.P., Ramzan, N., Dahal, K. (2019). Remote patient monitoring: A comprehensive study. *Journal of Ambient Intelligence and Humanized Computing*, 10 (1), 57-76. https://doi.org/10.1007/s12652-017-0598-x

[2] Hamil, H., Zidelmal, Z., Azzaz, M.S., Sakhi, S., Kaibou, R., Djilali, S., Ould Abdeslam, D. (2022). Design of a secured telehealth system based on multiple biosignals diagnosis and classification for IoT application. *Expert Systems*, 39 (4), e12765. https://doi.org/10.1111/exsy.12765

[3] Sofi, A., Regita, J.J., Rane, B., Lau, H.H. (2022). Structural health monitoring using wireless smart sensor network – An overview. *Mechanical Systems and Signal Processing*, 163, 108113. http://dx.doi.org/10.1016/j.ymssp.2021.108113

[4] Mohsan, S.A.H., Amjad, H. (2021). A comprehensive survey on hybrid wireless networks: Practical considerations, challenges, applications and research directions. *Optical and Quantum Electronics*, 53, 523. https://doi.org/10.1007/s11082-021-03141-1

[5] Occhiuzzi, C., Parrella, S., Camera, F., Nappi, S., Marrocco, G. (2021). RFID-based dual-chip epidermal sensing platform for human skin monitoring. *IEEE Sensors Journal*, 21 (4), 5359-5367. https://doi.org/10.1109/JSEN.2020.3031664

[6] Chan, E., Saint Clair, J. (2016). Bi-directional free space laser communication of gigabit ethernet telemetry data using dual atmospheric effect mitigation approach. In *Atmospheric Propagation XIII*. SPIE Vol. 9833. https://doi.org/10.1117/12.2225270

[7] Dhatchayeny, D.R., Cahyadi, W.A., Teli, S.R., Chung, Y.H. (2017). A novel optical body area network for transmission of multiple patient vital signs. In *2017 Ninth International Conference on Ubiquitous and Future Networks (ICUFN)*. IEEE, 542-544. https://doi.org/10.1109/ICUFN.2017.7993845

[8] Širaiy, B., Ilić, V., Toskić, L. (2021). Usability of wireless ECG body sensor for cardiac function monitoring during field testing. *Measurement Science Review*, 21 (2), 55-60. https://doi.org/10.2478/msr-2021-0008

[9] Ahilan, A., Deepa, P. (2016). Improving lifetime of memory devices using evolutionary computing basederror correction coding. In *Computational Intelligence, Cyber Security and Computational Models: Proceedings of ICC3 2015.* Springer, 237-245. https://doi.org/10.1007/978-981-10-0251-9_24

[10] Aveta, F., Refai, H.H., LoPresti, P.G. (2019). Multiple access technique in a high-speed free-space optical communication link: independent component analysis. *Optical Engineering*, 58 (3), 036111. https://doi.org/10.1117/1.OE.58.3.036111

[11] Wu, W., Pirbhulal, S., Sangaiah, A.K., Mukhopadhyay, S.C., Li, G. (2018). Optimization of signal quality over comfortability of textile electrodes for ECG monitoring in fog computing based medical applications. *Future Generation Computer Systems*, 86, 515-526. https://doi.org/10.1016/j.future.2018.04.024

[12] Rödiger, B., Ginthör, D., Labrador, J.P., Ramirez, J., Schmidt, C., Fuchs, C. (2020). Demonstration of an FSO/RF hybrid-communication system on aeronautical and space applications. In *Laser Communication and Propagation through the Atmosphere and Oceans IX*. SPIE Vol. 11506. https://doi.org/10.1117/12.2567034

[13] Szaj, W., Wojnarowska, W., Pajdo, B. (2021). First evaluation of the PTN-104 plethysmographic sensor for heart rate measurement. *Measurement Science Review*, 21 (5), 117-122. https://doi.org/10.2478/msr-2021-0017

[14] Mathuvanesan, C., Jayasankar, T. (2013). Performance analysis of singularity and irregular detection in human health monitoring using Lipschitz exponent function. *International Journal of Engineering Research & Technology (IJERT)*, 2 (6), 414-418.

[15] Vazquez-Lopez, Y., Rodriguez-Aleman, R., Romo-Cardenas, G. (2015). Design of a remote use ECG with an Optical Communication System (FSO) for Telemedicine Applications. In *World Congress on Medical Physics and Biomedical Engineering: IFMBE Proceedings*. Springer, 51, 1550-1553. https://doi.org/10.1007/978-3-319-19387-8_377

[16] Alyan, E.A., Aljunid, S.A. (2017). Development of wireless optical CDMA system for biosignal monitoring. *Optik*, 145, 250-257. https://doi.org/10.1016/j.ijleo.2017.07.053

[17] Tosi, D., Schena, E., Molardi, C., Korganbayev, S. (2018). Fiber optic sensors for sub-centimeter spatially resolved measurements: Review and biomedical applications. *Optical Fiber Technology*, 43, 6-19. https://doi.org/10.1016/j.yofte.2018.03.007

[18] Guiomar, F.P., Lorences-Riesgo, A., Ranzal, D., Rocco, F., Sousa, A. N., Fernandes, M. A., Brandão, B.T., Carena, A., Teixeira, A.L., Medeiros, M.C.R, Monteiro, P.P. (2020). Adaptive probabilistic shaped modulation for high-capacity free-space optical links. *Journal of Lightwave Technology*, 38 (23), 6529-6541. https://doi.org/10.1109/JLT.2020.3012737

[19] Ahmed, I., Karvonen, H., Kumpuniemi, T., Katz, M. (2020). Wireless communications for the hospital of the future: Requirements, challenges and solutions. *International Journal of Wireless Information Networks*, 27 (1), 4-17. https://doi.org/10.1007/s10776-019-00468-1

[20] Llorente-Vidrio, D., Ballesteros, M., Salgado, I., Chairez, I. (2022). Deep learning adapted to differential neural networks used as pattern classification of electrophysiological signals. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 44 (9), 4807 - 4818. https://doi.org/10.1109/TPAMI.2021.3066996

[21] Noel, M.M., Muthiah-Nakarajan, V., Amali, G.B., Trivedi, A.S. (2021). A new biologically inspired global optimization algorithm based on firebug reproductive swarming behaviour. *Expert Systems with Applications*, 183, 115408. https://doi.org/10.1016/j.eswa.2021.115408

[22] Asadi, K., Misra, D., Littman, M. (2018). Lipschitz continuity in model-based reinforcement learning. In *Proceedings of the 35th International Conference on Machine Learning*, 264-273.

[23] Esmail, M.A., Saif, W.S., Ragheb, A.M., Alshebeili, S.A. (2021). Free space optic channel monitoring using machine learning. *Optics Express*, 29 (7), 10967-10981. https://doi.org/10.1364/oe.416777

[24] Pavlásek, P., Rybář, J., Ďuriš, S., Hučko, B., Chytil, M., Furdová, A., Ferková, S.L., Sekáč, J., Suchý, V., Grosinger, P. (2020). Developments and progress in non-contact eye tonometer calibration. *Measurement Science Review*, 20 (4), 171-177. https://doi.org/10.2478/msr-2020-0021

[25] Appathurai, A., Carol, J.J., Raja, C., Kumar, S.N., Daniel, A.V., Malar, A.J.G., Fred, A.L., Krishnamoorthy, S. (2019). A study on ECG signal characterization and practical implementation of some ECG characterization techniques. *Measurement*, 147, 106384. https://doi.org/10.1016/j.measurement.2019.02.040

[26] Prathiba, G., Santhi, M., Ahilan, A. (2018). Design and implementation of reliable flash ADC for microwave applications. *Microelectronics Reliability*, 88, 91-97. https://doi.org/10.1016/j.microrel.2018.07.095

[27] Appathurai, A., Deepa, P. (2016). Radiation induced multiple bit upset prediction and correction in memories using cost efficient CMC. *Informacije MIDEM*, 46 (4), 257-266.

[28] Zhang, M., Li, H., Ge, T., Meng, Z., Gao, N., Zhang, Z. (2022). Integrated sensing and computing for wearable human activity recognition with MEMS IMU and BLE network. *Measurement Science Review*, 22 (4), 193-201. https://doi.org/10.2478/msr-2022-0024

[29] Vranic, I., Antic, B., Stojanovic, G., Al-Salami, H. (2019). Influence of the main filter on QRS-amplitude and duration in human electrocardio-gram. *Measurement Science Review*, 18 (1), 29-34. https://doi.org/10.2478/msr-2019-0005

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