IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Traitement du Signal
Vol. 38, No. 2, April, 2021, pp. 473-479
Journal homepage: http://iieta.org/journals/ts

Secure Transmission of EEG Data Using Watermarking Algorithm for the Detection of Epileptical Seizures

Akash Kumar Gupta[1*], Chinmay Chakraborty[1], Bharat Gupta[2]

[1] Department of Electronics and Communication Engineering, Birla Institute of Technology, Jharkhand 814142, India
[2] Department of Electronics and Communication Engineering, National Institute of Technology, Patna 800005, Bihar, India

Corresponding Author Email: akgupta@bitmesra.ac.in

https://doi.org/10.18280/ts.380227

Received: 28 May 2020
Accepted: 15 March 2021

Keywords:
DWT-DCT-BFO, EEG, healthcare, Internet of Things, patients monitoring, short time Fourier transform, watermarking

ABSTRACT

Internet of things (IoT) has a collection of multiple network-enabled devices like sensors, gateways, smartphones, and communication links (short and long ranges). Tremendous capacity of IoT system has made possible to monitoring and detection of epileptical seizures in real time. For this purpose, various smart devices and applications, helps to transmit information securely. Amalgamation of IoT with healthcare system provides opportunity to deal issues like security, detection of seizures and real time monitoring. The proposed model of cloud-enabled Health IoT system has been presented in this paper, gives the idea about monitoring of epileptical patients. For secured transmission of Electroencephalogram (EEG) data, digital watermarking technique has been used over two dimensional EEG data obtained through one dimensional EEG data by applying Short Time Fourier Transform (STFT). In this paper, watermarking of two dimensional EEG data has been done using discrete wavelet transform - discrete cosine transform (DWT-DCT) based Bacterial Foraging Optimization (BFO) technique and its performance has been figure out. Here, satisfactory watermarking performance in terms of Peak Signal to Noise Ratio (PSNR) 49.50 for class Z and 49.61 for class S EEG data along with Normalized Cross Correlation (NCC) 0.0039 for both classes of EEG data have been achieved.

1. INTRODUCTION

Epilepsy is an abnormal activity occurs in the brain and affects a large number of populations. The collected EEG signal is non-stationary and non-linear in nature, hence it's difficult to interpret by just visualization and detect epileptic seizures. As epileptic sufferers may also go through from specific sorts of troubles like accidents, injuries, which may additionally purpose of even loss of life also, consequently they require distinct care to keep away from all these and it is possible with the use of cloud based Health IoT system.

Health IoT system consist various wearable sensors and available very economically. These devices may help enormously for taking care of epileptic seizures and patients, which may provide information related to their care routines, treatments, drug dosage, physical activity etc. even such IoT based devices can monitor remote located patients [1, 2]. These Health IoT system provides the real time transmission of information and able to get quick response. Various device like smartphone, Bluetooth and others communication methods supports the system [3, 4]. In this Health IoT system cloud enabled technologies have been used, which provides necessary and sufficient storage requirements to share information in between users and experts with lover complexity, reduced cost, accuracy, speed and enhance quality of service [5, 6]. To improve the quality of health related service, security of individual health information must be required, which can be provided from user end. Watermarking is one of the ways to provide security on these health data, which can be applied on two dimensional of EEG data. The collected EEG data by Health IoT system from patients using different IoT devices may be in huge amount and difficult to handle it and very much chances to get attacked and loss of privacy. Using cloud services data can be stored safely and can be accessed by authenticate users like health experts and suggest further in faster way [7]. After safely storing of EEG data in cloud, its features can be extracted and classified for further seizure detection and patient monitoring. On the groundwork of classification accuracy professionals may predict about epilepsy and endorse suitable remedies or emergency services can be provided.

For secure transmission of EEG signal optical chaos has been introduced [8]. To hide EEG signal, author has used source of semiconductor laser to generate optical chaos, at the time of signal transmission and combination of EEG signal and optical chaos has been transmitted over optical fiber medium. Using the elliptic Curve Cryptography (ECC) including collision-resistant one way cryptographic hash function, the lightweight access control key agreement protocol has been proposed to create a secure communication connection in cloud-based IoT network [9]. For providing security on mobile health data transmission, author proposes a data encryption method that provides data integrity, confidentiality and authenticity [10]. Based on optimum path forest (OPF) clustering, network security monitoring has been presented by author [11]. Here, author has proposed OPF based on anomaly detection. Another data encryption method based on Rivest Cipher (RC5) algorithm including chaotic based scheduling has been proposed by author that uses symmetric key for the process of encryption and decryption.

Results have been analyzed against number of attacks [12]. Based on chaotic theory, a cryptosystem has been proposed for providing security and confidentiality during transmission, which follows scrambling and substitution architecture [13].

This paper deals with the monitoring of epileptic patients using cloud-enable Health IoT platform and focuses on the safe transfer of EEG information to the cloud, for which DWT-DCT based BFO watermarking approach was used. Related to this presented work, a watermarking algorithm based on DWT-DCT has been presented by Ghazvini et al. [14], which uses 2-level DWT algorithm to decompose the image and DCT has been applied on mid-level frequency sub-band. Here genetic algorithm has been used to optimize the performance. A watermarking algorithm based on DCT has been presented by Zhang et al. [15], in which original image has been decomposed into number of frequency bands and to embed watermark, first of all number of rows and rank both have been extended and using adaptive embedding method, watermark successfully incorporated and extracted. A wavelet based watermarking algorithm has been presented by Wang and Lin [16], which uses to embed each watermark bit in different band of frequency. This algorithm shows robustness in both, frequency as well as time domain.

A combined form of DWT-DCT based watermarking algorithm has been presented in the studies [17, 18]. In both of the papers, firstly 3 level DWT has been applied on image, after that Wang et al. [17] applies DCT on various block obtained using DWT, whereas Kasmani and Naghsh-Nilchi [18] used DCT transform of each sub-bands and PN sequence of watermark is embedded. In DWT-singular value decomposition (SVD) domain, a multiobjective evolutionary optimizer (MEO) based image watermarking has been presented by Gunjal and Mali [19], which uses haar wavelet to decompose the image then after SVD has been applied on mid-level frequency band. DWT-DCT-SVD based watermarking algorithm is presented by Loukhaoukha et al. [20]. In this paper, one level DWT has been applied on original image and various frequency bands have been obtained. Then after, DCT has been applied on lower level frequency band to obtain respective component of frequency, on which SVD has been applied to perform watermarking. An adaptive DWT-SVD based watermarking of image has been presented by Li et al. [21], which considered human visual characteristics. DWT, DCT and BFO based watermarking algorithm has been presented by Bharati et al. [22]. This paper presents the DWT-DCT-BFO based watermarking algorithm and evaluates efficiency. To apply watermark on EEG data, first of all STFT has been applied on one dimensional EEG data. Then after, watermarking has been applied on obtain two dimensional EEG data, which has been extracted in the cloud after successful transmission of information. In this paper, cloud-enable Health IoT system has been proposed for the monitoring and detection of epileptical seizures. To design such system, there are various challenges, from which we have deal, are presented by Hassanalieragh et al. [23]. To deal with electronics health record management, data acquisition and transmission in cloud based Health IoT system, an idea has been presented by Hossain and Muhammad [24]. Industrial internet of things (IIoT) based on cloud is effectively used for big data analysis been presented by ur Rehman et al. [25]. Security of epileptical data can also be enhanced by including compression techniques presented by Chakraborty [26].

EEG information can be obtained by positioning the electrodes over the scalp or by using wearable devices to track epileptic patients, which can be further pre-processed to eliminate any unnecessary components from the initial EEG signal. This information is firstly transmitted to cloud, where very huge amount of information can be stored and handled carefully. In this paper, to secure the patients data DWT-DCT based watermarking followed by BFO optimization has been performed. Such data can be used in the cloud for extraction and classification purposes of features. Experts can predict epileptic seizures on the basis of diagnosis accuracy and prescribe treatment and medication to patients, even in the event of an emergency, separate health-related support can be given by the service provider. The main objective is to perform transmission of secured patient's information to cloud framework and use of it for monitoring of remote located patients. Watermarking is a way to provide security on biomedical signals. In this paper, presented cloud enabled Health IoT system provides secure transmission and patient monitoring. The motivation for writing this paper is to use of cloud enabled service, as this technology growing very rapidly and interesting area of research.

The main purpose of this work is to gather knowledge and provide security on epileptical EEG data. To provide security watermarking has been applied on signal before transmission. A cloud based system model has been proposed here that relates IoT devices with communication methods. For this work the main contributions are given as below:

(1) Proposed a data flow model for cloud enabled Health IoT system for providing secure transmission and patient monitoring;
(2) Performed STFT on EEG signal (one dimensional) to get time-frequency data (two dimensional);
(3) DWT-DCT-BFO based watermark embedding;
(4) Watermark extraction.

This paper is structured as follows. Following the introduction of secure EEG data transmission using watermarking method to detect epileptic seizures, data flow model was developed for cloud-enabled health IoT framework. Further section describes methodologies and research for this paper explaining STFT and the watermarking scheme for EEG data based on DWT-DCT-BFO.As a consequence, paper presents watermarking performance, followed by conclusion and future work listed at the end.

2. PROPOSED MODEL FOR HEALTH IOT SYSTEM

With introduction of IoT in healthcare sector, medical services have been revolutionized. This Health IoT system also involves cloud-enabled features, which makes great impact on social development and provides good quality of service in reduced cost in quick way to users. A system model has been presented in Figure 1, which clearly indicates how patient's information (EEG data) can be collected and transmitted over the cloud through gateways [27]. System model reflects the aforementioned functions such as pre-processing, feature extraction, and then performing classification in the cloud itself. Hospitals / experts can access this data at the recipient end and can detect epileptic seizures on the basis of diagnosis accuracy. Experts may therefore suggest treatment, medicine or, in the event of an emergency may request service to service provider.

In this paper, DWT-DCT-BFO based watermarking method successfully applied to the EEG signal, which must be pre-processed in order to filter out any unwanted element. Here, the publically available Bonn dataset provided by Bonn university of Bonn has been used for watermarking purposes.

As this dataset is already pre-processed hence there is no need to pre-process it [28]. This dataset consists of both epileptic patient and healthy person EEG data. EEG data has been acquired from a healthy person during an eye-open and eye-closed condition, whereas data has been acquired from an epileptic patient during a seizure period as well as seizure-free period, which is collected in 23.6 seconds (4097 samples) and 173.61 Hz sampling frequency. Brief description of this Bon EEG dataset has been presented in Table 1.

Table 1. Representation of different classes of dataset

EEG data	Class	Type	Data acquisition
Healthy Person	Z	Normal	EEG signal obtained during eye opened
	O		EEG signal obtained during eye closed
Epileptic Patients	N	Seizure free	EEG signal during hippocampal development
	F		EEG epileptogenic area signal
	S	Seizure	EEG signal obtained during seizure period

This presented Bonn dataset is in one dimensional (time domain) form. Before transmission of these patients' information to the cloud through IoT devices, it is needed to secure the data. In this paper, watermarking has been used to provide security, which can be applied on two dimensional data EEG data. STFT is used to translate EEG information from time domain to time-frequency domain for this purpose. Then after, DWT-DCT-BFO based watermarking algorithm can be applied successfully.

3. STFT OF EEG DATA

STFT has been used in this paper over EEG data to perform time-frequency analysis [29].

Hamming window of odd size (N/4), where N is the number of data points, is used to perform STFT. Mathematical expression for STFT of message (EEG) signal x(t) with short hamming window h(t) is given by (1).

$$STFT(t,f) = x(t,f) = \int_{-\infty}^{\infty} x(\tau)h(\tau - t)e^{-if\tau}\, d\tau \qquad (1)$$

In Figure 2, class Z and class S of EEG data has been presented, which has been selected to perform STFT and watermarking. From this expression it is clear that here message signal is simply multiplied with hamming window for short period of time, resulting we can obtain two dimensional signal. Using time frequency analysis, we are able to find power spectrum density (PSD) of EEG signal, which serves energy distribution in time-frequency domain.

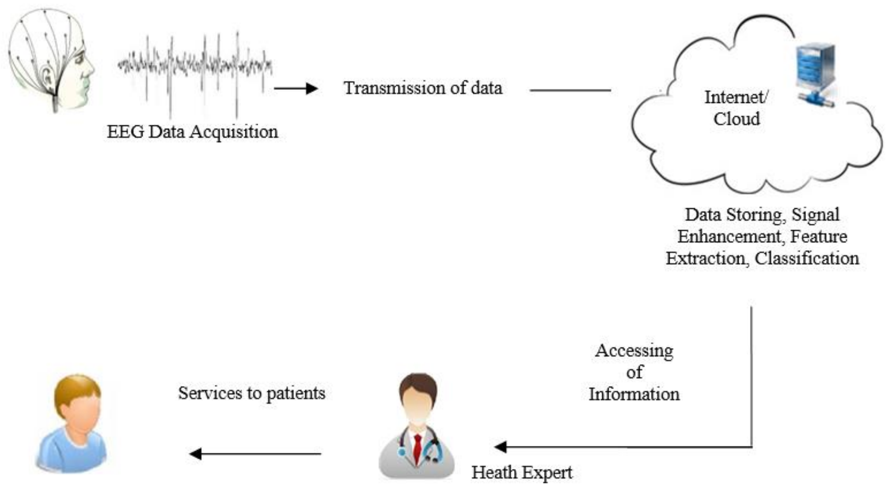
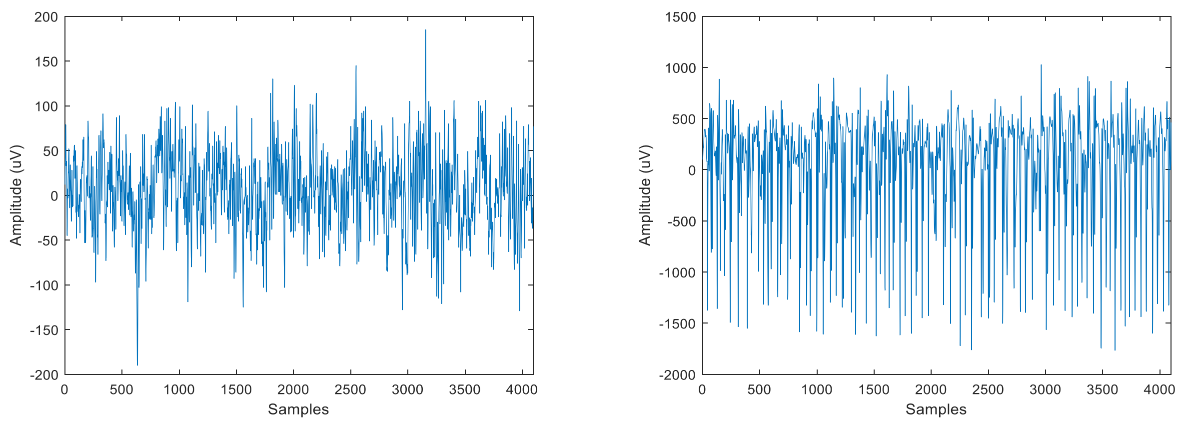
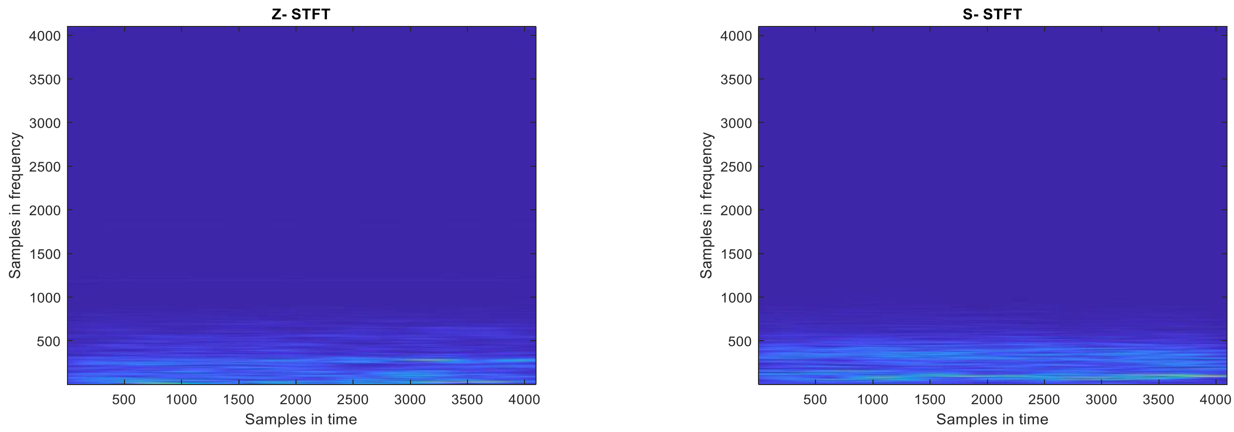


Figure 1. Data flow model for cloud-enabled health IoT system



(a) (b)



(c) (d)

Figure 2. EEG data (a) Class Z, (b) Class S&STFT of (c) Class Z and (d) Class S

4. DWT-DCT-BFO BASED WATERMARKING ALGORITHM

After performing STFT of EEG data, watermarking can be applied to secure the patient information which is going to be transmitting over the cloud. Figure 3, shows algorithmic flow chart here.

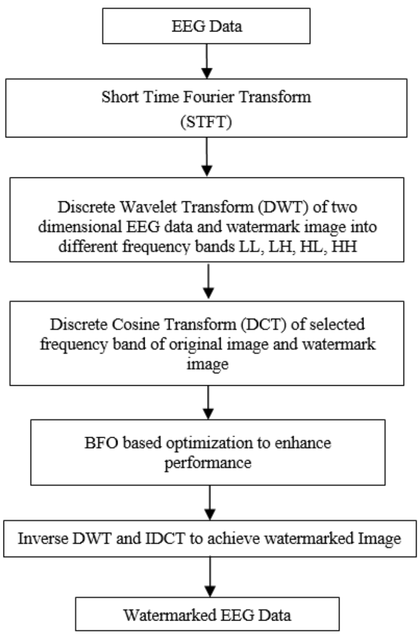


Figure 3. Flow chart of DWT-DCT-BFO based watermarking

4.1 Discrete wavelet transform

Discrete wavelet Transform is one of the frequency domain watermarking algorithms. As frequency domain algorithms are more effective in terms of imperceptibility and robustness, such algorithms are used very frequently. By enhancing the level of DWT, performance can be improved. In DWT based watermarking algorithm, it decomposes the two dimensional signal in to various frequency sub-bands namely LL, LH, HL, HH [30]. Now, according to level of DWT, respective sub-bands are again decomposing into further sub-band like LL sub-band may decomposes in to LL2, LH2, HL2, HH2. Here, watermark may be embedded in these sub-band and may extract in cloud by applying inverse DWT for feature extraction and classification.

4.2 Discrete cosine transform

Discrete cosine transform is also a frequency domain watermarking algorithm and robust against attacks. It allows decomposing of two dimensional signals into different frequency bands (lower and higher), which make it easier to apply watermark. After embedding watermark, this method uses original image as well as watermark for extraction process. First of all, DCT has to be performed on both obtained watermarked image and original image (Inverse DCT) [22, 31].

4.3 Bacterial foraging optimization

BFO is an optimization algorithm, having behaviour similar to genetic algorithms, proposed by Passino and Chakraborty [32, 33]. The main idea behind this algorithm is based on the E.coli bacteria swarm foraging strategy. The way bacteria search for their nutrients to increase the amount of energy per unit. They communicate by transmitting signals with each other and made their judgement accordingly. For searching nutrients, the way bacteria take their step is known as chemotaxis and elementary concept of BFO algorithm is to adapt and follow chemotactic movement of virtual bacteria.

DWT-DCT-BFO based method presented in this paper has already been applied in real world applications and various researchers from different fields are paying attention on this concept.

5. RESULT AND DISCUSSION

Class Z and Class S data were chosen from the publicly available Bonn dataset and STFT analysis was performed using 100 segments of each Z and S data class and the time-frequency domain EEG data was achieved. For providing security DWT-DCT-BFO based watermarking algorithm has been applied with the use of suitable key. Because of watermarking, imperceptibility is demonstrated in this paper by how much EEG signal gets skewed. This also gives EEG watermarking performance. PSNR and NCC has been calculated to get similarity index and imperceptibility between watermark image and extracted watermark.

Table 2. Performance evaluation using PSNR and NCC

Watermarking	EEG data	PSNR	NCC
DWT-DCT-BFO	Z class	49.5016	0.0039
based algorithm	S class	49.6058	0.0039

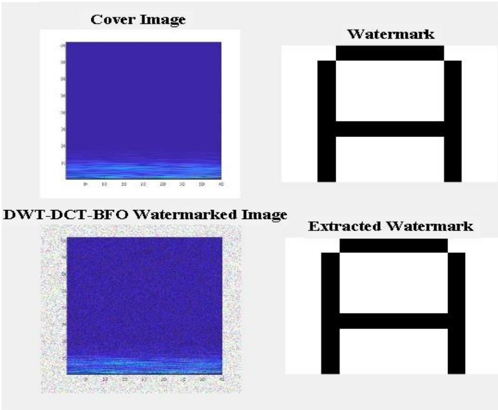


Figure 4. Embedding and extraction of Watermark

Table 2 shows the performance of watermarking in terms of PSNR and similarity as NCC for both healthy person EEG data (class Z) and epileptic patient EEG data (class S). To evaluate imperceptibility, we have used peak signal to noise ratio (PSNR) presented by Eq. (2) given below:

$$PSNR_{dB} = 20\log_{10}\left(\frac{\max(x_c)}{\sqrt{\frac{1}{N}\sum_1^N (x_c - x_w)^2}}\right) \quad (2)$$

Further NCC has been determined to check similarity, Here Figure 4, representing that watermark has been success fully applied and extracted using proposed algorithm.

6. PERFORMANCE COMPARISON

Here, Table 3, representing performance comparison of applied optimized watermarking algorithm on EEG data with standard algorithms.

Table 3. Performance comparison of proposed algorithm

Ref.	Method	Purpose	Cover/ Watermark	Host/ Message	Performance
[18]	Based on Joint DWT-DCT Transformation	Robustness, Imperceptibility	A binary watermark image	Grey scale Pepper image	PSNR of 37.27dB, similarity exist in between 0 to 1
[34]	An optimal discrete DWT–SVD based image watermarking	Robustness, Imperceptibility, Self adaptive DE algorithm	Gray scaled logo	Images named man and sailboat	PSNR 33.2837 and 34.8741 dB respectively, NC 0.85 to 0.95
[35]	SVD-based watermarking scheme in the spatial domain	Robust, Imperceptibility, Lower computational complexity	A binary watermark (logo)	Lena, Barbara, Boat, Airplane, Peppers, Baboon, Clock images	PSNR 48 to 49 dB NCC 0.95 to 1
[36]	LWT-DCT-SVD based watermarking	Robustness, Copyright protection	A binary watermark (logo)	Audio signal	PSNR 9 to 28 dB Capacity 172.26 bps
[37]	Blind DWT-SVD Watermarking	Preserving authenticity and integrity of medical data	Image	EEG Dataset for Emotion analysis	PSNR 45 to 55 dB
This Work	DWT-DCT-BFO based watermarking	Robustness, Copyright protection	Watermark logo	Bonn's EEG dataset	PSNR 49.6058 dB

7. CONCLUSION

In this paper, watermarking algorithm based on DWT-DCT-BFO successfully applied the sub-band of mid-level frequency obtained using level one DWT and DCT and optimized it using BFO. The paper's main objective is to evaluate watermarking efficiency. STFT was used to convert one-dimensional data into two-dimensional data to apply watermark on time-frequency information. Compared to other existing time frequency methods, STFT has the advantage of quick processing which makes it suitable for real-time detection purposes. Cloud-based medical IoT platform for epileptic patient monitoring is rising quite rapidly in the present era. With this system, patient feedback and recommendations can be made in real time. Although there is a data security issue, the use of EEG information watermarking methods has also made it possible to secure transmission, which provides patients with safe and superior quality of service. Good watermarking quality in terms of PSNR and NCC has been calculated here. Future work includes extraction and classification of features from EEG signal in the cloud itself to identify or predict patient epileptic seizures.

ACKNOWLEDGMENT

Author is grateful to R. G. Andrzejak, who has made the EEG database publically available.

REFERENCES

[1] Page, A., Kocabas, O., Soyata, T., Aktas, M., Couderc, J. P. (2015). Cloud-based privacy-preserving remote ECG monitoring and surveillance. Annals of Noninvasive Electrocardiology, 20(4): 328-337. http://dx.doi.org/10.1111/anec.12204

[2] Paradiso, R., Loriga, G., Taccini, N. (2005). A wearable health care system based on knitted integrated sensors. IEEE Transactions on Information Technology in Biomedicine, 9(3): 337-344.

http://dx.doi.org/10.1109/TITB.2005.854512
[3] Vergara, P.M., De La Cal, E., Villar, J.R., González, V.M., Sedano, J. (2017). An IoT platform for epilepsy monitoring and supervising. Journal of Sensors, 2017: 1-18. http://dx.doi.org/10.1155/2017/6043069
[4] Gupta, A., Chakraborty, C., Gupta, B. (2019). Medical information processing using smartphone under IoT framework. In Energy Conservation for IoT Devices, 206: 283-308. https://dx.doi.org/10.1007/978-981-13-7399-2_12
[5] Yin, Y., Zeng, Y., Chen, X., Fan, Y., (2016). The internet of things in healthcare: An overview. Journal of Industrial Information Integration, 1: 3-13. http://dx.doi.org/10.1016/j.jii.2016.03.004
[6] Bai, Y., Dai, L., Li, J. (2014). Issues and challenges in securing ehealth systems. International Journal of E-Health and Medical Communications (IJEHMC), 5(1): 1-19. http://dx.doi.org/10.4018/ijehmc.2014010101
[7] Bhawiyuga, A., Kartikasari, D.P., Amron, K., Pratama, O.B., Habibi, M.W. (2019). Architectural design of IoT-cloud computing integration platform. Telkomnika, 17(3): 1399-1408. http://dx.doi.org/10.12928/telkomnika.v17i3.11786
[8] Shahzadi, R., Anwar, S.M., Qamar, F., Ali, M., Rodrigues, J.J., Alnowami, M. (2019). Secure EEG signal transmission for remote health monitoring using optical chaos. IEEE Access, 7: 57769-57778. http://dx.doi.org/10.1109/ACCESS.2019.2912548
[9] Das, A.K., Wazid, M., Yannam, A.R., Rodrigues, J.J., Park, Y. (2019). Provably secure ECC-based device access control and key agreement protocol for IoT environment. IEEE Access, 7: 55382-55397. http://dx.doi.org/10.1109/ACCESS.2019.2912998
[10] Silva, B.M., Rodrigues, J.J., Canelo, F., Lopes, I.M., Lloret, J. (2019). Towards a cooperative security system for mobile-health applications. Electronic Commerce Research, 19(3): 629-654. http://dx.doi.org/10.1007/s10660-018-9296-9
[11] Guimaraes, R.R., Passos, L.A., Holanda Filho, R., de Albuquerque, V.H.C., Rodrigues, J.J., Komarov, M.M., Papa, J.P. (2018). Intelligent network security monitoring based on optimum-path forest clustering. IEEE Network, 33(2): 126-131. http://dx.doi.org/10.1109/MNET.2018.1800151
[12] Shahzadi, R., Anwar, S.M., Qamar, F., Ali, M., Rodrigues, J.J. (2019). Chaos based enhanced RC5 algorithm for security and integrity of clinical images in remote health monitoring. IEEE Access, 7: 52858-52870. http://dx.doi.org/10.1109/ACCESS.2019.2909554
[13] Mehta, G., Dutta, M.K., Kim, P.S. (2018). An efficient and lossless cryptosystem for security in tele-ophthalmology applications using chaotic theory. International Journal of E-Health and Medical Communications (IJEHMC), 7(4): 189-210. http://dx.doi.org/10.4018/IJEHMC.2016100102
[14] Ghazvini, M., Hachrood, E.M., Mirzadi, M. (2017). An improved image watermarking method in frequency domain. Journal of Applied Security Research, 12(2): 260-275. http://dx.doi.org/10.1080/19361610.2017.1277878
[15] Zhang, Q., Li, Y., Wei, X. (2012). An improved robust and adaptive watermarking algorithm based on DCT. Journal of Applied Research and Technology, 10(3): 405-415. http://dx.doi.org/10.22201/icat.16656423.2012.10.3.397
[16] Wang, S.H., Lin, Y.P. (2004). Wavelet tree quantization for copyright protection watermarking. IEEE Transactions on Image Processing, 13(2): 154-165. http://dx.doi.org/10.1109/TIP.2004.823822
[17] Wang, H.B., Yang, H.L., Wang, C.D., Wang, S.M. (2010). A new watermarking algorithm based on DCT and DWT fusion. In 2010 International Conference on Electrical and Control Engineering, Wuhan, China, 2614-2617. http://dx.doi.org/10.1109/iCECE.2010.640
[18] Kasmani, S.A., Naghsh-Nilchi, A. (2008). A new robust digital image watermarking technique based on joint DWT-DCT transformation. In 2008 Third International Conference on Convergence and Hybrid Information Technology, 2: 539–544. http://dx.doi.org/10.1109/ICCIT.2008.139
[19] Gunjal, B.L., Mali, S.N. (2015). MEO based secured, robust, high capacity and perceptual quality image watermarking in DWT-SVD domain. SpringerPlus, 4(1): 1-16. http://dx.doi.org/10.1186/s40064015-0904-z
[20] Loukhaoukha, K., Refaey, A., Zebbiche, K., Nabti, M. (2015). On the security of robust image watermarking algorithm based on discrete wavelet transform, discrete cosine transform and singular value decomposition. Applied Mathematics & Information Sciences, 9(3): 1159. http://dx.doi.org/10.12785/amis/090307
[21] Li, Q., Yuan, C., Zhong, Y.Z. (2007). Adaptive DWT-SVD domain image watermarking using human visual model. In The 9th International Conference on Advanced Communication Technology, 3: 1947-1951. http://dx.doi.org/10.1109/ICACT.2007.358752
[22] Bharati, S., Rahman, M.A., Mandal, S., Podder, P. (2018). Analysis of DWT, DCT, BFO & PBFO algorithm for the purpose of medical image watermarking. In 2018 International Conference on Innovation in Engineering and Technology (ICIET), pp. 1-6. http://dx.doi.org/10.1109/CIET.2018.8660796
[23] Hassanalieragh, M., Page, A., Soyata, T., Sharma, G., Aktas, M., Mateos, G., Andreescu, S. (2015). Health monitoring and management using Internet-of-Things (IoT) sensing with cloud-based processing: Opportunities and challenges. In 2015 IEEE International Conference on Services Computing, pp. 285-292. http://dx.doi.org/10.1109/SCC.2015.47
[24] Hossain, M.S., Muhammad, G. (2017). Emotion-aware connected healthcare big data towards 5G. IEEE Internet of Things Journal, 5(4): 2399-2406. http://dx.doi.org/10.1109/JIOT.2017.2772959
[25] ur Rehman, M.H., Yaqoob, I., Salah, K., Imran, M., Jayaraman, P.P., Perera, C. (2019). The role of big data analytics in industrial Internet of Things. Future Generation Computer Systems, 99: 247-259. http://dx.doi.org/10.1016/j.future.2019.04.020
[26] Chakraborty, C. (2021). Performance analysis of compression techniques for chronic wound image transmission under smartphone-enabled tele-wound network. International Journal of E-Health and Medical Communications (IJEHMC), 10(2): 345-364. http://dx.doi.org/10.4018/IJEHMC.2019040101
[27] Gupta, A.K., Chakraborty, C., Gupta, B. (2020). Sensing and monitoring of epileptical seizure under IoT platform. In Smart Medical Data Sensing and IoT Systems Design in Healthcare, 201-223. http://dx.doi.org/10.4018/978-1-7998-0261-7.ch009

[28] Andrzejak, R.G., Lehnertz, K., Mormann, F., Rieke, C., David, P., Elger, C.E. (2001). Indications of nonlinear deterministic and finite-dimensional structures in time series of brain electrical activity: Dependence on recording region and brain state. Physical Review E, 64(6): 061907. http://dx.doi.org/10.1103/PhysRevE.64.061907

[29] Tzallas, A.T., Tsipouras, M.G., Fotiadis, D.I. (2009). Epileptic seizure detection in EEGs using time–frequency analysis. IEEE Transactions on Information Technology in Biomedicine, 13(5): 703-710. http://dx.doi.org/10.1109/TITB.2009.2017939

[30] Yasmeen, F., Uddin, M.S. (2021). An efficient watermarking approach based on LL and HH edges of DWT-SVD. SN Computer Science, 2(82): 1-16. https://dx.doi.org/10.1007/s42979-021-00478-y

[31] Marasović, T., Papić, V. (2018). A comparative study of FFT, DCT, and DWT for efficient arrhytmia classification in RP-RF framework. International Journal of E-Health and Medical Communications (IJEHMC), 9(1): 35-49. http://dx.doi.org/10.4018/IJEHMC.2018010103

[32] Passino, K.M. (2002). Biomimicry of bacterial foraging for distributed optimization and control. IEEE Control Systems Magazine, 22(3): 52-67. http://dx.doi.org/10.1109/MCS.2002.1004010

[33] Chakraborty, C. (2017). Chronic wound image analysis by particle swarm optimization technique for tele-wound network. Wireless Personal Communications, 96(3): 3655-3671. https://dx.doi.org/10.1007/s11277-017-4281-5

[34] Ali, M., Ahn, C.W. (2014). An optimized watermarking technique based on self-adaptive DE in DWT–SVD transform domain. Signal Processing, 94: 545-556. http://dx.doi.org/10.1016/j.sigpro.2013.07.024

[35] Zhang, H., Wang, C., Zhou, X. (2017). A robust image watermarking scheme based on SVD in the spatial domain. Future Internet, 9(3): 45. http://dx.doi.org/10.3390/fi9030045

[36] Novamizanti, L., Budiman, G., Astuti, E.N.F. (2020). Robust audio watermarking based on transform domain and SVD with compressive sampling framework. TELKOMNIKA Telecommunication, Computing, Electronics and Control, 18(2): 1079-1088. http://dx.doi.org/10.12928/telkomnika.v18i2.14773

[37] Pham, T.D., Tran, D., Ma, W. (2015). A proposed blind DWT-SVD watermarking scheme for EEG data. In International Conference on Neural Information Processing, pp. 69-76. http://dx.doi.org/10.1007/978-3-319-26561-2_9

NOMENCLATURE

N	number of data points (sample)
x(t)	message signal
h(t)	hamming window
x(t, f)	STFT of message signal
IoT	Internet of Things
EEG	Electroencephalogram
STFT	Short time Fourier Transform
DWT	Discrete wavelet transform
DCT	Discrete Cosine transform
BFO	Bacterial foraging optimization
SVD	Singular value decomposition
PSNR	Peak signal to noise ratio
NCC	Normalized cross correlation
PN	Pseudo noise sequence
MEO	Multiobjective evolutionary optimizer
PSD	Power Spectrum density

Subscripts

[LL, LH, HH, HL]	level 1 coefficients of cover image
[LL2, LH2, HH2, HL2]	level 2 coefficients of cover image
x_c and x_w	amplitude of EEG and watermarked EEG signal