Power Efficient Signal Conversion and Quality Signal Compression Using LDS-ADC & Hybrid DCT for Biomedical Signals

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Abstract: In hospitals, large amount of EEG signals are recorded in daily basis and the compression of medical data is major challenge because of the limited storage capability. Moreover, transmitting the medical data among the networks in telemedicine based systems need to compress the data effectively. The efficient compression process not only improves the compression ratio but also needs to preserve the quality of the data. This paper presented a power efficient signal conversion and compression on EEG and ECG signals using low power dual slope analog to digital converter (LDS-ADC) and hybrid discrete cosine transform with improved emperor penguin optimization (Hybrid DCT-IEPO). Initially, the bio-signals such as ECG and EEG signals are acquired and converted into digital signal using a power efficient LDS-ADC. After the process of energy efficient signal conversion, ECG and EEG signal compression is performed in the next stage. Here, the hybrid discrete cosine transform (hybrid DCT) is applied on the converted digital signals resulting the number of coefficients. Subsequently, optimal coefficients are selected by utilizing emperor penguin optimization algorithm. Finally, inverse hybrid DCT reconstructs the signal with the selected optimal coefficients. Thus the reconstructed power efficient output signal is attained and it is utilized for various applications. The experimental results of the presented methodology is analysed with the existing approaches in regards of compression ratio. The presented work is implemented in MATLAB platform.

Key words: - Signal conversion, Power efficiency, Signal compression, Optimization, Hybrid methodology

1. Introduction

In recent days, research has the high interest in the area bio-medical signal applications. Bio-signals are the physiological signals that are used for measuring the electrical activity of the human organs like brain, heart, muscles etc. The commonly used bio signal are ECG (Electrocardigram), EEG (Electroencephalogram), and EMG (Electromyogram) [1]. To store and transmitting huge amount of data bio-medical signal compression becoming an increasing interest [2]. There has been a boom in research into portable, wearable, and implantable medical devices in recent years. Established medical services are under strain as the world's population grows [3]. To address the rising medical costs, there is a growing movement toward preventive medicine, which focuses on keeping patients safe and fit. To make these possible, technologies that continuously track physiological functions such as heart rate, muscle contraction, and so on are needed. One of the most significant applications of wearable computing is expected to be biomedical monitoring systems [4]. Various similar studies have been conducted in the past. Many of the biomedical monitoring system have the ability to work for a long time with a small battery. The needs of low power biomedical system have increasing day by day and the power efficient ADC technique also needed [5-7].

Moreover, the bio signal compression is the major need in the bio medical applications because of the transmission of large amount of medicinal data that is recorded in day to day life [7]. In bio signal compression, the reconstruction quality of bio-signals is most important. This means that these signals can be compressed without losing any information, allowing a biomedical device to save a significant amount of power [8, 9]. Biomedical signal plays a very important role in wide variety of applications. There are many research work concentrate on this field, but many of them failed at some point due to some limitations [10, 11]. There are many methods for achieving better bio signal data compression. Data can be compressed in general by removing duplication and irrelevant data [12].

Numerous methodologies are presented in the existing power efficient ADC like SAR (Successive approximation register) ADC [13], level crossing ADC [14], adaptive resolution signal ADC [15]. But the power efficiency is still a problem. Moreover, various bio signal compression techniques like convolutional auto encoder approach [16], deep learning procedure [17], Huffman compression [18], lossy compression [19], stockwell transform [20] are presented. The various techniques presented in existing approaches in regards of ADC is still having the power consumption issue. Moreover, the different techniques in the signal compression try to increase the level of compression but fail to preserve the quality of the signal.

Motivation:

The large number of recordings of bio-signals like EEG, ECG, and EMG in medical centres and hospitals on daily basis increases the need of medical data compression. Moreover, the compression of medical data becoming an important challenges because of the limited storage abilities. Hence, the effective medical data compression methodology is needed for the transmission of medical signal across the telemedicine networks. The existing approaches tries to increase the compression ratio without considering the quality level of compression. So, an efficient technique should be developed without losing the quality of the medical data because the quality of medical data is very important. This work presented a low power analog to digital conversion and effective data compression with hybrid DCT-IEPO. The presented approach provides enhanced compression of medical signal without losing the quality of the signal.

Contributions:

The main contributions of the presented approach is described as,

- To attain the power efficient analog to digital signal conversion, an improved low power dual slope analog to digital converter (LDS-ADC) is utilized.
- To achieve the effective bio signal compression hybrid DCT approach is presented. Here, the signals are reconstructed by the optimally selected coefficients using improved emperor penguin optimization (IEPO).
- The presented approach not only enhances the compression ratio and also preserves the quality of the reconstructed bio signal.

The organization of this research paper is described as: section 2 reviews the recent related works, the presented approach is described detail in section 3, results and their performance analysis is validated in section 4 and the conclusion is stated in the section 5 correspondingly.

2. Related Works

Van Assche et al. [21] developed a comparison of the power efficiency of level crossing ADC (LCADC) and compared with SAR ADC. The approach was designed for the low power consumption and compared against SAR ADC in terms of the signals like EAP, EMG, EEG, and ECG. Here the compression was done by Zero-Order-Hold (ZOH). LCADC was more efficient than the traditional method till a cross over point. This point reduces with the ratio of the maximum to the average slope in the application signal. The LCADC with a single-bit quantizer and without timer has achieved less power usage and the implemented result shows the effectiveness of the proposed method.

Hou et al. [22] presented an ultra-low-power level LCADC with on-chip adaptive sampling. The efficiency of the LCADC chip was verified by two signals. When the input signal varied fast, the scaling ratio will be high and when it is varied slowly, the scaling ratio will be less. In this approach, less number of samples was produced. A 61-nW LC-ADC with chip area is evaluated by merging a high-precision comparator and adaptive sampling function on chip. Finally, the implemented results proved that the LCADC depicted an advantage of power and area.

Antony et al. [23] developed an asynchronous adaptive threshold LC ADC with high SNDR for low power on the basis of a new threshold technique for ECG sensor. This approach uses irregular sampling and is based on the levels of the quantization. The adaptive threshold was achieved using computing the average of the minimum and maximum of the input signal in the predetermined window. For reconstructing the signal, polynomial interpolation was utilized. In the end, the comparisons of the evaluated results have achieved a low supply voltage and less area.

Khalid M. Hosny et al. [24] introduced an effective bio signal compression depends on discretized Tchebichef moments and ABC (artificial bee colony) optimization. The presented approach was applied in the different signal datasets like EEG, EMG and ECG. Here, the optimal selection of features was performed with the ABC procedure. This enhances the compression performance on the bio signals. The compression quality was improved by the chosen of features using ABC. The feature extrication with the presented moments also enhances the performance of the presented approach.

Rajasekar and Pushpa latha [25] presented a Huffman quantization scheme for the compression of EEG signal. The developed methodology was the lossless technique for data compression. The developed technique focussed on improving the accuracy level of reconstruction. Moreover, the reconstruction is attained in minimal processing time without losses in the signal. The approach compresses the EEG signal because the size of EEG signal was larger. The Huffman based transformation scheme was utilized for the optimal compression of EEG signal.

3. Proposed Methodology

This paper presented a power efficient signal conversion and compression on EEG and ECG signals using low power dual slope analog to digital converter (LDS-ADC) and hybrid discrete cosine transform with improved emperor penguin optimization (Hybrid DCT-IEPO). Initially, the bio signals such as ECG and EEG signals are acquired and converted into digital signal using an power efficient LDS-ADC. After the process of energy efficient signal conversion, ECG and EEG signal compression is performed in the next stage. Here, the hybrid discrete cosine transform (hybrid DCT) is applied on the converted digital signals and resulting the number of coefficients. Subsequently, optimal coefficients are selected by utilizing emperor penguin optimization algorithm. Finally, inverse hybrid DCT reconstructs the signal with the selected optimal coefficients. Thus the reconstructed power efficient output signal is attained and it is utilized for various applications. The schematic diagram of the presented methodology is depicted in figure 1.

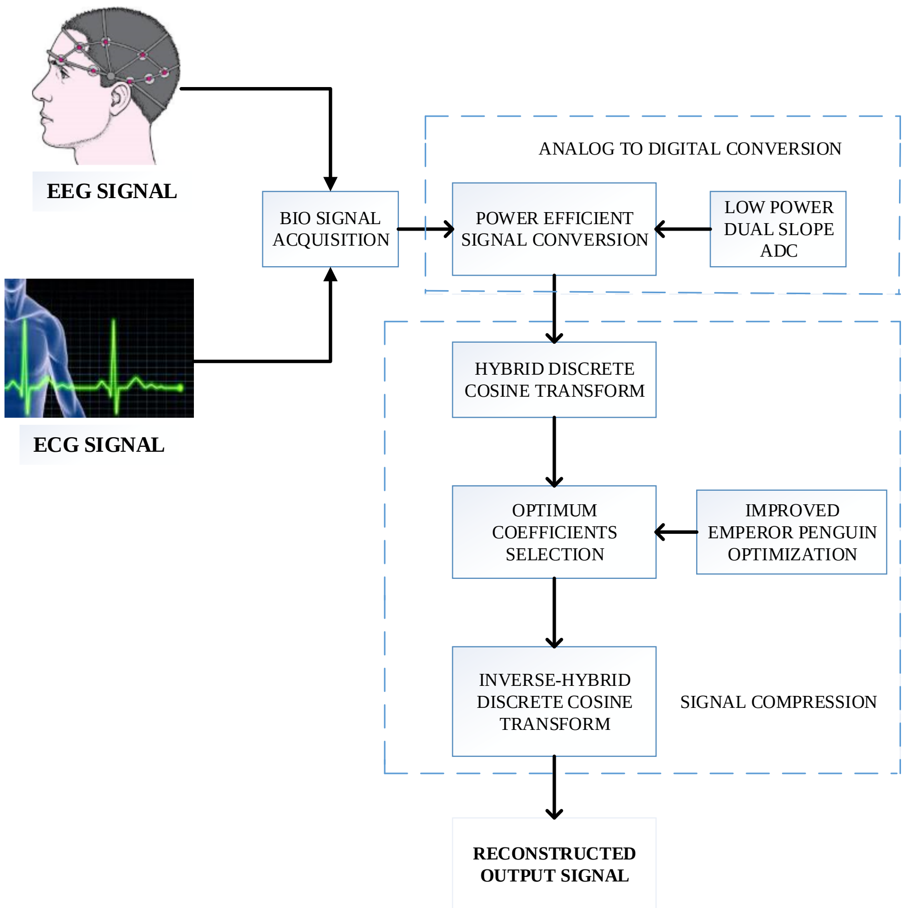

Figure 1. Schematic diagram of the presented methodology

3.1 Bio Signal Acquisition

The bio signals such as EEG and ECG signals are collected from the medical recordings and the acquired signals are initially in the form of analog and they need to convert into digital signal for the use of further processing. The general acquisitions of EEG and ECG signal recordings are described in the subsections,

3.1.1 EEG Signal Acquisition

Electroencephalography (EEG) signal is the monitoring process of electrical activity generated in brain. It is utilized to know the brain condition of the humans. This will be helpful for diagnosing the brain diseases of the patients. The activity of brain is recorded by placing the electrodes in different locations on the scalp. These electrodes producing the EEG signal is used for examining the brain activity.

3.1.2 ECG Signal Acquisition

Electrocardiogram (ECG) is the process of monitoring the electrical activity of the heart. In case of any abnormalities find in the heart function, the ECG clearly depicts the state of heart condition and it will be helpful for the prediction of heart disease. The ECG signal record is by placing the electrodes in the patient chest. In ECG, the signal of heart variations in the form of waveforms and in normal ECG five symbols such as P, Q, R, S, and T are existing. In this work, bio signals such as ECG and EEG are considered for the processing. The input EEG and ECG signals are initially converted into analog to discrete (ADC) form. The process of energy efficient signal conversion by using dual slope ADC is presented in this work and it is described in the subsequent section.

3.2 Power Efficient Analog to Digital Signal Conversion Using Low Power Dual Slope Adc (Lds-Adc)

The low power dual slope structure needs two times of single slope technique for process it in two integration cycles. A dual slope ADC is developed by the addition of simple integration to the single slope ADC, Moreover, the integration cycles for one conversion generating the error occurrence is corrected in dual slope ADC. Hence, the presented structures not having any gain error.

3.2.1 Design and Conversion Procedure:

The low power dual slop ADC integrating an analog input signal for an amount of time and it is determined via the counter overflow at the output. The integration of the reference signal to the input signal the output ramp voltage becomes zero. The ADC generally starts by the integration of ramp and ground with the positive slope to the negative analog voltage. Finally, this is attained in the ground through the integration of known voltage value at input.

The first part of the analog to digital signal conversion is in a fixed time interval of length $\bar{t}_1$. When the integration process starts, the binary counter starts to count and it triggers the switch at input for connecting the reference value once after it overflows. The time model at first time is represented in condition (1),

$$\bar{t}_1 = 2^M \bar{t}_{CLK} \tag{1}$$

The resultant voltage of the integrator at the end of first integration cycle is described as,

$$V_{out} = \frac{V_{in}\bar{t}_1}{RC} \tag{2}$$

The higher input voltage is larger the value at the end of the integration value. Afterwards at the input, switch is connected with the reference value in the next integration period. Moreover, the binary counter starts the counting of next integration cycle. The integrator value at the end of the second integration cycle is represented as,

$$V_{out} = \frac{V_{ref}\bar{t}_2}{RC} \tag{3}$$

Here, V_{ref} represents the reference voltage. This reference voltage discharges the capacitor regardless of analog input at a constant slope. The integrator output voltage once crosses the zero volts in the period of discharging, then the counter will stops and enabling the latch. By utilizing the conditions (2) and (3) the resultant voltage is described in condition (4),

$$\frac{V_{out}}{V_{ref}} = \frac{\bar{t}_2}{\bar{t}_1} \tag{4}$$

In condition (4), the right side signifies the digital output of dual slope ADC. The left side of the condition (4) signifies the expected digital output. This condition (4), proves that the presented dual slope ADC is not depends on any resistor or capacitor. Thus the issue in the single slope ADC is avoided. Moreover, control logic is introduced at the end of ADC to rearrange the integrator. This eventually resets and controls the counter when the new values are obtained by the latch.

The LDS-ADC overcomes the issues present in the single slope ADC. Furthermore, the process of design is very simple and fewer components are used. The converter uses minimum power and it results the significant noise rejection ability.

3.3 Signal Compression Using Hybrid Dct-Iepo

The hybrid discrete cosine transform is applied on the bio medical signals. The hybrid DCT is applied on the output signal of LDS-ADC.

$$Y(k) = \left(\frac{2}{N}\right)^{1/2} c_k \sum_{k=0}^{N-1} y(n) \cos\left[\frac{(2n+1)k\pi}{2N}\right], \qquad k = 0,1,2....N-1 \tag{5}$$

In the same way, inverse operation of this is described as,

$$y(n)=\left(\frac{2}{N}\right)^{1/2}\sum_{n=0}^{N-1}c_kY(k)\cos\left[\frac{(2n+1)n\pi}{2N}\right],\qquad n=0,1,2....N-1 \tag{6}$$

In conditions (5) and (6), c_k is evaluated as per the subsequent condition (7),

$$c_k=\begin{cases}\left(1/2\right)^{1/2} & for\quad k=0\\ 1 & for\quad k\neq 0\end{cases} \tag{7}$$

The coefficient $Y(k)$ is depends on the average value DC components. DCT is a most widely utilized compression scheme due to of its better power efficient behaviour.

3.3.1 Optimal Coefficients Selection Using Improved Emperor Penguin Optimization (IEPO) For Signal Compression

The selection of optimal coefficients in the output of hybrid DCT is performed by utilizing the IEPO. The flow diagram of the IEPO for optimal coefficients selection is given in figure 2.

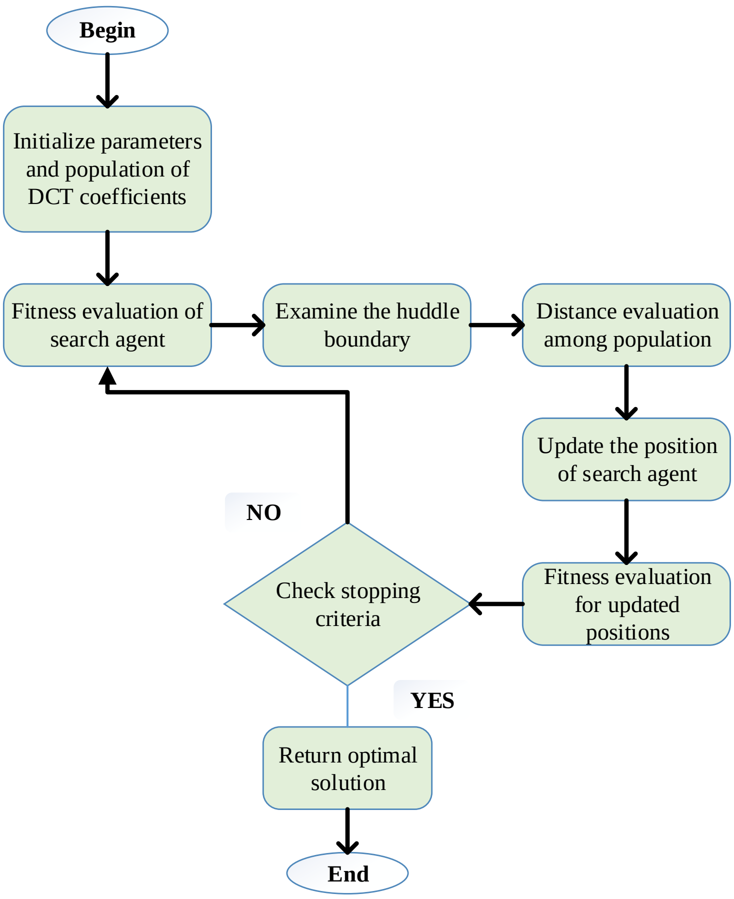

Figure 2. Flow diagram of Emperor penguin optimization

The main objective of the emperor penguin optimization algorithm is finding an optimized move of the penguins. The huddle behaviour of the penguins is mathematically described in this section. Consider, the huddle is situated on the distributed area with the coefficients. Initially, huddle boundary is arbitrarily created by the emperor penguins. Afterwards, the temperature level is evaluated around the huddle boundary. Then, distances among the penguins are evaluated and it is utilized for the exploration and exploitation process of optimization. At the end, best optimal solutions are attained. The optimization steps are described in the subsequent sections.

Huddle Boundary of Emperor Penguins: Generation and Determination

In this stage, the two neighbourhood penguins are huddle in the distributed boundary depending on the velocity of wind $w(n)$. The huddle boundary is generated as per the condition (8),

$$B_{huddle} = w(n) + (D_y) * N_p(n) \quad (8)$$

Here, B_{huddle} signifies the huddle boundary, $w(n)$ signifies the velocity of wind, D_y represents the density function, and $N_p(n)$ signifies the number penguins.

Distance Evaluation among the Penguins

To attain the best solution, distance is evaluated among the penguins and the boundary is determined by linking the positions of penguins with lowest neighbourhood. The distance among the penguins are computed with the condition (9),

$$D(p) = N_p(h) + w_f * Y_n \quad (9)$$

Here, $D(p)$ signifies the distance among the penguins, $N_p(h)$ signifies the number of penguins in the huddle, w_f signifies the weight factor that used for the selection of optimal solution with reduced iterations and Y_n signifies the arbitrary number in the uniform distribution. In condition (9), weight factor w_f is computed by the subsequent condition (10).

$$w_f = \exp\left(\frac{I_k}{I_k(\max) - 1}\right) \quad (10)$$

Here, w_f signifies the weight in iteration I_k, $I_k(\max)$ signifies the maximum number of iterations, and signifies the current iteration number and $I_k \leq I_k(\max)$.

Relocation of Effective Mover

The number of penguins are located in the huddle boundary, in that the penguin which has highest value of $D(p)$ is the 'mover'. The 'mover' relocates from its current position to the new position where the distance value gets minimum. After the relocation of the penguin positions, again the new huddle boundary is computed by utilizing the condition (11),

$$E_{(P+1)} = \lambda + E_{(P)} \quad (11)$$

Here, $E_{(P+1)}$ represents the updated positions of the emperor penguins, λ signifies the determining component for getting the optimal solution, and $E_{(P)}$ signifies the highest value of effective mover. Thus the optimal solution is obtained for the selection of coefficients in signal compression.

3.3.2 Inverse Hybrid Dct

The inverse hybrid DCT is described as,

$$y(n) = \left(\frac{2}{N}\right)^{1/2} \sum_{n=0}^{N-1} \overline{C}_k Y(k) \cos\left[\frac{(2n+1)n\pi}{2N}\right], \qquad n = 0,1,2....N-1 \quad (12)$$

Here, $\overline{C}_k$ represents the coefficients that optimally selected by the emperor penguin optimization for reconstruction. Thus the presented signal conversion and compressed signal reconstruction process reduces the power consumption and supports the bio medical applications.

4. Results and Discussion

The experimental results of the presented power efficient signal conversion and compression for biomedical signals using LDS-ADC and DCT-IEPO is implemented in the MATLAB platform. The performance of the presented approach is examined with the different existing approaches in regards of different performance measures such as compression ratio (CR), mean squared error (MSE), peak signal to noise ratio (PSNR), percentage root mean square error difference (PRD), quality score (QS) and power consumption.

4.1 Performance Metrics

The performance of the presented approach is examined with the different existing approaches in regards of different performance metrics such as CR, MSE, PSNR, PRD, QS and power consumption are described as,

4.1.1 Compression Ratio (Cr)

It is the estimation of data size reduction performance. The higher the compression ratio proves that the presented approach is effective in the performance. The CR measure is computed by the subsequent condition (13),

$$\overline{C}_{ratio} = \frac{\tilde{S}_{uncompressed}}{\tilde{S}_{compressed}} \tag{13}$$

Here, $\overline{C}_{ratio}$ signifies the compression ratio, $\tilde{S}_{uncompressed}$ signifies the size of signal before compression, and $\tilde{S}_{compressed}$ signifies the size of the compressed signal.

4.1.2 Mean Squared Error

Mean squared error estimates the average error among the reconstructed bio signal and for the signal before compression. This is the measure of the quality of the reconstructed signal. The MSE is computed as per the subsequent condition (14),

$$M_{SE} = \frac{1}{n}\sum_{k=1}^{M}\left(Y_k - Y_k''\right) \tag{14}$$

Here, Y_k signifies the original signal, Y'' signifies the reconstructed signal.

4.1.3 Peak Signal to Noise Ratio

This is the measure of ratio amongst the power of maximum power signal to the power of noise. It is evaluated in the subsequent condition (15),

$$\overline{P}_{SNR} = 10\log_{10}\left(\frac{\overline{A}_{signal}}{\overline{A}_{noise}}\right) \tag{15}$$

4.1.4 Percentage Root Mean Square Difference (Prd)

It is an amount of distortion intermediate to the original signal reconstructed EEG and ECG waveforms. The PRD measure is evaluated by utilizing the subsequent conditions (16),

$$\overline{PRD} = \sqrt{\frac{\sum_{k=1}^{M}(y_k - y_k^r)^2}{\sum_{k=1}^{M} y_k^{\;2}}} \tag{16}$$

Here, y_k signifies the input bio signal (EEG, ECG) after signal conversion, signifies the reconstructed output EEG and ECG signal correspondingly.

4.1.5 Quality Score

This is evaluated by the ratio of compression ratio to PRD. It is an important metric in the analysis of performance and that to select the effective compression methodology with the avoidance of error occurrence in the reconstruction. The quality square (QS) computes the effectiveness of the compression methodology. The quality score is computed by the subsequent condition (17),

$$\overline{QS} = \frac{C_{ratio}}{\overline{P}_{RD}} \tag{17}$$

Here, $\overline{QS}$ represents the quality score, C_{ratio} signifies the compression ratio, and $\overline{P}_{RD}$ signifies the PRD measure.

4.1.6 Power Consumption

It is the measure of power utilization in the particular processing. It is evaluated by the ratio of total amount of energy consumed in the particular processing to the specified time. The power utilization for the presented signal conversion and compression process is evaluated by the subsequent condition (18),

$$C_{power} = \frac{P_{Total}}{T_S} \tag{18}$$

Here, C_{power} signifies the power consumption, P_{Total} signifies the total amount of energy used in the process, and T_S signifies the specified time interval.

4.2 Performance Analysis

In this section, the performance of the presented approach is examined with the different existing approaches. The power efficiency of the presented approach is examined with the different existing approaches and the power consumption of the considered ECG and EEG bio signals with the presented approach is depicted in figure 3.

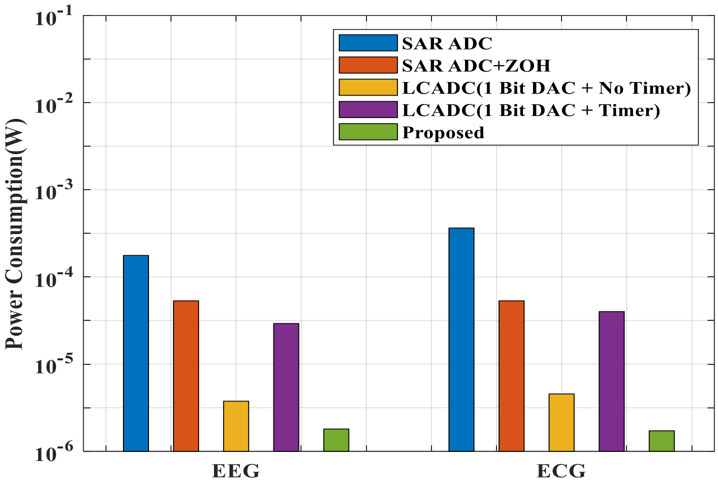

Figure 3. Evaluated power consumption for EEG and ECG signals

In figure 3, the evaluated power utilization for EEG and ECG signals is depicted and it proves that the presented approach utilizes minimum power than the different existing methodologies like SAR ADC, LCADC (ZOH), LCADC + Timer (FOH), LCADC (FOH), LCADC + Timer (ZOH) [21]. Moreover, the compression ratio performance of the presented methodology is depicted in figure 4.

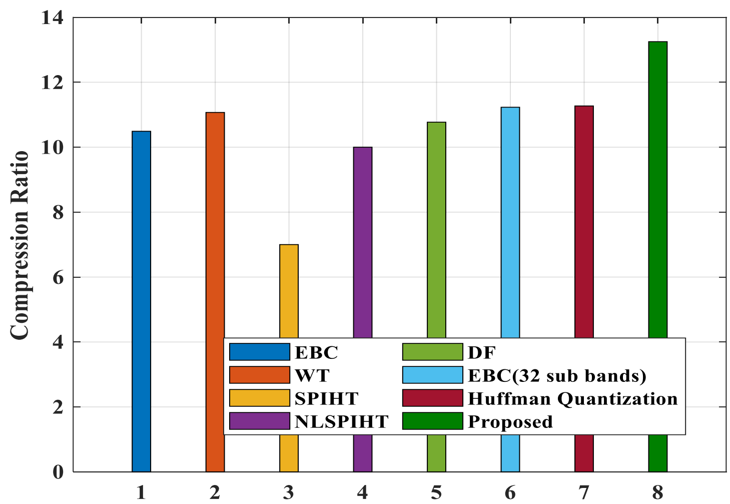

Figure 4. Comparison analysis in regards of compression ratio

The figure 4 provides the performance examination of the presented approach compression ratio and different existing approaches like energy based coding (EBC), Wavelet transform (WT), set partitioning in hierarchical tree (SPIHT), no list SPIHT (NLSPIHT), dipole fitting (DF), EBC-32 sub bands, and Huffman quantization [25]. The presented technique attains improved performance in regards of CR than the previous approaches. Moreover, the performance of CR, PRD and PSNR with the presented approach is displayed in figure 5.

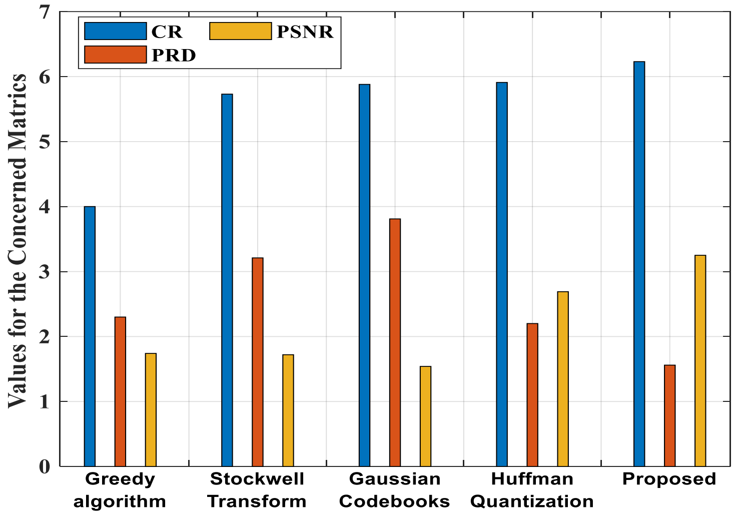

Figure 5. Comparison analysis in regards of CR, PRD, and PSNR

The above mentioned figure 5 proves that the presented approach attains improved performance in regards of CR, PRD and PSNR than the existing greedy algorithm, stockwell transform, Gaussian codebooks, Huffman quantization, and Huffman quantization [25] approaches. Moreover, the MSE performance of the presented approach is depicted in figure 6,

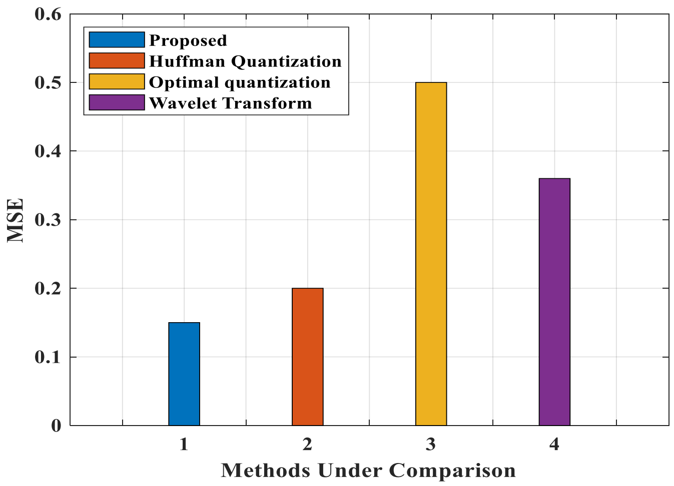

Figure 6. Comparison analysis in regards of MSE

The figure 6 proves that the presented approach provides the quality reconstruction by attaining reduced MSE value. The comparison analysis in regards of CR, PRD and quality score is depicted in figure 7.

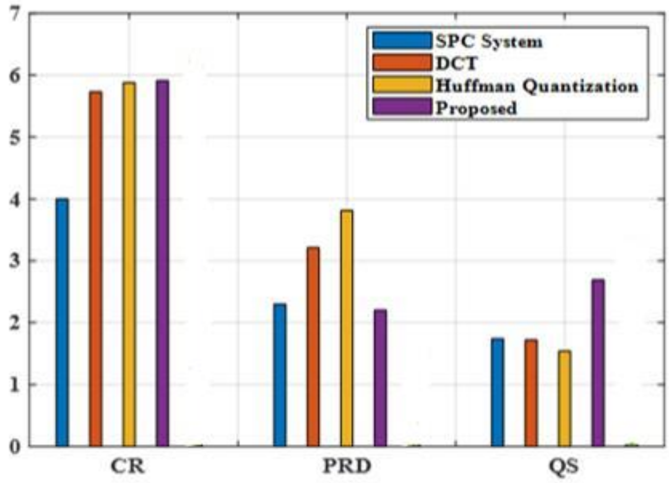

Figure 7. Comparison analysis in regards of CR, PRD, and QS

The figure 7 proves that the presented approach provides significant improvement in regards of CR, PRD and QS than the existing SPC system, general DCT, Huffman quantization [25] approaches. Moreover, the presented approach is examined with PRD performance measure and it is depicted in figure 8.

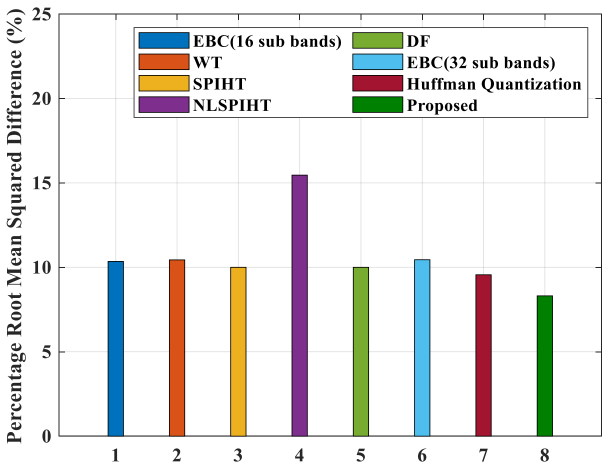

Figure 8. Comparison analysis in regards of PRD

The figure 8 depicts that the presented approach attains reduced PRD than the existing EBC, WT, SPIHT, NLSPIHT, DF, EBC-32 sub bands, and Huffman quantization approaches [25]. Thus the presented approach provides improved performance than the number of existing approaches.

5. Conclusion

This paper presented a power efficient signal conversion and compression on EEG and ECG signals by utilizing an low power dual slope analog to digital converter (LDS-ADC) and hybrid discrete cosine transform with emperor penguin optimization (Hybrid DCT-IEPO). Initially, efficient analog to digital conversion is performed on the ECG and EEG signals by utilizing a power efficient LDS-ADC. Subsequently, ECG and EEG signal compression is performed after energy efficient signal conversion. The hybrid DCT is applied on the output signal of LDS-ADC and resulting number of coefficients. Afterwards, optimal coefficients are chosen by utilizing emperor penguin optimization and finally, inverse hybrid DCT reconstructs the signal with the chosen optimal coefficients. The experimental analysis of the presented approach provides the significant improvements than the different existing approaches in regards of different performance measures like compression ratio, MSE, PSNR, PRD, QS and power consumption. In future work, improved techniques will be provided with the consideration of security in the transmission of medical data for various applications.

References

[1] Bencherqui A, Daoui A, Karmouni H, Qjidaa H, Alfidi M, Sayyouri M (2022) Optimal reconstruction and compression of signals and images by Hahn moments and artificial bee Colony (ABC) algorithm. Multimedia Tools and Applications Vol. 81No. 21, pp.29753-83.

[2] Adel M, El-Naggar M, Darweesh MS, Mostafa H (2018) Multiple hybrid compression techniques for electroencephalography data. In2018 30th international conference on microelectronics (ICM) pp. 124-127. IEEE.

[3] Parvez Mahmud MA, Huda N, Farjana SH, Asadnia M, Lang C (2018) Recent advances in nanogenerator-driven self-powered implantable biomedical devices. Advanced Energy Materials Vol. 8, No. 2, pp. 1701210.

[4] Liu Y, Wang H, Zhao W, Zhang M, Qin H, Xie Y (2018) Flexible, stretchable sensors for wearable health monitoring: sensing mechanisms, materials, fabrication strategies and features. Sensors Vol. 18, No. 2, pp. 645.

[5] Chen SL, Villaverde JF, Lee HY, Chung DW, Lin TL, Tseng CH, Lo KA (2017) A power-efficient mixed-signal smart ADC design with adaptive resolution and variable sampling rate for low-power applications. IEEE Sensors Journal Vol. 17, No. 11, pp. 3461-9.

[6] Singh T, Tripathi SL (2021) Design of a 16-bit 500-MS/s SAR-ADC for low-power application. InElectronic Devices, Circuits, and Systems for Biomedical Applications pp. 257-273. Academic Press.

[7] Hussein AF, Hashim SJ, Aziz AF, Rokhani FZ, Adnan WA (2017) A real time ECG data compression scheme for enhanced bluetooth low energy ECG system power consumption. Journal of Ambient Intelligence and Humanized Computing pp. 1-4.

[8] Mahmood SD, Panessai IY (2021) A Tele Encephalopathy Diagnosis Based on EEG Signal Compression and Encryption. InAdvances in Cyber Security: Second International Conference, ACeS 2020, Penang, Malaysia, December 8-9, 2020, Revised Selected Papers Vol. 1347, pp. 148. Springer Nature.

[9] Jeon G, Ahmad A, Cuomo S, Wu W (2019) Special issue on bio-medical signal processing for smarter mobile healthcare using big data analytics. Journal of Ambient Intelligence and Humanized Computing Vol. 10:3739-45.

[10] Terlapu SK, Ravuri V, Nayak SS (2021) Reconstruction of level cross sampled signals using sparse signals & backtracking iterative hard thresholding. Journal of Scientific & Industrial Research Vol. 80, No. 03, pp. 245-8.

[11] Khan S, Yairi T (2018) A review on the application of deep learning in system health management. Mechanical Systems and Signal Processing Vol. 107:241-65.

[12] Chandra S, Sharma A, Singh GK (2021) A comparative analysis of performance of several wavelet based ECG data compression methodologies. Irbm Vol. 42, No. 4, pp. 227-44.

[13] Nasserian M, Peiravi A, Moradi F (2019) An adaptive-resolution signal-specific ADC for sensor-interface applications. Analog Integrated Circuits and Signal Processing, Vol. 98:125-35.

[14] Marisa T, Niederhauser T, Haeberlin A, Wildhaber RA, Vogel R, Goette J, Jacomet M (2017) Pseudo asynchronous level crossing ADC for ECG signal acquisition. IEEE transactions on biomedical circuits and systems Vol. 11, No. 2, pp. 267-78.

[15] Jing Y, Wang Z, Shen L, Zhang Y, Chen P, Ru J, Ye L (2023) An Information-Aware Adaptive Data Acquisition System using Level-Crossing ADC with Signal-Dependent Full Scale and Adaptive Resolution for IoT Applications. In2023 IEEE International Symposium on Circuits and Systems (ISCAS) pp. 1-4. IEEE.

[16] Al-Marridi AZ, Mohamed A, Erbad A (2018) Convolutional autoencoder approach for EEG compression and reconstruction in m-health systems. In2018 14th international wireless communications & mobile computing conference (IWCMC) pp. 370-375. IEEE. DOI: 10.1109/IWCMC.2018.8450511

[17] Al-Sa'D MF, Tlili M, Abdellatif AA, Mohamed A, Elfouly T, Harras K, and O'Connor MD (2018) A deep learning approach for vital signs compression and energy efficient delivery in mhealth systems. IEEE Access Vol. 6:33727-39. DOI: 10.1109/ACCESS.2018.2844308

[18] Elaskary RM, Saeed M, Ismail T (2017) Non-uniform quantized Huffman compression technique for EEG data. In2017 13th international computer engineering conference (ICENCO) pp. 219-223. IEEE. DOI: 10.1109/ICENCO.2017.8289791

[19] Mentzer F, Gool LV, Tschannen M (2020) Learning better lossless compression using lossy compression. InProceedings of the IEEE/CVF conference on computer vision and pattern recognition pp. 6638-6647.

[20] Jha CK, Kolekar MH (2018) Electrocardiogram data compression using DCT based discrete orthogonal Stockwell transform. Biomedical Signal Processing and Control Vol. 46:174-81. https://doi.org/10.1016/j.bspc.2018.06.009

[21] Van Assche J, Gielen G (2020) Power efficiency comparison of event-driven and fixed-rate signal conversion and compression for biomedical applications. IEEE Transactions on Biomedical Circuits and Systems Vol. 14, No. 4, pp. 746-56. DOI: 10.1109/TBCAS.2020.3009027

[22] Hou Y, Qu J, Tian Z, Atef M, Yousef K, Lian Y, Wang G (2018) A 61-nW level-crossing ADC with adaptive sampling for biomedical applications. IEEE Transactions on Circuits and Systems II: Express Briefs Vol. 66, No. 1, pp. 56-60. DOI: 10.1109/TCSII.2018.2841037

[23] Antony A, Paulson SR, Moni DJ (2019) Asynchronous adaptive threshold level crossing ADC for wearable ECG sensors. Journal of medical systems Vol. 43:1-8. https://doi.org/10.1007/s10916-019-1186-8

[24] Hosny KM, Khalid AM, Mohamed ER (2018) Efficient compression of bio-signals by using Tchebichef moments and Artificial Bee Colony. Biocybernetics and Biomedical Engineering Vol. 38, No. 2, pp. 385-98. https://doi.org/10.1016/j.bbe.2018.02.006

[25] Rajasekar P, Pushpalatha M (2020) Huffman quantization approach for optimized EEG signal compression with transformation technique. Soft Computing Vol. 24:14545-59. https://doi.org/10.1007/s00500-020-04804-z

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