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An Evaluation on Primarily DCT-based ECG Diagnosis Mechanisms and its Implications

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Abstract— **In this literature review, synthesized studies on the software of Discrete Cosine Transformation (DCT) model for analysing electrocardiogram (ECG) indicators are articulated in a summary. The techniques found in this study are developed for the purposed (i) noise reduction (ii) function extraction and (iii) data compression that aim to (i) beautify diagnostic accuracy, (ii) tackling challenges inclusive of signal quality and (iii) information quantity management. The objectives of the evaluation included comparing DCT-driven noise attenuation methods, benchmarking the accuracy of function extraction, figuring out compression algorithms that hold scientific information, comparing hybrid approaches, and assessing their impacts on diagnostic accuracy and computational efficiency. A systematic analysis of studies making use of standard ECG databases and various DCT-based methodologies become performed, emphasizing quantitative metrics like compression ratio, percentage root mean rectangular distinction, and classification accuracy. Research by Qin et al. (2017) showcases a robust system for analyzing electrocardiogram (ECG) data. The system first cleans the signal using DCT-based filtering with adaptive thresholds, which effectively removes common noise like baseline wander and muscle interference without distorting the ECG's morphological features. This cleaned data is then used for feature extraction, where DCT coefficients are fed into a machine learning model, achieving exceptional arrhythmia classification accuracy of over 98% and highlighting its strong diagnostic potential. The analysis reveals a key trade-off in ECG signal compression as (i) Compression Performance: DCT and hybrid transforms achieve high compression ratios while preserving signal fidelity; (ii) Computational Cost: A significant drawback is their complexity, raising concerns about real-time use. This issue is exacerbated in integrative models that combine DCT with wavelets or classifiers for better performance; (iii) Overall Significance: DCT is confirmed as a critical component for optimizing ECG processing in telemedicine and real-time monitoring and finally (iv) Future Direction: These results guide the development of standardized, efficient DCT-based systems to enhance cardiac diagnostic workflows and device integration.**

Keywords— **Discrete Cosine Transformation (DCT), Electrocardiogram (ECG), Signal, Accuracy, Classification**

I. INTRODUCTION

The analysis of electrocardiogram (ECG) signals using the Discrete Cosine Transform (DCT) has become a pivotal research field, driven by its potential to boost diagnostic accuracy through enhanced noise reduction, feature extraction, and data compression. The field has progressed from basic transform methods to sophisticated hybrid and adaptive algorithms that utilize DCT for its efficiency in energy compaction and signal representation (Picariello et al., 2024; Thorat, 2012) [39, 47].

This research is critically relevant due to the growing need for long-term, high-frequency ECG monitoring, which produces massive datasets that demand efficient storage and transmission (Feng et al., 2025; Soni et al., 2022) [12, 44]. Given that cardiovascular diseases are a leading global cause of mortality, refining ECG analysis is essential for prompt and precise diagnosis (Hamad, n.d.; Soni et al., 2022) [15].

A central challenge in this area is achieving a balance between high compression ratios and effective noise reduction while preserving the clinically significant features of the ECG signal to ensure diagnostic value is not lost (Luanloet et al., 2023; Belkacem et al., 2018) [28, 6]. Despite numerous proposed techniques, a significant knowledge gap remains in optimally combining DCT-based methods to perform noise suppression, feature extraction, and compression simultaneously on diverse ECG datasets (Kumar & Ramachandran, 2024; Soni et al., 2018; Lin et al., 2022) [21, 45, 27]. The scientific community is also divided on the best approach; while some studies advocate for wavelet-based methods due to their superior local feature preservation, others champion DCT for its superior energy compaction and computational efficiency (Ali et al., 2020; F Z. & Rr G., 1993; Thorat, 2012) [4, 11, 47]. This unresolved debate can lead to the loss of vital diagnostic information and suboptimal performance in real-world telemedicine applications (Soni et al., 2022; Abdul Baqi et al., 2021) [44, 2].

Conceptually, this review is grounded in the framework that DCT acts as a transform-domain tool, concentrating the energy of an ECG signal into a small number of coefficients, which facilitates both noise reduction and compression (Pandey et al., 2016; Lai et al., 2013) [38, 22]. The sparsity created by the DCT also enables efficient feature extraction for tasks like classification and anomaly detection (Picariello et al., 2024; Marasovic & Papić, 2016) [39, 33]. The interconnection of these concepts supports the overarching goal of improving diagnostic accuracy through integrated signal processing strategies (Hamad, n.d.; Zhou et al., 2018) [15, 50].

The purpose of this systematic review is to critically appraise and synthesize recent progress in DCT-based ECG analysis, with a specific focus on noise reduction, feature extraction, and compression. It aims to bridge the identified knowledge gap by providing a comprehensive evaluation of different methodologies, comparing their performance, and assessing their applicability in clinical and telemedicine settings to ultimately contribute to better diagnostic outcomes (Pal et al., n.d.; Soni et al., 2022) [37, 44].

The methodology for this review involves a structured analysis of peer-reviewed literature selected for its relevance to DCT applications in ECG processing. The inclusion criteria prioritize recent studies that address noise, features, and compression, while non-DCT-based methods are excluded. The findings will be organized thematically to clearly present current trends, persistent challenges, and promising future research directions (Picariello et al., 2024; Kaushal et al., 2024; Rebollo- Neira, 2024) [39, 41].

II. Literature Review

Noise reduction efficiency:

Research into noise reduction for ECG signals has effectively utilized Discrete Cosine Transform (DCT) methods. Approximately ten studies, including those by Hamad (n.d.) and Belkacem et al. (2018), demonstrate that DCT-based pre-processing and hybrid techniques successfully suppress various types of interference, such as baseline wander, muscle artifacts, and random noise, leading to significantly clearer signals [15, 6]. A key strength of these approaches is their ability to preserve the critical morphological features of the ECG. Researchers like Feng et al. (2025) and Lin et al. (2022) have developed algorithms that use adaptive thresholding and hierarchical decomposition within the DCT domain to precisely isolate and remove noise components without distorting the underlying cardiac signal [12, 27].

Furthermore, DCT-based methods show a performance advantage over conventional techniques. Studies by Hegde et al. (2011) indicate that adaptive filtering and Least Mean Squares (LMS) algorithms operating in the DCT domain achieve superior convergence and more effective noise cancellation [17].

Function Extraction Accuracy:

Evidence from five studies confirms the high efficacy of DCT-derived features for detecting cardiac events and classifying arrhythmias, with performance metrics for sensitivity and precision regularly reported above 98%. The discrimination of abnormal beats under noisy conditions is further enhanced by feature extraction techniques that amalgamate DCT with energy operators or random projections. The application of DCT is also prominent in machine learning pipelines, where it serves as a powerful tool for feature dimensionality reduction, facilitating near-perfect recognition rates in several studies (Picariello et al., 2024; Sharmila & Reddy, 2015; Marasovic & Papić, 2016) [39, 42, 33].

Compression Ratio (CR):

Research indicates a trade-off in ECG signal compression:

Compression Range: Achievable compression ratios are highly variable, spanning from ~5:1 to >50:1, and are dependent on the specific method and its clinical context (Lai et al., 2013; Luanloet et al., 2023) [22, 28].

High-Ratio Techniques: Hybrid methods, which fuse DCT with wavelet transforms or adaptive quantization, typically achieve the highest compression ratios without critically compromising signal fidelity (Feng et al., 2025; Surekha & Patil, 2014) [12, 46].

Diagnostic-Grade Techniques: For applications requiring absolute data integrity, lossless and near-lossless compression are used, but they inevitably result in lower compression ratios (Soni et al., 2018; Pandey et al., 2016) [45, 38].

Quality of Signal Reconstruction:

Evaluation of compression techniques reveals that PRD values typically fall below 1% for high-fidelity methods and rise to around 5% for lossy compression, with concomitant SNR values regularly surpassing 25 dB in robust algorithms (Moon et al., 2020; Kaushal et al., 2024) [34, 20]. The implementation of optimized quantization and adaptive thresholding has been shown to significantly enhance reconstruction quality, resulting in lower distortion (Pandey et al., 2016; Alam & Rahim, 2008) [38, 3].

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The development of hybrid and two-dimensional DCT methods has further advanced the field by promoting greater signal sparsity, which in turn improves reconstruction accuracy and achieves a more favorable equilibrium between data reduction and the preservation of critical signal information (Buddy et al., 2022; Lee & Buckley, 1999) [25].

Diagnostic Accuracy impact:

Research on DCT-based ECG processing reveals three critical insights:

Maintained Diagnostic Value: Compression and pre-processing using DCT consistently maintain, and in some cases improve, the accuracy of arrhythmia classification (Picariello et al., 2024; Marasovic & Papić, 2016) [39, 33].

Importance of Reconstruction: The high classification accuracy achieved by deep learning models on decompressed data—surpassing that of compressed-only data—underscores that reconstruction quality is paramount for subsequent analysis (Soni et al., 2022) [44].

Feature Preservation is Key: For compressed data to be clinically useful, the techniques must reliably preserve diagnostically critical features such as QRS complexes and R-peaks (Moon et al., 2020; Hamad, n.d.) [34, 15].

The above literature review on DCT-based ECG analysis concludes with the following points:

Strengths: The research demonstrates DCT's strong capability for energy compaction, noise suppression, and data reduction, often yielding improved diagnostic outcomes when integrated with other techniques.

Persistent Challenges: Significant hurdles remain in optimizing the trade-off between compression and fidelity, reducing computational load for real-time use, and managing the complexity of advanced hybrid algorithms.

Future Direction: The field has produced valuable insights but now requires standardized evaluation protocols and rigorous testing in real-world clinical scenarios to translate research findings into practical tools.

III. Methodology

To analyse the literatures critically, following two kinds of evaluations are carried out:

A. Thematic evaluation of Literature:

The application of the Discrete Cosine Transform (DCT) in ECG signal processing is structured around three primary objectives:

Noise Reduction: DCT serves as an effective pre-processing step, significantly improving signal clarity by attenuating common artifacts like baseline wander and muscle noise.

Feature Extraction: The transform's coefficients are leveraged to isolate and identify clinically critical features, including QRS complexes and arrhythmic patterns, with a high degree of precision.

Data Compression: Through both pure DCT and hybrid approaches that incorporate wavelets or machine learning, these methods enable efficient data storage and transmission for telemedicine by maintaining high compression ratios without sacrificing diagnostic fidelity.

A growing body of work is now exploring adaptive, hybrid systems that integrate DCT with other signal processing and classification tools to enhance diagnostic accuracy and computational performance.

B. Chronological evaluation of Literature:

The evolution of DCT-based ECG analysis over the past three decades can be summarized as follows:

Early Focus: Initial research concentrated on parametric modelling and basic DCT applications for data compression.

Intermediate Development: Subsequent studies developed more advanced hybrid and adaptive methods, combining DCT with wavelets and machine learning.

Current Trends: Modern advances are tackling real-world challenges like real-time processing, data encryption, and creating optimized algorithms for telemedicine, often by integrating deep learning for classification.

This entire progression demonstrates a consistent effort to balance the competing demands of compression efficiency, signal quality, and clinical relevance.

IV. Discussion

Our discussion on above critical evaluation of literatures is divided two aspects – one is theoretical implications and other is sensible implications.

Theoretical Implications

The literature substantiates the theoretical principle that the Discrete Cosine Transform (DCT) effectively leverages the energy compaction property of ECG signals, facilitating efficient noise reduction, feature extraction, and data compression.

This supports established signal processing theory regarding the value of transform-domain sparsity for biomedical data (Picariello et al., 2024; Belkacem et al., 2018; Lin et al., 2022) [39, 6, 27].

Hybrid methodologies that integrate DCT with wavelet transforms or compressive sensing frameworks demonstrate enhanced performance by capitalizing on the complementary strengths of time-frequency localization and sparsity. This advances theoretical models for multi-domain signal representation (Kumar & Ramachandran, 2024; Surekha & Patil, 2014; F.Zr & Rr G., 1993) [21, 46, 11].

Furthermore, the use of adaptive thresholding and optimization algorithms—such as COOT bird optimization and Regula-Falsi methods—within the DCT domain expands the theoretical understanding of how to balance compression efficiency with signal fidelity through precise parameter tuning (Buddy et al., n.d.; Pandey et al., 2016; Lin et al., 2022) [38, 27].

Theoretical progress is also evident in the creation of transform-domain adaptive filtering algorithms (e.g., variable step-size Griffiths' LMS). These enhance noise cancellation by utilizing DCT's superior frequency resolution compared to traditional Fourier-based techniques (Hegde et al., 2012; Hegde et al., 2011) [18, 17].

The evidence also challenges the prevailing assumption that wavelet-based methods are universally superior for ECG analysis. DCT-based approaches are shown to achieve comparable or better performance in specific contexts; particularly for noise reduction and baseline wander removal (Belkacem et al., 2018; Lin et al., 2022; Ranjeet et al., 2011) [6, 27, 40].

Finally, theoretical insights into the trade-off between compression ratio and diagnostic accuracy are deepened by studies confirming that DCT-based compression and feature extraction can successfully preserve critical ECG features like QRS complexes and arrhythmia markers, thereby validating their clinical relevance (Picariello et al., 2024; Sharmila & Reddy, 2015; Soni et al., 2022) [39, 42, 44].

Practical Implications

The high compression ratios achieved by DCT-based algorithms, often enhanced with entropy coding and adaptive quantization, have significant practical utility for telemedicine and remote cardiac monitoring. These methods reduce storage and bandwidth demands without sacrificing diagnostic quality (Feng et al., 2025; Luanloet et al., 2023; Abdulbaqi et al., 2021) [12, 28, 2].

Integrating DCT with machine learning classifiers, including random forests and deep convolutional neural networks, enables automated, accurate arrhythmia detection from compressed or reconstructed ECG data. This enhances real-time diagnostic capabilities in both clinical and mobile health settings (Picariello et al., 2024; Marasovic & Papić, 2016; Soni et al., 2022) [39, 33, 44].

The practical deployment of DCT-based noise reduction and baseline wander correction improves signal quality in wearable and ambulatory ECG devices, increasing the reliability of continuous cardiac monitoring in non-clinical, noisy environments (Belkacem et al., 2018; Lin et al., 2022; Hegde et al., 2012) [6, 27, 18].

The proven computational efficiency and hardware-friendly nature of certain DCT implementations (e.g., DCT-IV) make them suitable for embedded systems and low-power devices, which is crucial for developing scalable and cost-effective ECG monitoring solutions (Lai et al., 2013; Lai et al., 2012) [23, 22].

Evidence indicates that hybrid compression schemes, which combine DCT with wavelet or zero-tree coding, can optimize performance while retaining clinically relevant signal features. This offers practical frameworks for next-generation ECG data management systems (Buddy et al., n.d.; Pal et al., 2022; Surekha & Patil, 2014) [37, 46].

Despite these advances, challenges remain in balancing high compression efficiency with the low latency required for real-time processing, particularly in high-frequency, long-duration monitoring scenarios. However, adaptive and hierarchical DCT-based methods show considerable promise in overcoming these constraints for practical applications (Feng et al., 2025; Kumar & Ramachandran, 2024; Soni et al., 2022) [12, 21, 44].

V. CONCLUSION & RECOMMENDATIONS

The collective research confirms the Discrete Cosine Transform (DCT) as a cornerstone technique in ECG signal analysis, effectively enhancing signal quality, feature extraction, and data compression to improve diagnostic accuracy. DCT's core strength lies in its energy compaction property, which facilitates the attenuation of noise—such as baseline wander, muscle artifacts, and random interference—without significantly distorting the ECG's essential morphological features. This performance is often boosted by hybrid methods that merge DCT with wavelet transforms, empirical mode decomposition, or adaptive filtering, leading to superior de-noising and clearer identification of QRS complexes.

Despite this effectiveness, challenges persist in adapting these techniques to non-stationary noise and managing their computational complexity for real-time applications.

In feature extraction, DCT coefficients have proven to be compact and highly discriminative, enabling high-accuracy classifications of cardiac abnormalities like arrhythmias. The literature shows that integrating these coefficients with energy operators, random projections, and machine learning classifiers can achieve classification accuracy exceeding 98%, even in noisy conditions. A key limitation, however, is the reliance on meticulous coefficient selection and labelled datasets, which can hinder the generalizability and interpretability of these models across diverse patient populations and signal qualities.

For data compression, DCT-based methods achieve a wide range of compression ratios, successfully balancing data reduction with signal fidelity. Hybrid approaches that combine DCT with wavelets or optimized quantization consistently deliver higher compression efficiency while preserving diagnostically critical information. While lossless and near-lossless techniques offer lower compression, they are indispensable for sensitive diagnostic applications. Metrics like Percent Root-mean-square Difference (PRD) and Signal-to-Noise Ratio (SNR) confirm that crucial features such as R-peaks and QRS complexes remain intact after compression, which is vital for reliable diagnosis. The central challenge remains navigating the trade-off between compression ratio, signal fidelity, and algorithmic complexity, particularly for resource-constrained, real-time telemedicine systems.

Hybrid models that integrate DCT with other transforms or machine learning represent a promising direction, leveraging complementary strengths across noise reduction, feature extraction, and compression. However, their increased computational demands and complex parameter optimization hinder straightforward clinical adoption. Furthermore, while hardware-accelerated DCT implementations show promise for real-time processing; many studies are confined to offline analysis, revealing a significant gap in their validation within practical, real-world tele-monitoring scenarios.

In conclusion, DCT-based methodologies have substantially advanced the field of ECG signal processing and compression. To fully realize their potential in tele-cardiology and continuous monitoring, future work must focus on establishing standardized evaluation metrics, conducting robust clinical trials across diverse datasets, and optimizing these algorithms for computational efficiency in real-world applications

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