Wavelet-Enhanced Deep Learning for Sleep Apnea Classification: A Comprehensive Analysis

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***Abstract*— Sleep apnea is a common and potentially serious sleep disorder marked by repeated interruptions in breathing during sleep, which can lead to severe health consequences if not properly managed. Traditional diagnostic methods, often reliant on manual analysis of polysomnographic data, can be cumbersome and inaccessible. This study presents a comprehensive analysis of a novel system for the automatic classification of sleep apnea events using a wavelet-enhanced deep learning approach. The proposed method integrates the Discrete Wavelet Transform (DWT) for robust feature extraction, capturing both time and frequency domain characteristics of respiratory signals. These features are subsequently employed in a Convolutional Neural Network (CNN) to precisely classify three distinct types of sleep apnea: obstructive sleep apnea (OSA), central sleep apnea (CSA), and mixed sleep apnea (MSA). Utilizing a dataset comprising 1146 annotated apneic events, the system demonstrates high accuracy and robustness, achieving classification accuracies of 92.8% for OSA, 92.6% for CSA, and 90.0% for MSA. Our experimental results on the Physionet MIT-BIH polysomnography database (xx overnight recordings) revealed that proposed system achieved accuracies of % for OSA, % for CSA, and % for MSA. This approach underscores the potential of combining wavelet transforms with deep learning to offer a reliable, efficient, and non-intrusive solution for sleep apnea diagnosis, paving the way for improved patient outcomes and facilitating large-scale sleep studies.**

Keywords—apnea, deep learning, wavelet transform, support vector machine

I. Introduction

Sleep apnea is a widespread but potentially serious sleep disorder that involves repeated disruptions in breathing during sleep [1]. These disruptions, known as apneas, can result in various health problems, including cardiovascular diseases, daytime fatigue, and cognitive impairment. Sleep apnea is typically divided into three categories: obstructive sleep apnea (OSA), central sleep apnea (CSA), and mixed sleep apnea (MSA), which is a combination of the other two. OSA, the most common form, occurs due to a physical obstruction of the upper airway, despite the body's efforts to breathe [2]-[5]. Conversely, CSA arises when the brain fails to transmit the necessary signals to the muscles responsible for breathing, causing a lack of respiratory effort. MSA exhibits characteristics of both OSA and CSA.

Traditional methods for diagnosing sleep apnea primarily rely on overnight polysomnography (PSG) conducted in specialized sleep labs [5]. While PSG is highly accurate, it is also expensive, time-consuming, and inconvenient for many patients, often leading to underdiagnosis. The need for a non-intrusive, efficient, and accessible diagnostic tool has driven the development of innovative methods for sleep apnea detection and classification. Recent advancements in technology have introduced wearable devices and home-based monitoring systems, which utilize sophisticated algorithms to analyze physiological signals and detect apnea events in real time [6]-[7].

The classification of apneas is critical for accurate diagnosis and effective treatment. Each type of apnea has distinct characteristics and underlying causes, necessitating different therapeutic approaches. Accurate classification not only aids in tailoring treatments but also reduces the need for repeated diagnostic tests and consultations, optimizing resource utilization and reducing healthcare costs [8]-[9].

In this study, we present a comprehensive analysis of an advanced system that leverages the Discrete Wavelet Transform (DWT) for feature extraction, combined with a Convolutional Neural Network (CNN) for the classification of sleep apnea events. The DWT is particularly effective in capturing both time and frequency domain characteristics of respiratory signals, providing a rich set of features for the CNN to process. This approach aims to enhance the accuracy and reliability of sleep apnea classification, offering a significant improvement over traditional methods and facilitating large-scale sleep studies.

The main contribution of the work is combining wavelet transforms with deep learning, the proposed system offers a non-intrusive, efficient, and scalable solution for sleep apnea diagnosis. This method has the potential to improve patient outcomes and facilitate large-scale sleep studies, addressing the limitations of traditional diagnostic methods.

The structure of the paper is as follows: Section II, Literature Review, provides a comprehensive overview of previous research in sleep apnea classification, with a focus on the methodologies and technologies used, such as machine learning and signal processing techniques. Section III, Materials and Methods, describes the dataset utilized in this study, the signal acquisition process, and the methodology, including the application of the Discrete Wavelet Transform (DWT) for feature extraction and the design of the Convolutional Neural Network (CNN) for classification. Section IV, Results, presents the performance metrics of the proposed system, such as accuracy, sensitivity, and specificity, assessed on both seen and unseen data. Section V, Discussion, interprets the results, comparing the proposed approach with existing methods and highlighting the advantages of integrating wavelet transform with deep learning. Finally, Section VI, Conclusion, summarizes the findings, discusses the implications for future research, and