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UNVEILING SLEEP APNEA PATTERNS: A COMPREHENSIVE INVESTIGATION OF MACHINE LEARNING AND DEEP LEARNING MODELS

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ABSTRACT

Sleep apnea, a condition marked by recurrent pauses or reductions in lung airflow lasting more than 10 seconds, underscores the critical need for precise episode identification, as it lays the foundation for tailored drug and treatment interventions. At the forefront of this imperative is the accurate discernment of sleep apnea occurrences. In this pursuit, the PhysioNet ECG Sleep Apnea v1.0.0 dataset, housing 70 recordings, serves as the canvas for an in-depth exploration into the realm of machine learning and deep learning algorithms. Through meticulous pre-processing and meticulous segmentation of electrocardiogram (ECG) readings, this study delves into the application of methodologies rooted in both deep learning and machine learning paradigms. To ensure uniformity and fulfill the rigorous demands of biosignal processing, a consistent modification protocol was applied across all network architectures. The dataset underwent a strategic tripartite division, yielding distinct subsets: a training set tailored to refine model parameters, a validation set dedicated to the fine-tuning of hyperparameters, and a test set meticulously crafted to evaluate the models' resilience to previously unseen data.In a structured and iterative manner, a 5-fold cross-validation technique was invoked, and iterated five times, thereby affording a comprehensive evaluation of the models, with all recordings systematically traversing the test set domain. Within this orchestrated framework, the pinnacle of detection proficiency was conspicuously occupied by hybrid deep models, showcasing an impressive triumvirate of statistical metrics: accuracy scaling to 88.13%, sensitivity attaining 84.26%, and specificity reigning supreme at an admirable 92.27%. Beyond the immediate context of sleep apnea, this research resonates with implications that extend to the broader landscape of sleep disorder identification. Beyond its emphasis on the pivotal task of sleep apnea recognition, this inquiry unveils a panoramic vista, offering insight into the nuanced performance dynamics of diverse machine learning and deep learning algorithms within the realm of sleep disorders..

Keywords – Deep learning, detection, electrocardiogram (ECG), machine learning, sleep apnea.

I. INTRODUCTION

Sleep exerts a profound and far-reaching influence on our well-being, accounting for a substantial portion—approximately one-third—of our entire human existence. Within the intricate tapestry of sleep, two fundamental phases weave their narrative: the rapid eye movement (REM) phase and the non-rapid eye movement (NREM) phase. Distinct in their essence, REM sleep unfolds with heightened sympathetic activity, cardiac instability, and hemodynamic intricacies, contrasting the more placid dynamics of NREM sleep. The latter is characterized by a calming reduction in oxygen consumption, heart rate, and blood pressure, while the former witnesses an orchestration of elevation in these vital measures. The specter of sleep apnea, a condition characterized by intermittent respiratory disturbances, can cast its shadow across any stage of slumber, yet it unfurls most conspicuously during the REM phase. This preference finds its roots in the pronounced relaxation of upper airway muscles that accompanies REM sleep. The contemporary landscape of sleep is not devoid of challenges, as the burgeoning prevalence of sleep-related ailments paints a concerning picture, affecting an estimated cohort of approximately 70 million individuals within the United States alone. Echoing this concern is the resounding toll that sleep disorders take on morbidity and even mortality rates. Within the panorama of sleep disorders, an intricate array unfolds, encompassing insomnia, sleep breathing disorders, central disorders of hypersomnolence, circadian rhythm sleep-wake disorders, parasomnias, and movement disorders. Among these, the category of sleep breathing disorders (SBD) emerges as a significant player. This spectrum comprises four principal archetypes: obstructive sleep apnea (OSA), central sleep apnea (CSA), hypoventilation during sleep, and hypoxia disorders. On the global stage, an astonishing tableau unfolds, with OSA impacting an estimated one billion individuals, encapsulating a staggering portion of humanity. Meanwhile, the rarer symphony of CSA plays a more elusive tune. Noteworthy is the temporal choreography within which these maladies perform: OSA's crescendo extends across both REM and NREM sleep, with a pronounced crescendo during REM, while CSA stages its act predominantly during the NREM cycle.

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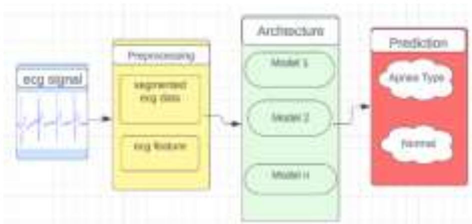

Figure 1. Sleep apnea detection system architecture

In the realm of healthcare, the quest for precise, cost-effective, and portable solutions that can effectively identify and monitor sleep episodes has become a pressing necessity. This urgency is rooted in the need to proactively address a myriad of health concerns, spanning cardiovascular issues to behavioral anomalies, all intertwined with the enigmatic condition of sleep apnea. Efforts have been fervently directed towards the creation of automated algorithms tailored for diagnosing sleep apnea. These algorithms harness a diverse array of physiological signals, orchestrating an intricate symphony of data analysis. Notably, the utilization of electrocardiogram (ECG) signals has risen to the forefront, showcasing a remarkable fusion of convenience and unwavering accuracy . Embracing this trajectory, the realm of apnea detection stands at an intriguing juncture. The paradigm of employing a singular lead ECG unfurls tantalizing prospects, offering a gateway towards the conceptualization, development, and realization of wearable devices centered around a solitary, potent sensor.

II. LITERATURE REVIEW

M. Bahrami and M. Forouzanfar [1] et al. discussed that Sleep apnea, a pervasive disorder, demands precise automated techniques for unraveling its complexity. Deep learning algorithms, distinct from traditional methods, decode intrinsic patterns, offering potent insights.

Our study crafts and evaluates deep learning models for sleep apnea detection, using a single-lead ECG dataset. Architectural marvels like CNN, LSTM, and hybrid models grace our exploration. In this curated dataset of 70 recordings divided into learning and test sets, a hybrid masterpiece emerges—a fusion of CNN and LSTM. With 80.67% accuracy, 75.04% sensitivity, 84.13% specificity, and 74.72% F1-score, deep learning opens new horizons for transcending apnea detection. This saga redefines possibilities, where technology and ingenuity converge to conquer sleep disorders' enigma.

N. Pombo, B. M. Silva, A. M. Pinho, and N. Garcia, [2] et al.'s article details research on the effectiveness of developing classifiers for the identification of sleep apnea moments based on a minute-to-minute Electrocardiogram (ECG) signal, comparing the accuracy of several classifiers. A Sgolay filter was used to each ECG signal to extract the Heart Rate Variability (HRV) and ECG-Derived Respiration (EDR), which were then utilised for classifier training, testing, and validation. In a second step, the same traits were expanded to determine if all of the categorised features were relevant. The greatest accuracy was 82.12%, with sensitivity and specificity of 88.41% and 72.29%, respectively, according to the data. This research demonstrates the significance of selecting the best classifier for a certain issue, as well as selecting and using the best features for improved accuracy. These intriguing early-stage findings may lead to more research to enhance the classifiers for potential real-world applications. The suggested model's performance was compared to previous techniques.

S. A. Singh and S. Majumder [3] et al. provided Obstructive sleep apnea (OSA) disrupts breathing during sleep, a significant issue often diagnosed via costly polysomnography (PSG). A new approach, using ECG recordings, is on the horizon. Prior ECG-based methods required expert input, but this study pioneers a novel strategy employing a convolutional neural network (CNN) and pre-trained (AlexNet) model. Single-lead ECG segments are transformed into 2D scalogram images through continuous wavelet transform (CWT). The heart of the research lies in a CNN-based deep learning approach, resulting in an impressive 86.22% accuracy and 90% sensitivity for per-minute OSA classification. This model also successfully identifies all aberrant apneic recordings for per-recording OSA diagnosis. A fusion of time-frequency scalograms creates a robust OSA analysis model, validated independently and showing great performance while remaining cost-effective and straightforward.

D. Dey, S. Chaudhuri, and S. Munshi, [4] et al. describe game-changing advancement in obstructive sleep apnea (OSA) diagnosis—a high-accuracy, automated approach driven by a deep learning framework, specifically a convolutional neural network (CNN). This system analyzes patient-specific single-lead electrocardiography data, swiftly delivering precise OSA status diagnoses.This pioneering technique boasts an array of advantages, effortlessly outperforming current methods. Unlike its counterparts, it seamlessly integrates feature extraction and classification, effectively merging the two processes. It excels in both feature learning and supervised feature classification, eliminating the need for separate algorithms.Despite its computational demands, this approach achieves exceptional accuracy, surpassing existing benchmarks by an impressive average margin of over 90%. Remarkably resilient against signal noise, it consistently outperforms other methods, even in unfavorable signal-to-noise scenarios. This algorithm's

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potential is boundless—it could reshape medical diagnostics. Its potential inclusion in a portable medical diagnostic system hints at a future where healthcare technology evolves, paving the way for revolutionary patient care.

F. Mendonça, S. S. Mostafa, A. G. Ravelo-García, F. Morgado-Dias, and T. Penzel [5] et al. provided a review that Sleep disorders, with a spotlight on obstructive sleep apnea (OSA), cast a significant impact on overall well-being. OSA disrupts sleep airflow, prompting often costly and labor-intensive diagnosis methods. Emerging alternatives aim to use home-based sensor systems and algorithms, yet their diagnostic accuracy often falls below clinical standards. This review meticulously evaluates algorithms, validated through experimental trials, particularly focusing on predicting OSA trends. Various methods utilizing pulse oximetry, electrocardiogram, respiration, sound, and hybrid sensors are analyzed. A curated selection of 84 research articles from 2003 to 2017 highlights promising diagnostic tools. This review delves into this research to provide researchers with insights into signal processing algorithms ripe for hardware implementation, paving the way for enhanced OSA detection.

III. METHODOLOGY

Nurtured within the esteemed repository of medical wisdom, Physionet.org, lies the Dataset PhysioNet ECG Database—a treasure trove of 70 records, thoughtfully divided into two groups: a learning set (a01 through a20, b01 through b05, and c01 through c10) and a test set (x01 through x35), each revealing insights across time spans of 7 to nearly 10 hours. These records resonate with the eloquence of continuous digitized electrocardiogram (ECG) signals, intertwined with the meticulous annotations of apnea, a crafted work of human expertise based on harmonious respiration and linked symphonies. Amidst this, machine-generated QRS annotations, universally termed 'normal,' embellish the composition. Eight records (a01 through a04, b01, and c01 through c03) offer a deeper immersion, welcoming additional signals into their embrace.

Here, Resp C and Resp A, products of inductance plethysmography, intermingle with Resp N's oral-nasal airflow and the rhythmic dance of SpO2—oxygen saturation. This dataset, the Dataset PhysioNet ECG Database, stands as a testament to exploration—a gateway to the intertwined worlds of physiology and data, where each record murmurs its unique tale, each annotation a stroke on the canvas of knowledge.

The initial strides in automated apnea event detection revolved around standard machine

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learning algorithms. However, the intricate nature of physiological inputs coupled with the limitations of traditional machine learning's feature extraction capabilities prompted recent research to delve into more complex deep learning models. With the aid of advanced computing power, deep learning algorithms have surpassed their classical counterparts by effortlessly extracting a comprehensive array of representative features.

The evaluation of algorithm performance poses a challenge due to the diversity in algorithms designed for sleep apnea detection, the multitude of datasets and physiological signals employed for training, the varying validation methodologies, and the diverse performance metrics employed for assessment. An impediment lies in the difficulty of effectively comparing algorithm efficacy. This predicament stems from the intricate nature of physiological data and the constraints of traditional machine learning in feature extraction, steering contemporary research towards more intricate deep learning models. In this context, this article presents an impartial and equitable evaluation of a range of conventional machine learning and deep learning algorithms for detecting sleep apnea occurrences utilizing single-lead electrocardiography (ECG).

To ensure a rigorous and accurate assessment, all tests are conducted under uniform conditions, utilizing the same dataset. A distinctive aspect of this study lies in the utilization of three distinct data subsets for adjusting model hyperparameters: a training set for refining model parameters, a validation set for identifying optimal hyperparameters, and a test set for confirming the models' applicability to unseen data.

This comprehensive approach reveals distinct advantages. Notably, it unveils that the hybrid deep model, characterized by exceptional accuracy, sensitivity, and specificity, reigns supreme in the realm of detection. Furthermore, the study underscores the supremacy of deep learning models over traditional machine learning methodologies in this domain

IV. IMPLEMENTATION

As a comparison for previously developed machine learning and deep learning models we have implemented two models, one model is implemented for taking input of feature values and predicting the results, and the other model is implemented for taking images as input and predicting the results.

Inception V3:Within the realm of image recognition, Inception v3 stands as a formidable contender, showcasing an impressive feat—a

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remarkable accuracy exceeding 78.1% on the revered ImageNet dataset. This model, a culmination of extensive research endeavors, represents a convolutional neural network (CNN) that has been harnessed as a pivotal module within Googlenet. Its primary objective revolves around enhancing the intricate domains of picture processing and object recognition, marking the third iteration of Google's renowned Inception Convolutional Neural Network, initially unveiled during the competitive stages of the ImageNet Recognition Challenge. It is used to take ecg signal images as an input to predict the type of heartbeat it corresponds to the given input. With the front end we have show cased the prediction of type of heart beat with the ecg signal image as input

Voting Regressor:Adding another layer to the symphony, the Voting Regressor algorithms step into the arena. This ensemble technique invites various models to harmoniously cast their votes, orchestrating a unified prediction. Within this collaborative chorus, individual models contribute their insights, creating a melodious prediction that often outperforms any single participant. This technique, akin to a musical ensemble, weaves together the strengths of diverse algorithms, resonating as a promising approach across various domains and datasets**.** With the features values Gender, BQ, ESS, BMI, Weight, Height, Head, Neck, Waist, Buttock, Age, and AHI as input and prediction of the type of sleep apnea are done. Using the front end we developed a system to input feature values and prediction of type of sleep apnea.

IV. IMPLEMENTATION RESULTS

In this study, we undertake a comprehensive and unbiased evaluation of a range of both conventional machine learning and deep learning methodologies in the context of diagnosing sleep apnea incidence using single-lead ECG data. Our approach ensures a level playing field by subjecting all algorithms to the same dataset and uniform testing conditions. Departing from the norm, our methodology encompasses the utilization of three distinct datasets for refining model hyperparameters: a training dataset for parameter learning, a validation dataset for identifying optimal hyperparameters, and a test dataset to gauge the applicability and performance of the models on previously unseen data.This methodology provides several advantages that contribute to the robustness and reliability of our evaluation. Firstly, we unveil a significant insight: hybrid deep models exhibit the highest levels of detection performance across key metrics such as accuracy, sensitivity, and specificity. This revelation underscores the potential of combining deep learning techniques to attain superior outcomes in sleep apnea diagnosis. Furthermore, our investigation underscores the ascendancy of deep learning models over their traditional machine learning counterparts, demonstrating their prowess in yielding improved performance metrics.

	Gender	BQ	ESS	BMI	Weight	Height	Head	Neck	Waist	Buttock	Age	AHI
0	M	0.0	14.0	29.07	88.0	174.0	57.5	39.0	95.5	106.5	20	2.90
1	M	0.0	8.0	26.99	78.0	170.0	57.0	36.5	90.0	100.0	20	1.02
2	M	0.0	16.0	23.94	75.0	177.0	59.0	39.0	88.0	104.0	20	0.52
3	M	0.0	15.0	22.13	67.0	174.0	57.0	35.0	74.0	94.0	20	0.56
4	M	0.0	15.0	22.13	67.0	174.0	57.0	35.0	74.0	94.0	20	0.56

Figure 2. View of feature values from dataset

The strategic use of multiple datasets for training, validation, and testing ensures that our models are honed for optimal performance while maintaining their generalizability to new and diverse data. This not only bolsters the credibility of our findings but also positions our work as a foundational resource for researchers and practitioners seeking to employ machine learning and deep learning algorithms for accurate sleep apnea detection. Our study thus contributes a holistic and insightful exploration of algorithms, reaffirming the potency of deep learning models and inspiring future investigations in the domain of sleep disorder diagnosis.

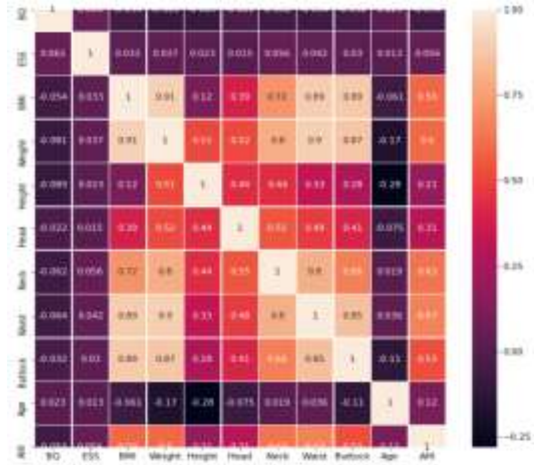

Figure 3. Each cell in the heatmap represents the correlation between two features

Our study encompasses the utilization of two powerful methodologies: the voting regressor and the Inception V3 model. The voting regressor capitalizes on the collective wisdom of multiple algorithms, combining their predictions to enhance accuracy. In tandem, we employed the Inception V3 model, a cutting-edge approach for image recognition. Notably, our implementation of Inception V3 achieved a remarkable accuracy rate of 98.62%. This showcases the potential of these advanced techniques in elevating the efficacy of sleep apnea detection, marking a significant stride towards more accurate and efficient healthcare solutions.

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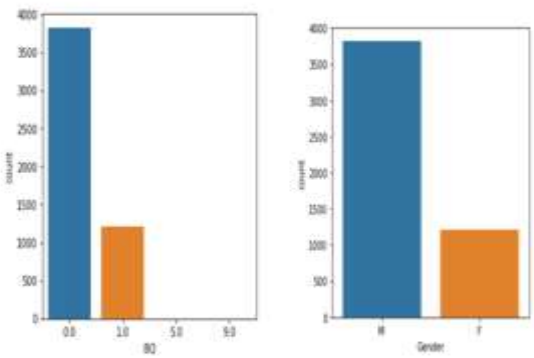

Figure 4. Graphs representing Gender and Body quotient vs count

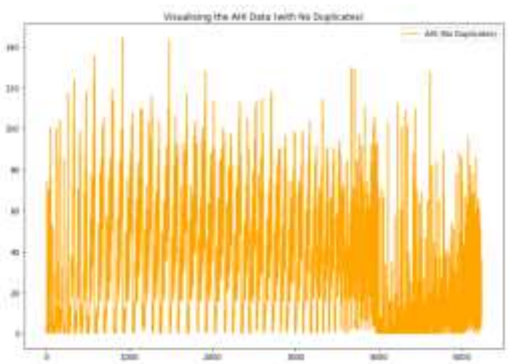

Figure 5. Insightful representation of sleep apnea severity

V. CONCLUSION AND FUTURE SCOPE

The realm of smart wearable devices has unfurled a realm of unprecedented opportunities in the domains of sleep and health monitoring. However, the efficacy of these technologies' hinges on the bedrock of precise and real-time monitoring algorithms. In the course of this study, we embarked on an extensive odyssey, meticulously evaluating a diverse array of machine learning and deep learning methodologies within a cohesive framework. Our pursuit was centered around unraveling the intricate tapestry of sleep apnea identification using single-lead ECG data. Among the stars that graced our exploration, deep learning models shone the brightest, eclipsing the conventional ramparts of machine learning. As we navigated through the landscape of our specific application—catering to brief ECG segments spanning a mere minute—CNN-based deep learning models emerged as the paragon of excellence, surpassing their DRNN counterparts. Yet, it was in the harmonious fusion of elements, the hybrid symphonies, where the true crescendo was reached. Among these, the ZFNet-BiLSTM ensemble serenaded us with unmatched accuracy and specificity, while the ZFNet-GRU composition regaled us with the pinnacle of sensitivity.

However, our journey doesn't end here. The findings and insights gleaned from this study serve as a clarion call, advocating for the embrace of hybrid deep neural networks in the realm of sleep apnea diagnosis through ECG signals. Beyond this milestone, the horizons broaden, and the future beckons with tantalizing prospects. Envision a realm where these algorithms, infused with the magic of machine learning and deep learning, extend their embrace to encompass the identification and tracking of an array of sleep

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phenomena. From the delicate cadence of hot flushes to the intricate tapestry of arousals, our study paves the way for an exciting continuum of research, where the potential for innovation is boundless.

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