Scalogram-based multimodal signal classification using deep learning

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in

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by

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Nomenclature

Acronyms / Abbreviations

AC Autocorrelation

ALS Amyotrophic Lateral Sclerosis

AUC area under the ROC curve

BCI Brain-Computer Interface

Bior Biorthogonal wavelets

CA Channel Attention

CBAM Convolutional block attention module

CF Crest Factor

*Cgau*8 Complex gaussian wavelet

CJD Creutzfeldt-Jakob Disease

Coif Coiflets

CV Coefficient of Variation

Db Daubechies wavelets

DNN Deep Neural Networks

DT Decision Tree

DWT Discrete Wavelet Transform

EEG Electroencephalogram

EMG Electromyogram

ERD Event-Related Desynchronization

Fbsp Frequency B Spline wavelet

FN False Negatives

FP False Positives

HD Huntington's disease

HR Harmonic Ratios

IMU Inertial Measurement Units

KNN K-Nearest Neighbors

LR Logistic Regression

LSTM Long Short-Term Memory

MAV Mean Absolute Value

MDF Median Frequency

Mexh Mexican hat wavelet

MGAS Medial gastrocne- mius

ML Machine Learning

MLP	Multi-layer perceptron
MNF	Mean Frequency
MNP	Mean Power
MSA	Multiple System Atrophy
NB	Naïve Bayes
NDD	Neurodegenerative Diseases
PD	Parkinson’s disease
PIVD	Prolapsed Intervertebral Disc
PPV	Peak-to-Peak Value
PRC	Precision-Recall Coverage
PSD	Power Spectral Density
PSP	Progressive Supranuclear Palsy
RA	Rheumatoid Arthritis
ReLU	Rectified Linear Unit
CNN	Convolution Neural Networks
CWT	Continuous Wavelet Transform
RF	Random Forest
RMS	Root Mean Square
ROC	Receiver Operating Characteristic

SA	Spatial Attention
SB	Spectral Bandwidth
SC	Spectral Centroid
SD	Standard Deviation
SE	Spectral Entropy
SF	Spectral Flatness
SGD	Stochastic gradient descent
$Shan$	Shannon wavelet
$SM1$	Spectral Moments 1
$SM2$	Spectral Moments 2
$SM3$	Spectral Moments 3
SVM	Support Vector Machine
Sym	Symlets
TA	Tibialis anterior
TN	True Negatives
TP	True Positives
MNF	Total Power
VCF	Variance Central Frequency
$vGRF$	Vertical ground reaction force
ZC	Zero Crossing

Preface

Biomedical engineering has recently experienced significant advancements, particularly in classifying neuromuscular activity using electroencephalography (EEG) and electromyography (EMG) signals. These technologies have become increasingly important in applications such as brain-computer interfaces (BCIs) and gait analysis, offering new possibilities for diagnosis and rehabilitation. However, these signals' inherent noise and variability present challenges that can hinder classification accuracy. This thesis aims to address these challenges by investigating the use of scalograms—visual representations that capture both the time and frequency components of signals to improve the precision of neuromuscular activity classification. The research presented in this thesis is structured to systematically build upon each chapter's findings, providing a comprehensive understanding of the methodologies and advancements in this domain.

Chapter 1 introduces the motivation behind the research, outlining the challenges in neuromuscular activity classification and the study's objectives.

Chapter 2 offers an in-depth literature review on gait analysis and BCIs. It discusses the methodologies and technologies employed in the field, including signal processing techniques and feature extraction methods. The chapter also introduces the applications of EEG and EMG across various domains while providing a foundational overview of machine learning and deep learning.

Chapter 3 focuses on the classification of hemiplegic gait abnormalities using EMG signals. The research demonstrates the effectiveness of an ensemble classifier in identifying hemiplegic gait patterns, achieving high accuracy, and highlighting the potential for applications in diagnosis and rehabilitation.

Chapter 4 extends the classification to other gait abnormalities, including rheumatoid arthritis, osteoarthritis, and prolapsed intervertebral disc (PIVD), using EMG scalograms.

Additionally, this chapter explores the classification of neurological disorders like Parkinson's disease, amyotrophic lateral sclerosis (ALS), and Huntington's disease, utilizing scalograms generated from foot insole data.

Chapter 5 presents the application of attention networks for classifying EMG scalograms related to various gait abnormalities. This chapter emphasizes the impact of combining different wavelet family scalograms on classification accuracy, showcasing how attention mechanisms can significantly enhance the performance of classification models.

Chapter 6 investigates the classification of hand movements using a combination of EEG and EMG scalograms. By employing CNNs and transfer learning, the study demonstrates how integrating these signals can improve classification accuracy, reduce noise, and mitigate signal variability, offering promising advancements for healthcare and assistive technology applications.

Chapter 7 concludes the thesis by summarizing the key findings, discussing the contributions to gait analysis and signal processing, and proposing directions for future research. The chapter also reflects on the current study's limitations and the future scope.

Abstract

Recent advancements in the classification of neuromuscular activity using electroencephalography (EEG) and electromyography (EMG) signals have demonstrated significant potential in applications such as brain-computer interfaces (BCI) and gait analysis. EMG, which captures electrical activity from muscles, is crucial for assessing muscle function, fatigue, and abnormalities, while EEG, which records brain activity, plays a critical role in BCI research. However, both signals are susceptible to noise and variability, impacting classification tasks' accuracy and precision. This research aims to mitigate these limitations by utilizing scalograms, which are plots of time and frequency components of the signal. The study increased classifier performance using models ranging from conventional machine learning classifiers to attention networks and transfer learning. This research highlights the effectiveness of scalograms in enhancing classification accuracy for gait abnormalities associated with conditions such as hemiplegia, Parkinson's disease, and rheumatoid arthritis. Further, integrating EEG and EMG scalograms for hand movement classification, primarily through CNNs and transfer learning, led to improved classification accuracy. These findings highlighted the potential of scalogram-based deep learning techniques in enhancing diagnostic accuracy.

Graphical Abstract