DFT based EEG signal decomposition for mental state analysis

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***Abstract*—This paper presents a DFT-based approach for mental state analysis from EEG signal to enhance accuracy and computational efficiency for real-world applications.EEG analysis for mental state analysis is challenging due to moving nature of Electroencephalogram, signal to noise ratio, overlapping bands, etc.To address these issues,the proposed method integrates Fast Fourier Transform , an advanced version of Discrete Fourier transform (DFT) to form power spectrum of the alpha,gamma,beta, theta and delta waves and analysis to improve the accuracy of results. Matlab was used for the basic program that integrates it with the Python Graphical user interface.**

The EEG signals were taken from a data set containing 15 EEG recordings of a subject.The proposed approach gives an accurate final analysis of the subject's mental state. Furthermore, the model was deployed in a Python GUI for real-time analysis.This study highlights the effective integration of digital signal processing with programming for efficient EEG analysis.

***Index Terms*—Discrete Fourier Transform, Power Spectrum, Fast Fourier Transform, Digital Signal Processing, Python GUI**

I. Introduction

Electroencephalography or EEG checks the brain activity through a non-invasive by placing electrodes on the scalp.It captures voltage fluctuation in brain that happens as a result of ionic current flow,It is usually measured in micro volts.It is widely used in clinical field to assess sleep,alertness,fatigue etc.It has limited spacial resolution compared to MRI.

The purpose of this is to develop an efficient and accurate EEG analysis system using Matlab and python integrated with DFT method.Such a system has practical applications in medical world.Previous methods include wavelet transform,EMD and VMD.These methods require more computational resources,suffer from instability,mode mixing and high run time making it less suitable for real-time use.These method also has interoperability challenges and require additional post-processing,

To overcome this DFT provides a clear,efficient and interpretable outputs with minimal overhead.It has fast computation(via FFT),low complexity and direct extraction pf frequency-domain features that points to EEG bands.Thus,it is ideal for mental state analysis and low power devices.

II. Related Work

In this section,we summarize few previous works and our paper's contribution in this field.Several studies have explored decomposition techniques for mental state analysis.Khare et al.(2023) utilized wavelet transform, for classification of mental states.It had high accuracy nut requires complex computational resources.Islam and Lee(2022) applied Multivariate Empirical Mode decomposition.It again has high accuracy but faced the issue of high runtime and complexity.Yang et al.(2024) used Variational mode decomposition for the same.But it did not have anything better than empirical method.Wang et al.(2023) combined intrinsic time scale decomposition with temporal convolution to recognize depression.This involves deep architectures and complex decomposition.Alshamrani et al(2024) proposed an entropy based matrix method.This had good performance but require multiple feature extraction stages.

III. Our contribution

1.An integration of Discrete Fourier Transform via Fast Fourier transform and programming.

2.Comprehensive evaluation of a subject's 15 EEG recordings with a focus on accuracy and fast computation.

3.Easy implementation and direct mapping to EEG bands power,enabling real-time,low power mental state analysis without sacrificing clarity.

The flow of this paper is as follows.Section IV introduces the methodology of the proposed system,Section V talks about the results and discussions and Section VI is the conclusion.The references are listed at the end.

IV. Methodology

This section describes the proposed methodology,Discrete Fourier Transform via Fast Fourier Transform to calculate power density.

A.Signal acquisition and preprocessing:
A single channel EEG signal was taken of duration 1 second

and sampled at 1000 Hz giving 1000 raw data points.No additional preprocessing was done in this simplified case .

B.Frequency domain transformation:

The resulting output was converted to frequency domain Fast Fourier transformation and its magnitude was squared to get the power density.

$$P(f) = |\text{FFT}(x(t))|^2 \quad (1)$$

C.Band power decomposition:

The power spectrum was divided into five main bands of frequency.
a.delta(0 to 4 Hz):Deep sleep or pathological condition
b.theta(4 to 8 Hz): Drowsiness or meditative state
c.alpha (8 to 13 Hz): Relaxed but wakefulness (eyes closed)
d.beta (13 to 30 Hz): Alertness and concentration
e.Gamma (30 to 100 Hz): High-level cognition and sensory processing
For each band,power was calculated by integration of density over a range of frequency.

$$\text{Band Power} = \int_{f_1}^{f_2} P(f)\, df \quad (2)$$

f1 and f2 are frequencies
Present your results with figures or tables and provide analysis.

D.Mental State interpretation

Based on the relative magnitude of power ,it is mapped to the mental states associated.

E.Visualization:

plotting the results on graph

V. Results and Discussion

A.Band decomposition and power spectral density:15 one second recordings were analyzed and power and power spectral density was calculated using FFT. All the recordings showed a significant presence of delta that is bands with frequency less than 4 Hz,
B.Band power statistics

TABLE I
Mean EEG Band Power Across 15 Recordings

Band	Frequency Range (Hz)	Mean Power ($\mu unit$)
delta	0.5 to 4	7570234021
theta	4 to 8	1528912782
alpha	8 to 13	314654628.1
beta	13 to 30	790553551.3
gamma	30 to 100	891635257.9

C.Mental state interpretation: The consistent dominance of delta across the recordings suggest that the subject is in deep sleep or is unconscious.It suggests any one of the following conditions:a)Sleep stages 3 and 4 b)Brain injury or pathological conditions.c)Deep meditation or anesthetized condition(rare).The suppression of other bands confirms this further.

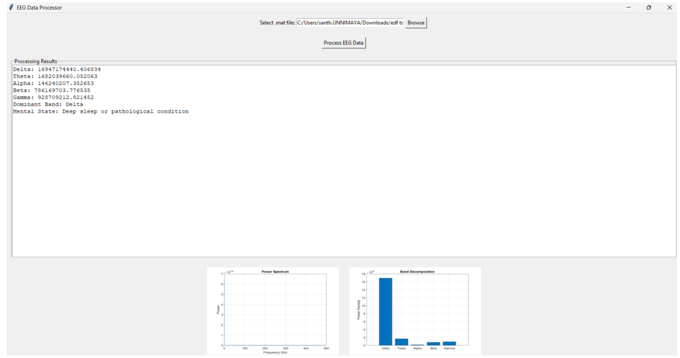

Fig. 1. The output obtained from recording 1

D.Implications:This result shows that this method can be used in:
a)Sleep stage classification(sleep or alert)
b)Consciousness monitoring
c)Detection of fatigue
E.Limitations and future work:While this method is efficient for 1 second recordings in which signals are assumed to be stationery,it may not be practical in real time non stationery signals which cannot be captured by FFT alone,Using wavelet analysis,envelope tracking along with it could help solving this issue.
Future works include multi channel EEG along with subject specific variability for broader analysis.

VI. Conclusion

This study helped me understand the importance Discrete Fourier transform and Digital signal processing in real time world especially the medical world..By analyzing 15 one second EEG recording i was able to come to a conclusion of his/her mental state through power calculation.The excessive presence of delta represents deep sleep or some pathological or medical conditions. Future works include multi channel EEG analysis,non-stationery EEG analysis.

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