# An Adaptable Filter Bank Optimization Method for Evaluating EEG Activation Complexity Using Intensity Analysis

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***Abstract*— Electroencephalograms detect variations in brain wave patterns that provide information about a person's cognitive states and help identify neurological diseases. We overcome time-frequency resolution trade-offs associated with Fourier analysis by using a wavelet filtering method to extract continuous intensity measures of key EEG bands. We used simulated data to validate the method's ability to quantify specific EEG band intensities in continuous time. With this method, we introduced a novel complexity measurement referred to as "Activation Complexity". We applied these techniques to 49 subject's EEG data collected under hypoxic and non-hypoxic conditions and identified a significant increase ($p < 0.05$) in activation complexity within a localized region in the back left side of brain for hypoxic versus non-hypoxic trials.**

## I. INTRODUCTION

Electroencephalograms (EEGs) detect and track variations in brain wave patterns related to electrical activity of the brain. EEG analysis provides information about a person's cognitive states such as response inhibition, level of concentration, arousal and even diagnostic information regarding diseases such as Alzheimer's and epilepsy. These analyses typically use Fourier methods to examine the intensity of specific frequency bands (i.e. $\delta$, $\theta$, $\alpha$, etc.) in segments of time that are limited by time/frequency resolution trade-offs. Thus, these methods do not capture continuous frequency band intensity changes over time.

Recently, there has been a movement in the community to examine EEG complexity using entropy to predict cognitive states and diseases. These entropy measures are applied to an entire signal without time segmentation or distinguishing between different EEG bands. These approaches lack both time and frequency specificity.

We propose a wavelet filter bank approach that addresses both the aforementioned challenges and examines the intensity of isolated frequencies in continuous time. We coin the term "EEG Activation Complexity (AC)" to refer to the calculation of entropy using the peak-to-peak timing of a frequency band.

## II. METHODS

### A. *Intensity Filter Bank*

This research extends the plateau minimization filter bank construction method of Vinzenz von Tscharner [1] in three primary ways: (1) by sequentially optimizing sets of wavelet frequency bands ($W_i$), (2) by adding optimization constraints to isolate individual EEG bands, and (3) by modifying constraints to ensure biorthogonality. We adopt a "flattened Gaussian" as the mother wavelet ($\hat{\psi} = e^{-a(f-f_c)^2-b(f-f_c)^4}$) and employ a non-linear scaling function, where $f$ is the frequency, $f_c$ is the center frequency, and $a$ & $b$ are tuning parameters. This method produces a filter bank that approximately resolves all EEG frequency bands while maintaining an adequate plateau value (i.e. the deviation of the plateau value from being perfectly flat).

### B. *Activation Complexity (AC)*

Calculating AC is achieved by first quantifying the instantaneous differences in the peak-to-peak timing of a given EEG wavelet band's intensity. The complexity of the timing for each wavelet band is measured using sample entropy.

## III. RESULTS

### A. *Signal Simulations*

We demonstrated a one-to-one relationship between the simulated data generated using stationary sinusoidal waves and non-stationary sinusoidal waves with linearly increasing frequency time series and corresponding intensity activation patterns as function of time and frequency.

### B. *Physiological Applications*

*1) Data:* This method was applied to EEG data collected from 49 subjects exposed to three 10 min bouts of normobaric hypoxic (12% $O_2$/15k ft) and non-hypoxic conditions (22% $O_2$/sea-level) at NASA Langley Research Center.

*2) Intensity Analysis:* We demonstrated a significant decrease in the normalized power of wavelet $W_6$ (mid-level $\beta$ band: 15.19-18.37 Hz) across all but three sites ($O_1$, $F_1$, and $C_2$) during hypoxic trials.

*3) Activation Complexity:* During the hypoxic trials, this work shows a significant increase ($p < 0.05$) in complexity localized at the back left side of the brain, specifically $P_7$, $O_1$, $O_2$, and $P_3$ for wavelets $W_2$ to $W_7$, $W_2$ to $W_6$, $W_5$ to $W_7$, and $W_5$ to $W_9$, respectively.

## IV. CONCLUSION

We demonstrated that this method can recover continuous readings of intensity of both stationary and non-stationary simulated signals. Furthermore, we demonstrated that activation complexity of EEG band peak-to-peak timings can distinguish between hypoxic and non-hypoxic conditions. The success of these methods facilitates future analyses of diseases and physiological sensory changes.

## REFERENCES

[1] V. Von Tscharner, "Intensity analysis in time-frequency space of surface myoelectric signals by wavelets of specified resolution," *Journal of Kinesiology and Electromyography*, vol. 6, no. 10, pp. 433–45, 2000.

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