

**ANALYSIS OF ELECTROENCEPHALOGRAPH  
SIGNALS FOR DETECTING FATIGUE IN HUMAN  
DRIVERS**

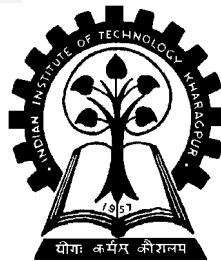
*Thesis submitted to the  
Indian Institute of Technology, Kharagpur  
For award of the degree*

*of  
Doctor of Philosophy  
by*

**Sibsambhu Kar**

Under the supervision of

**Prof. Aurobinda Routray**



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**FEBRUARY 2011**

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## CERTIFICATE

This is to certify that the thesis entitled **Analysis of Electroencephalograph Signals for Detecting Fatigue in Human Drivers**, submitted by Sibsambhu Kar to the Indian Institute of Technology, Kharagpur, is a record of bona fide research work under my supervision and I consider it worthy of consideration for the award of the degree of Doctor of Philosophy of the Institute.

---

(Aurobinda Routray)

Supervisor

Date:

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Place: IIT Kharagpur

Date: 25.06.2012

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## DECLARATION

I certify that

- a. The work contained in the thesis is original and has been done myself under the general supervision of my supervisor.
- b. The work has not been submitted to any other Institute for any degree or diploma.
- c. I have followed the guidelines provided by the Institute in writing the thesis.
- d. I have conformed to the norms and guidelines given in the Ethical Code of Conduct of the Institute.
- e. Whenever I have used materials (data, theoretical analysis and text) from other sources, I have given due credit to them by citing them in the text of the thesis and giving their details in the references.
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## Abstract

This thesis deals with the detection and quantification of fatigue in drivers (vehicle operators) using electroencephalogram (EEG). The prime objective of the work is to find the trends in various EEG parameters and correlate them with other types of fatigue indicators such as subjective assessment, blood bio-chemicals (RBS, Urea and Creatinine) and ocular parameter (PERCLOS, Blink rate). An experimental set up and a number of experiments for collecting different types of data were designed and built a database of more than 40 vehicle operators at various levels of fatigue and drowsiness. The artifacts in the recorded signals were removed using two different methods (i) wavelet thresholding and (ii) variable window moving average filtering (proposed) and various existing parameters along with some new fatigue indicating parameters have been computed from the artifact free signals. These parameters are either relative energy of various bands of signal, or ratio of the relative energies, or different types of entropies. These parameters along with subjective assessment (based on questionnaire) have been used to quantify the unknown fatigue level. The variation of EEG synchronization during various states of brain has also been explored for detecting fatigue. Synchronization between all the electrodes is mapped into unweighted and weighted networks to quantify the state of fatigue using some standard network parameters. The method was further modified for time complexity reduction using eigen-EEG and less number of electrodes. The results have been correlated with blood bio-chemicals, ocular parameters (percent closure of eyes or PERCLOS and blink rate), and subjective assessment. Finally, various stages of fatigue have been classified using Hidden Markov model (HMM).

*Keywords: Driver's Fatigue, Electroencephalograph, Synchronization Likelihood, Complex Networks, Fatigue estimation, Hidden Markov Model.*

## LIST OF ABBREVIATIONS

ART	Auditory Response Test
CNS	Central Nervous System
db4	Daubechies 4 Wavelet
DFT	Discrete Fourier Transform
DWT	Discrete Wavelet Transform
EEG	Electroencephalogram
ECG	Electrocardiogram
EMG	Electromyogram
EMD	Empirical Mode Decomposition
FFT	Fast Fourier Transform
HMM	Hidden Markov Model
ICA	Independent Component Analysis
IMF	Intrinsic Mode Function
MI	Mutual Information
MF	Multiplying Factor
MRI	Magnetic Resonance Imaging
fMRI	functional Magnetic Resonance Imaging
PCA	Principal Component Analysis
PERCLOS	Percentage Closure of Eyes
PSD	Power Spectral Density
PVT	Psychomotor Vigilance Test
RBS	Random Blood Sample
RE	Renyi Entropy
SL	Synchronization Likelihood
SL	Synchronization Likelihood Matrix
SE	Shannon Entropy
ST	S Transform
TMT	Tread Mill Test
TsE	Tsallis Entropy
WT	Wavelet Transform
VRT	Visual Response Test

## CONTENTS

Title Page	
Certificate by the Supervisor	
Acknowledgement	
Declaration	
Abstract	
List of Abbreviations	
<b>1. EEG and Fatigue</b>	
1.1. Introduction . . . . .	1
1.2. Fatigue in drivers . . . . .	2
1.3. Detection of fatigue . . . . .	5
1.4. Detection of fatigue from EEG . . . . .	7
1.5. Methods of EEG signal analysis . . . . .	11
1.6. Motivations behind the thesis . . . . .	12
1.7. Organization of the thesis . . . . .	12
<b>2. Experiments and data collection</b>	
2.1. Introduction . . . . .	15
2.2. Steps of experiments . . . . .	15
2.3. Experimental set up for simulated driving. . . . .	16
2.4. Experiment Details . . . . .	16
2.4.1. Experiment-1: Actual Driving and Driving related tasks . . . . .	16
2.4.2. Experiment-2: Simulated driving tasks with sleep deprivation. . . . .	19
2.4.3. Experiment-3: Actual driving tests for validation. . . . .	22
2.4.4. Experiment-4: Simulated driving . . . . .	23
2.4.4. Limitations of the experiments . . . . .	24
2.5. Discussions . . . . .	25
<b>3. Preprocessing of EEG signals</b>	
3.1. Introduction . . . . .	27

3.2. Filtering and normalization . . . . .	28
3.3. Artifact removal . . . . .	28
3.3.1. Wavelet Thresholding . . . . .	29
3.3.2. Variable window moving average filter . . . . .	31
3.3.3. Comparison of the artifact removal methods for simulated EEG . . . . .	35
3.4. Signal decomposition . . . . .	36
3.4.1. Decomposition of signal using Discrete Wavelet Transform . . . . .	36
3.4.2. Decomposition of signal using Empirical Mode Decomposition . . . . .	36
3.5. Discussions and Conclusions . . . . .	38
<b>4. Parametric characterization of EEG signals for detecting fatigue</b>	
4.1. Introduction . . . . .	41
4.2. Methodology . . . . .	42
4.2.1. Wavelet Relative Energy and Ratios . . . . .	42
4.2.2. Wavelet Entropy . . . . .	43
4.3. Results and Discussions . . . . .	45
4.3.1. Energy-based Analysis . . . . .	45
4.3.2. Entropy Analysis . . . . .	46
4.3.3. Spatial distribution of the parameters . . . . .	49
4.4. Conclusions . . . . .	50
<b>5. EEG synchronization and complex networks for fatigue detection</b>	
5.1. Introduction . . . . .	51
5.2. Methodology . . . . .	52
5.2.1. Computation of synchronization . . . . .	52
5.2.2. Formation of networks . . . . .	57
5.2.3. Characterization of networks . . . . .	58
5.2.4. Results . . . . .	60
5.3. Discussions . . . . .	65
5.4. Conclusions . . . . .	69
<b>6. Advanced EEG synchronization Analysis</b>	
6.1. Introduction . . . . .	71
6.2. Principal Component Analysis (PCA) of EEG segments (Eigen-EEG) . . . . .	71

6.2.1. Computation of eigen-EEG . . . . .	71
6.2.2. Results . . . . .	73
6.3. Principal networks and classification of stages of fatigue using HMM .	78
6.3.1. Computation of principal networks . . . . .	79
6.3.2. Hidden Markov Model . . . . .	80
6.3.3. Results . . . . .	81
6.4. Conclusions . . . . .	83
<b>7. Experimental validation of trends in EEG parameters with respect to other measurements</b>	
7.1. Introduction . . . . .	85
7.2. Correlation with ocular measurements. . . . .	86
7.3. Correlation with blood bio-chemicals . . . . .	90
7.4. Correlation with Subjective Assessment of Fatigue . . . . .	93
7.5. Estimation of fatigue level . . . . .	95
7.6. Conclusions . . . . .	97
<b>8. Conclusions</b> . . . . .	99
References . . . . .	105
Appendix I Questionnaire for subjective assessment of fatigue . . . . .	117
Appendix II EEG parameter values of all subjects (Experiment 1 & 2) . . . . .	118
Publications from this Thesis . . . . .	122
Author's Biography . . . . .	123