

## **Declaration**

The copyright of this thesis belongs to the author under the terms of the United Kingdom Copyright Acts as qualified by University of Strathclyde Regulation 3.49. Due acknowledgement must always be made of the use of any material contained in or derived from this thesis.

## **Acknowledgements**

I take this opportunity to thank individuals who directly and indirectly helped me to complete this final project for the course of M.Sc. in Bioengineering. At the outset I would like to thank Professor William Sandham for providing his invaluable supervision.

I would also like to thank my classmate and dear friend Amit Pujari for his feedback, advice and for being so proactively a part of my progress during the completion of my thesis. I owe a big thanks to my friends Rajasekharam Naidu Pujala and Gopal Valsan for their time and help.

I take this opportunity especially to thank Anne Marie for her help and support. I am always going to be thankful for being a part of the Bioengineering department. Last but not least I would like to thank my parents and Ashita Kaul who encouraged me and gave me their wonderful support during this wonderful odyssey.

## Abstract

Biosignals are physiological signals that are recorded from various parts of the body. Some of the major biosignals are electromyograms (EMG), electroencephalograms (EEG) and electrocardiograms (ECG). These signals are of great clinical and diagnostic importance, and are analysed to understand their behaviour and to extract maximum information from them. However, they tend to be random and unpredictable in nature (non-linear). Conventional linear methods of analysis are insufficient. Hence, analysis using non-linear and dynamical system theory, chaos theory and fractal dimensions, is proving to be very beneficial.

In this project, ECG signals are of interest. Changes in the normal rhythm of a human heart may result in different cardiac arrhythmias, which may be fatal or cause irreparable damage to the heart when sustained over long periods of time. Hence the ability to identify arrhythmias from ECG recordings is of importance for clinical diagnosis and treatment and also for understanding the electrophysiological mechanism of arrhythmias.

To achieve this aim, algorithms were developed with the help of MATLAB<sup>®</sup> software. The classical logic of correlation was used in the development of algorithms to place signals into the various categories of cardiac arrhythmias. A sample set of 35 known ECG signals were obtained from the Physionet website for testing purposes. Later, 5 unknown ECG signals were used to determine the efficiency of the algorithms.

A peak detection algorithm was written to detect the QRS complex. This complex is the most prominent waveform within an ECG signal and its shape, duration and time of occurrence provides valuable information about the current state of the heart. The peak detection algorithm gave excellent results with very good accuracy for all the downloaded ECG signals, and was developed using classical linear techniques. Later, a peak detection algorithm using the discrete wavelet transform (DWT) was implemented. This code was developed using non-linear techniques and was amenable for implementation. Also, the time required for execution was reduced, making this code ideal for real-time processing.

Finally, algorithms were developed to calculate the Kolmogorov complexity and Lyapunov exponent, which are non-linear descriptors and enable the randomness and chaotic nature of ECG signals to be estimated. These measures of randomness and chaotic nature enable us to apply correct interrogative methods to the signal to extract maximum information. The codes developed gave fair results. It was possible to differentiate between normal ECGs and ECGs with ventricular fibrillation. The results show that the Kolmogorov complexity measure increases with an increase in pathology, approximately 12.90 for normal ECGs and increasing to 13.87 to 14.39 for ECGs with ventricular fibrillation and ventricular tachycardia. Similar results were obtained for Lyapunov exponent measures with a notable difference between normal ECG (0 – 0.0095) and ECG with ventricular fibrillation (0.1114 – 0.1799). However, it was difficult to differentiate between different types of arrhythmias.

# Contents

## Chapter 1

<b>Introduction.....</b>	<b>01</b>
1.1 Background.....	01
1.2 Aims and Objectives.....	02
1.3 Thesis Overview.....	02

## Chapter 2

<b>Cardiology and the Electrocardiogram.....</b>	<b>04</b>
2.1 The Heart.....	04
2.1.1 Anatomy of the Heart.....	04
2.1.2 Heartbeat Cycle.....	05
2.1.3 Cardiac Conduction System and the ECG.....	06
2.1.3.1 Conduction System.....	06
2.2 The Electrocardiogram (ECG).....	08
2.3 Arrhythmias.....	10

## Chapter 3

<b>Biosignals.....</b>	<b>14</b>
3.1 Biosignals.....	14
3.2 Theory.....	14
3.2.1 Non-linear Theory.....	14
3.2.2 Dynamic Systems.....	16
3.2.3 Chaos Theory and Fractals.....	18
3.2.4 Chaos Theory.....	18
3.2.5 Fractals.....	21
3.2.6 Fuzzy logic.....	24
3.2.6.1 Introduction.....	24
3.2.6.2 Features.....	25

3.2.6.3	Application.....	25
3.2.7	Artificial Neural Networks.....	26
3.2.7.1	Introduction.....	26
3.2.7.2	Structure.....	26
3.2.7.3	Features.....	28
3.2.7.4	Application.....	28

## Chapter 4

<b>Literature Review.....</b>	<b>29</b>
Introduction.....	29
4.2 Lyapunov Exponent .....	29
4.3 Correlation Dimension.....	30
4.4 Fuzzy Clustering.....	32
4.5 ANN.....	33
4.6 Wavelet Transform .....	35
4.7 Conclusions.....	37

## Chapter 5

<b>MATLAB Software Development and Implementation.....</b>	<b>39</b>
5.1 DATA.....	39
5.2 Software Development .....	39

## Chapter 6

<b>Result and Analysis.....</b>	<b>43</b>
6.1 Results of Algorithm 1 (Time-Series Representation of ECG Signal).....	43
6.2 Results of Algorithm 2 (Peak Detection using Threshold Method).....	46
6.3 Results of Algorithm 3 (Correlation of Unknown Signal with Known Signal)...	49
6.4 Results of Algorithm 4 (Correlation of Signals in Data Set).....	50
6.5 Results of Algorithm 5 (Identifying Unknown Signals into Various Category)...	53

6.6	Results of Algorithm 6 (Peak Detection and Heart Beat Rate using DWT).....	54
6.7	Results of Algorithm 7 (Kolmogorov Complexity of ECG Signal).....	57
6.8	Results of Algorithm 8 (State-Space Representation and Lyapunov Exponent)..	58
6.9	Comparison of Linear and Non-linear techniques.....	61

## **Chapter 7**

<b>Conclusions and Future work.....</b>	<b>64</b>
7.1 Conclusions.....	64
7.2 Future work.....	66
<b>References.....</b>	<b>68</b>
<b>Bibliography.....</b>	<b>72</b>
<b>Appendix I: List of Figures.....</b>	<b>73</b>
<b>Appendix II: List of Tables.....</b>	<b>75</b>
<b>Appendix III: Contribution to the Project.....</b>	<b>76</b>
<b>Appendix IV: Components of Compact Disc.....</b>	<b>77</b>