

# CONTENTS

## *List of Figures*

### **Chapter 1: Introduction**

<i>1.1 Nonlinear Systems and Dynamics</i> .....	1
<i>1.2 Human Heart - A nonlinear system</i> .....	2
<i>1.3 Action Potential: the building block of ECG</i> .....	3
<i>1.4 Electrocardiogram (ECG)</i> .....	6
<i>1.5 Nonlinearity Analysis in ECG</i> .....	9

### **Chapter 2: Literature Survey**

<i>2.1 Mathematical Model of Cardiac Rhythm</i> .....	11
<i>2.2 Generation of ECG</i> .....	13
<i>2.3 Controlling Chaos in Cardiac Rhythm</i> .....	16

### **Chapter 3: Chaos Theory**

<i>3.1 Introduction</i> .....	18
<i>3.2 Sensitivity to Initial Conditions</i> .....	19
<i>3.3 Phase Space and Phase Trajectories: Stability, Attractors and Repellers</i> ...	20
<i>3.4 Non Periodicity</i> .....	21
<i>3.5 Limit Cycle Motion: Periodic Attractors</i> .....	21
<i>3.6 Chaotic Attractor</i> .....	22

### **Chapter 4: Work Done: Bifurcation Analysis of modified Van Der Pol model of Heart**

<i>4.1 Introduction</i> .....	24
<i>4.2 ECG Simulation</i> .....	25
<i>4.3 Arrhythmias under Study and their Simulation</i> .....	28
<i>4.3.1 Atrial Flutter</i> .....	29
<i>4.3.2 Atrial Fibrillation</i> .....	30
<i>4.3.3 Ventricular Flutter</i> .....	31

<i>4.3.4 Ventricular Fibrillation</i> .....	32
<b>4.4 The Bifurcation Diagram</b> .....	33
<i>4.4.1 Introduction</i> .....	33
<i>4.4.2 Stability Analysis: Atrial Flutter</i> .....	34
<i>4.4.3 Stability Analysis: Ventricular Flutter</i> .....	36

## **Chapter 5: Work Done: Stability Analysis using Lyapunov Exponent Spectrum**

<i>5.1 Introduction</i> .....	38
<i>5.2 Calculating Lyapunov Exponents</i> .....	39
<i>5.3 Lyapunov Exponent of modified Van Der Pol Oscillator</i> .....	41

## **Chapter 6: Results and Conclusion** ..... 43

## **REFERENCES**

## List of Figures

1. Labelled diagram of the human heart	2
2. Ions diffusion in action potential	4
3. The action potential graph	5
4. A 12 lead ECG electrode placement	7
5. Schematic representation of normal ECG waveform	8
6. Modified Van Der Pol system response	13
7. Schematic sketch of an ECG cardiac cycle	13
8. Heart mathematical models based on three and four oscillators	14
9. The cardiac conduction system	15
<b>10. An icon of <a href="#">chaos theory</a> - the <a href="#">Lorenz attractor</a></b>	<b>18</b>
11. Lorenz attractor with different initial conditions	20
12. Phase Trajectory of modified van der pol oscillator	22
13. An ECG from a patient showing the transitions	24
14. Simulated ECG showing normal rhythm in MATLAB	27
15. comparison of Real and Simulated ECG for Atrial Flutter	29
16. comparison of Real and Simulated ECG for Atrial Fibrillation	30
17. comparison of Real and Simulated ECG for Ventricular Flutter	31
18. comparison of Real and Simulated ECG for Ventricular Fibrillation	32
19. Bifurcation diagram of ECG (atrial flutter) for parameter: $u_{32} = -2$ to 10	34
20. Phase potrait for atrial flutter	35
21. Bifurcation Diagram of ECG (ventricular flutter) for parameter: $d_3 = -10$ to 50	36
22. Phase potrait for ventricular flutter	37
23. Evolution of two nearby trajectories: calculation of the Lyapunov exponent	39
24. Lyapunov Exponent Plot for $\alpha$ varying from -1 to 9	41
25. Chaotic Response of cardiac pacemaker	42
26. Stabilization of Chaotic response at $\alpha = 8$	43