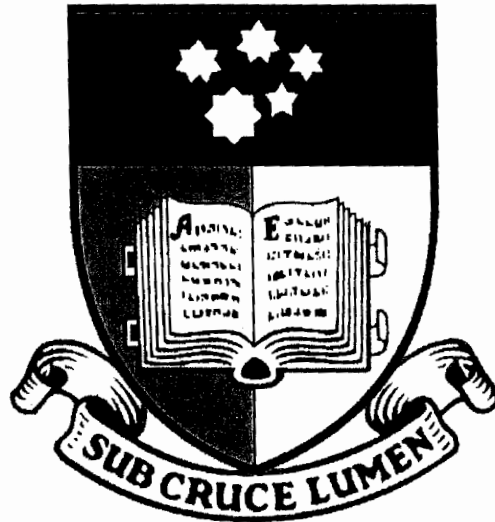


# Visualisation and Pattern Recognition of Heart Rate Variability



Ben Raymond



Thesis submitted for the degree of  
Doctor of Philosophy

March 1999

Departments of Electrical and Electronic Engineering  
and Applied Mathematics  
The University of Adelaide  
Australia

# Abstract

---

Analysis of heart rate variability (HRV) may be used as a noninvasive probe of autonomic nervous system activity. It has found application in many situations where autonomic function is of interest, such as diabetic autonomic neuropathy, hypertension, and recovery following myocardial infarction. This thesis considers various signal processing aspects of HRV analysis; in particular, those of data visualisation and classification.

Frequency domain techniques are popular for HRV processing since the oscillations in the signal are largely separable by frequency. The analysis of spectral HRV data is conventionally performed by considering the power contained in sub-bands within the spectrum. This approach is not ideal: the choice of the limits of the sub-bands can be difficult, and the band-power values do not have a convenient physiological interpretation.

In this thesis, data visualisation techniques - specifically the least-squares scaling and the generative topographic mapping - are applied to the analysis of spectral HRV data. These techniques take a high-dimensional data set and construct a two-dimensional representation in which the relationships between the data are preserved. This allows simple graphical depiction and visual exploration of the data by the user. With spectral data, this approach allows the physiological significance of the data to be ascertained without the need to perform sub-band analysis. The techniques are quite general and may be applied to the analysis of data from other processing methods, such as nonlinear HRV analysis and cardiovascular system modelling. The use of the least-squares scaling and the generative topographic mapping for the visualisation of spectral HRV data is demonstrated on data from two studies: one on sleep apnoea, and the other on the effects on propranolol and posture on heart rate variability.

The fusion of HRV with information from other sources is one method of improving the reliability of HRV analysis. The use of classification techniques for information fusion is investigated in the second part of this thesis. For the discrimination of heart rate data by posture and propranolol, the fusion of HRV information with mean heart rate is shown to yield better discrimination than the use of HRV alone. The use of HRV with other diagnostic information for the detection of sleep apnoea is also explored.

# Table of contents

---

<i>Statement of originality</i>	vii
<i>Acknowledgements</i>	ix
<i>Glossary and abbreviations</i>	xi
<i>Related publications</i>	xv
<i>Chapter 1 Introduction</i>	1
1.1 Research problem	1
1.2 Justification for the research	3
1.3 Thesis outline	4
1.4 Scope	6
<i>Chapter 2 Heart rate variability</i>	7
2.1 Physiology of heart rate variability	8
2.1.1 Sources of heart rate variability	10
2.2 Processing methods	12
2.2.1 Time domain methods	14
2.2.2 Graphical methods	14
2.2.3 Frequency domain methods	14
2.2.4 Multi-signal processing	25
2.2.5 Conclusions	29
2.3 Clinical applications of heart rate variability analysis	30
2.3.1 Risk assessment for myocardial infarction patients	30
2.3.2 Hypertension	31
2.3.3 Diabetic autonomic neuropathy	32
2.3.4 Other applications	32
2.3.5 Conclusions	33
2.4 Fundamental limitations of heart rate variability analysis	33
2.4.1 As a probe of autonomic tone	33
2.4.2 Arrhythmias	35
2.5 Research issues in heart rate variability processing	36
2.6 Summary	40

<i>Chapter 3 Data visualisation</i>	41
3.1 Visualisation algorithms	43
3.1.1 Multidimensional scaling	45
3.1.2 The generative topographic mapping	54
3.1.3 Kohonen's self-organising map	56
3.1.4 Conclusions	59
3.2 Interpreting mappings	60
3.3 Summary	61
<i>Chapter 4 Visualisation of heart rate variability data</i>	63
4.1 Data preprocessing	63
4.1.1 The least-squares scaling	63
4.1.2 Parametric spectral estimation	67
4.1.3 The generative topographic mapping	68
4.2 Case study 1	68
4.2.1 Methods	69
4.2.2 Results and discussion	70
4.2.3 Conclusions	79
4.3 Summary	79
<i>Chapter 5 Generalisation and prior information</i>	81
5.1 Feedforward networks for least-squares scalings	81
5.1.1 Training the network	82
5.2 Regularisation	84
5.2.1 Assessing regularisation	85
5.2.2 Regularisation in least-squares scaling networks	86
5.2.3 Multilayer perceptron	94
5.2.4 Regularisation and the generative topographic mapping	95
5.2.5 Conclusions	95
5.3 Prior information	97
5.3.1 Prior information and the generative topographic mapping	100
5.3.2 Prior information and generalisation	103
5.3.3 Conclusions	105
5.4 Case study 2: Sleep apnoea	105
5.4.1 The sleep apnoea/hypopnoea syndrome	105
5.4.2 Methods	107
5.4.3 Results and discussion	108
5.4.4 Conclusions	126
5.5 Summary	127
<i>Chapter 6 Information fusion and classification</i>	129
6.1 The shared mixture classifier	130
6.2 Heart rate variability and mean heart rate	132
6.2.1 Changes with posture and propranolol	133
6.2.2 Conclusions	136
6.3 Other diagnostic information	136
6.3.1 Application to sleep apnoea	137
6.3.2 Heart rate variability and oximetry data	139
6.3.3 Conclusions	141
6.4 Summary	141

<i>Chapter 7 Concluding remarks</i>	143
7.1 Recapitulation	143
7.1.1 Data visualisation	143
7.1.2 Generalisation	144
7.1.3 Prior information	144
7.1.4 Classification	144
7.2 Contributions of this thesis	145
7.3 Implications for heart rate variability analysis	147
7.4 Implications for future work	148
7.4.1 Visualisation of heart rate variability data	148
7.4.2 Other aspects of heart rate variability processing	148
<i>Appendix A Normalisation of heart rate and heart period</i>	151
<i>Appendix B Case study 1 results</i>	155
<i>Appendix C Rotation and translation of least-squares scalings</i>	157
<i>Appendix D The modified generative topographic mapping</i>	161
<i>Appendix E Classification of heart rate variability in normal and hypertensive subjects</i>	163
<i>Reference list</i>	173