The application of classification techniques to the heart rates of miners in escapeways

Ruibao Feng

University of Wollongong

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THE APPLICATION OF CLASSIFICATION TECHNIQUES TO THE HEART RATES OF MINERS IN ESCAPEWAYS

A thesis submitted in partial fulfillment of the requirement for the award of the degree of

Master of Engineering (Honours)

From

University of Wollongong

by

RUIBAO FENG

November, 1998

Department of Civil, Mining and Environmental Engineering
DECLARATION

This is to certify that the research work presented in this thesis was carried out by
the author for a degree of Master of Engineering (Honours) in the Department of
Civil, Mining and Environmental Engineering, University of Wollongong,
Wollongong, Australia. This thesis has not been submitted for the same purpose to
any other University.

RUIBAO FENG

November, 1998
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Final word of thanks to my wife, Wei Liang, for all her support, patience and keeping up with the long lonely nights during the period of this research study.
ABSTRACT

The techniques of signal processing and pattern classification have been applied, in this thesis, for the classification of the miners' heart rates during rescue operations. These techniques were used because of the limitations noted of the traditional statistical approach used in analyzing the nonstationary heart rates of the miners during rescue operations.

The properties and application scope of wavelet are discussed. An appropriate wavelet, namely db4, is selected to perform a dyadic decomposition of the miners' heart rates. The decomposition results are prepared for extracting the feature vectors.

Some programs developed in MATLAB language are used for extracting feature vectors from the decomposition results of the miners' heart rate data.

Pattern classification techniques are discussed. One program package of classification, based on the LBG algorithm, is applied for the classification of the miners' heart rates.

The classification method used produced encouraging result in spite of limited sample size.

The result of the study provides a significant trial in analyzing the nonstationary time series, such as the heart rates of miners during rescue operations, by using signal processing and pattern classification techniques. A total of 37 subjects were classified into four groups. Group 4 members were associated with relatively higher oxygen consumption rates.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>DECLARATION</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>ii</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>iii</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>iv</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>vi</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>viii</td>
</tr>
</tbody>
</table>

## CHAPTER 1  GENERAL INTRODUCTION

1.1 Introduction 1
1.2 Problem Definition 5
1.3 Scope of Work 6

## CHAPTER 2  SIGNAL PROCESSING TECHNIQUES

2.1 Introduction 7
2.2 Characteristics of Fourier Transform 7
2.3 Characteristics of Short Time Fourier Transform 9
2.4 Characteristics of Wavelet and Multiresolution Analysis 11
   2.4.1 Wavelet 11
   2.4.2 Multiresolution Analysis 20
2.5 A Comparison between the Wavelet Transform and the Short Time Fourier Transform 22

## CHAPTER 3  PATTERN RECOGNITION AND CLASSIFICATION

3.1 Introduction 24
3.2 Feature Extraction 27
3.3 Pattern Classification 31
   3.3.1 Bayes Linear Classifier 32
3.3.2 Euclidean Distance Classifier 33
3.3.3 LBG Classifier for Pattern Classification 34

CHAPTER 4  CLASSIFICATION OF HEART RATES 36

4.1 Field Simulation Data 36
4.2 Classification of the Miners' Heart Rates 42
4.3 Discussion of the Classification Result 59

CHAPTER 5  SUMMARY AND CONCLUSIONS 62

5.1 Summary 62
5.2 Conclusions 62
5.3 Recommendations for Further Work 63

REFERENCES 64

APPENDICES 67

APPENDIX A-1  The m-file for extracting the feature vectors 68
APPENDIX A-2  C++ programs for Feature Vectors Classification 73
APPENDIX B  A list of feature vectors 85
APPENDIX C  Time versus heart rate of subjects 94
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Heart rates versus duration of subject No. 1 data</td>
<td>2</td>
</tr>
<tr>
<td>1.2 Moving windows versus mean value</td>
<td>4</td>
</tr>
<tr>
<td>1.3 Typical correlogram of stationary time series data</td>
<td>4</td>
</tr>
<tr>
<td>1.4 Correlogram of subject No. 1 data</td>
<td>5</td>
</tr>
<tr>
<td>1.5 Correlogram of subject No. 13 data</td>
<td>5</td>
</tr>
<tr>
<td>1.6 The flow chart of the heart rates data classification</td>
<td>6</td>
</tr>
<tr>
<td>2.1 Haar wavelet</td>
<td>15</td>
</tr>
<tr>
<td>2.2 The db4 wavelet and its scaling function and decomposition filters</td>
<td>16</td>
</tr>
<tr>
<td>2.3 Coiflets2 wavelet</td>
<td>16</td>
</tr>
<tr>
<td>2.4 Biorthogonal 3.9 wavelet</td>
<td>17</td>
</tr>
<tr>
<td>2.5 Symlet 4 wavelet</td>
<td>18</td>
</tr>
<tr>
<td>2.6 Morlet wavelet</td>
<td>18</td>
</tr>
<tr>
<td>2.7 Mexican hat wavelet</td>
<td>19</td>
</tr>
<tr>
<td>2.8 Meyer wavelet</td>
<td>19</td>
</tr>
<tr>
<td>2.9 Multiresolution analysis decomposition</td>
<td>20</td>
</tr>
<tr>
<td>2.10 Multi-stage perfect reconstruction</td>
<td>22</td>
</tr>
<tr>
<td>3.1 Pattern recognition system flowchart</td>
<td>25</td>
</tr>
<tr>
<td>3.2 The feature &quot;Acceleration&quot;</td>
<td>29</td>
</tr>
<tr>
<td>3.3 The sub-level waveforms of discrete signals</td>
<td>30</td>
</tr>
<tr>
<td>4.1 Time versus heart rate of subject</td>
<td>37</td>
</tr>
<tr>
<td>4.2 Wavelet toolbox main menu</td>
<td>43</td>
</tr>
<tr>
<td>4.3 Wavelet 1-D tool menu</td>
<td>44</td>
</tr>
<tr>
<td>4.4 Wavelet 1-D analysis window</td>
<td>45</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES (Continued)

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5</td>
<td>Decomposition of the subject No. 1 data using <em>Haar wavelet</em></td>
</tr>
<tr>
<td>4.6</td>
<td>Decomposition of the subject No. 1 data using <em>db4 wavelet</em></td>
</tr>
<tr>
<td>4.7</td>
<td>Decomposition of the subject No. 1 data using <em>bior2.2 wavelet</em></td>
</tr>
<tr>
<td>4.8</td>
<td>Decomposition of the subject No. 1 data using <em>coiflet3 wavelet</em></td>
</tr>
<tr>
<td>4.9</td>
<td>Decomposition of the subject No. 1 data using <em>Symlet4 wavelet</em></td>
</tr>
<tr>
<td>4.10</td>
<td>Acceleration definition</td>
</tr>
<tr>
<td>4.11</td>
<td>The reconstruction signal $x$ of level $j$ detail versus amplitude</td>
</tr>
<tr>
<td>4.12</td>
<td>Group versus oxygen consumption rate</td>
</tr>
<tr>
<td>4.13</td>
<td>Group versus body mass</td>
</tr>
<tr>
<td>4.14</td>
<td>Group versus age</td>
</tr>
<tr>
<td>4.15</td>
<td>Group versus mine</td>
</tr>
</tbody>
</table>
## LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1 Comparison between short time Fourier transform and wavelet transform</td>
<td>23</td>
</tr>
<tr>
<td>4.1 Summary of South Bulli Colliery trials</td>
<td>38</td>
</tr>
<tr>
<td>4.2 Summary of Elouera Colliery trials</td>
<td>39</td>
</tr>
<tr>
<td>4.3 Summary of Myuna Colliery trials</td>
<td>40</td>
</tr>
<tr>
<td>4.4 Summary of Crinum Colliery trials</td>
<td>41</td>
</tr>
<tr>
<td>4.5 Procedures for classification of the miners' heart rate</td>
<td>42</td>
</tr>
<tr>
<td>4.6 The composition of the feature vectors in an Excel file</td>
<td>53</td>
</tr>
<tr>
<td>4.7 The classification result of the miners' heart rates</td>
<td>58</td>
</tr>
</tbody>
</table>
Chapter 1

General Introduction

1.1 Introduction

In the recent Moura No.2 incident eleven lives were lost underground (MacKenzie-Wood et al, 1997). The Warden’s Inquiry into the Moura No.2 incident contained a number of recommendations aimed at reducing the likelihood of future coal mine accidents. The recommendations included the following extract:

"... development and introduction of oxygen based escape systems from underground coal mines, as means to maximise the likelihood of survival, in the event of fires or explosion."

There is a general consensus for the need to use the Self-Contained Self-Rescuer (SCSR) unit to minimise loss of life in accidents in Australian coalmines. The state of Queensland has recognised this need and has identified the SCSR unit as the means to do this. It became the approved standard unit in Queensland in 1998. A SCSR unit is a closed circuit, demand sensitive, breathing apparatus, which makes oxygen available to a wearer for a period of time. Its operation is completely independent of the surrounding atmosphere. Once properly donned, the SCSR unit can assist a miner to escape from an area containing smoke, toxic gases or an oxygen deficient atmosphere. The oxygen consumption ($\dot{V}O_2$) and the heart rates are correlated. Hence, a prediction of $\dot{V}O_2$, and consequently the duration of an SCSR unit, can be made by monitoring the heart rate of a miner. MacKenzie-Wood et al (1997) conducted a field study in
1997 with the objective of determining a method for predicting an individual's oxygen requirements when escaping from underground. The researchers evaluated personal factors such as age, weight, and physical fitness, that may influence an individual's oxygen requirement when escaping from an underground place of work to the surface or a place of safety (MacKenzie-Wood et al, 1997). Using the results from field simulated escape trials, a linear regression model, which predicts the oxygen run-out time of the SCSR unit, was developed. This model is given in Equation 1.1.

\[ \dot{V}O_2 = \frac{6.0W + 15HR}{500} + 0.332 \]  

(1.1)

where:
\[ \dot{V}O_2 \]: Oxygen consumption (litres/min).
\[ HR \]: Average heart rate (bpm).
\[ W \]: Body mass.

SCSR unit Duration: "run out" time (in minutes) = \(100/\dot{V}O_2\), for 100 litre SCSR unit.

Fig. 1.1 shows a typical heart rate profile of one of the subjects who participated in the field study. In applying Equation 1.1 to this Fig. 1.1, the heart rates of the subject are averaged over a period of 75 minutes. This reduces the heart rate to 88 bpm.

Fig. 1.1: Heart rates versus duration of subject No. 1 data
For a body mass of 84 kg, the run out time of the SCSR unit for this subject is 62.35 min, and the observed oxygen "run out" time for a 100 litre capacity SCSR unit is 70.25 min. The advantage and attractiveness of Equation 1.1 is its simplicity and minimum input data requirement.

The underlying assumption, in applying average heart rate to Equation 1.1, is that the heart rate of an individual is stationary over time, that is, the mean heart rate and the correlogram are invariant with time. The mean value and the covariance defined by Equations 1.2 and 1.3 (Box and Jenkins, 1976) are:

\[ \mu = E[x_t] \] (1.2)

\[ \gamma_k = \text{cov}[x_t, x_{t+k}] = E[(x_t - \mu)(x_{t+k} - \mu)] \] (1.3)

where:

- \( x_t \) — the heart rate at time \( t \).
- \( \mu \) — the mean value of the heart rate.
- \( \gamma_k \) — the covariance function or autocovariance between \( x_t \) and \( x_{t+k} \) separated by \( k \) intervals of time.

Using a moving window of five-minute duration, the mean value of the heart rate over each window is determined for the time series data presented in Fig. 1.1.

The results of this simple exercise are presented in Fig. 1.2 which shows clearly that the average heart rate varies between 68 and 105 bpm and the stationarity requirement expressed by Equation 1.2 is not invariant with time.
Another test for the stationarity of time series data is the autocorrelation ($\rho_k$) test. This is defined in terms of the autocovariance at lag $k$, $\gamma_k$ (see Equation 1.3), and expressed as follows:

$$
\begin{align*}
\rho_0 &= \gamma_0 / \gamma_0 = 1 \\
\rho_1 &= \gamma_1 / \gamma_0 \\
&\quad \ldots \\
\rho_k &= \gamma_k / \gamma_0 
\end{align*}
$$

A graph of the autocorrelation function is called the correlogram. Fig. 1.3 is a typical correlogram of a stationary process. One of the properties of a stationary process is that the autocorrelation ($\rho_k$) tends effectively to zero beyond a lag $k$ (practically zero after lag 5 in Fig. 1.3).

Fig. 1.2: Moving windows versus mean value

Fig. 1.3: Typical correlogram of stationary time series data
The correlograms for the heart rates of subjects 1 and 13 who participated in the MacKenzie-Wood et al (1997) field simulated trials are shown in Figs. 1.4 and 1.5. From the above discussion we can conclude that the heart rates data of the field simulation are of a non-stationary time series and that Equation 1.1 must be used with caution.

![Fig. 1.4: Correlogram of subject No.1 data](image1)

![Fig. 1.5: Correlogram of subject No.13 data](image2)

1.2 Problem Definition

Results from Figs. 1.2, 1.4 and 1.5 clearly show that the heart rates, monitored by MacKenzie-Wood et al (1997), are not stationary. For a non-stationary process described by the miners' heart rate the use of Equation 1.1 is not appropriate. Any prediction model must incorporate the underlying random process of individual heart rates. This suggests that the use of the simple linear model, defined in Equation 1.1, to
predict the oxygen requirement of miner's, is not appropriate. What is required is a methodology, which recognises the underlying non-stationary process of the heart rates. This thesis aims to develop a methodology for analysing the miners' non-stationary heart rates and use the results for predicting oxygen consumption rates of miners in accident situations.

1.3 Scope of Work

The objective of this thesis is to propose an alternative method for prediction of the oxygen consumption rate, for nonstationary heart rates. The analytical tools used to predict the oxygen consumption rates are wavelets and pattern-recognition concepts. These are recognized as ideal for analysing nonstationary, time series data such as heart rates (Crowe, 1997).

The methodology used in this thesis involves the following four steps:

1. Decomposition of the heart rates time series data using wavelet technique.
2. Extracting and selecting the feature vectors from the decomposed data.
3. Using a pattern classification technique to classify the feature vectors into different groupings.
4. Analysing the relationships between the results of classification with field data.

A simplified flowchart of the above classification method is depicted in Fig. 1.6.

![Flowchart](image)  
**Fig. 1.6: The flow chart of the heart rate data classification**
Chapter 2
Signal Processing Techniques

2.1 Introduction

Signals provide information about the inherent variables of a phenomenon (Chen, 1988). Signals are in different forms including audio, video and monitored data. Some of these signals are compressed, transmitted and recovered for various purposes. Usually these signals and their interaction are represented in the time domain, but this does not mean that progression versus time is always the best representation for their analysis. A number of different techniques may be used to map the time representation of signals and systems into another space, to make their analysis simpler and more meaningful. Among these mapping techniques, the three commonly used methods are:

1. Fourier Analysis,
2. Short Time Fourier Analysis, and
3. Wavelet Analysis.

The above three signal processing techniques are briefly discussed in the following sections.

2.2 Characteristics of Fourier Transform

Fourier analysis, which includes the Fourier series and the Fourier transform, is one of the analytical tools which may be applied to the analysis of continuous-time,
discrete-time signals and systems (Chen, 1988). In the early 1800s, Joseph Fourier discovered that he could superimpose sines and cosines to represent other functions of signals (Graps, 1995). With the Fourier techniques, a signal can be decomposed into a linear combination of sinusoids extending throughout the duration of the signal. Fourier analysis is useful when determining the underlying frequencies of a signal, that is, it provides good frequency discrimination. However, it is poor at pinpointing when these frequencies occur, that is, it has poor time definition (Crowe, 1997).

In signal analysis few, if any, tools are as universal as the Fourier techniques. This is because of the connections between time and frequency. It is used as the keystone of modern signal processing (Bentley and McDonnell, 1994). The Fourier transform (Equation 2.1) and its inverse (Equation 2.2) are defined as follows:

\[ F(\omega) = \int_{-\infty}^{\infty} f(t) \exp(-j\omega t)dt \]  
\[ f(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} F(\omega) \exp(j\omega t)d\omega \]  

where:

\[ F(\omega) \] – the Fourier transform of the signal \( f(t) \).

Using the identity

\[ \exp(j\omega t) = \cos k\theta + j \sin k\theta \]  

the inverse transform can be described in terms of sine and cosine functions rather than complex exponentials:

\[ f(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} F(\omega)(\cos \omega t + j \sin \omega t)d\omega \]
From the above, it can be seen that the Fourier transform $F(\omega)$ of a signal is a function describing the contribution of sines and cosines to the construction of the original time domain signal. The contribution, of these so-called basis functions, is limited in time only by the duration of the signal being analyzed.

The time independence of the basis functions of the Fourier transform results in a signal description purely in the frequency domain. The description of a signal, either as a function of time or as a spectrum of frequency components, contradicts our everyday experiences. The human auditory system relies upon both time and frequency parameters to identify and describe sounds. For example, to reproduce a piece of music, not only should all the correct notes be played but these notes should also be played in the correct order.

The Fourier transforms are ideal for the analysis of stationary signals (signals whose statistical properties do not evolve with time) and this idea remains at the center of signal processing.

In order to improve the slight imperfection of Fourier analysis, an alternative technique that is based on Fourier analysis was developed. It is referred to as the **Short Time Fourier Transform (STFT)**. In the next section, the concept and the characteristics of the STFT technique are reviewed.

### 2.3 Characteristics of Short Time Fourier Transform

For the analysis of nonstationary signals a function is required that transforms a signal into a joint time-frequency domain. Such a description can be achieved using the Short-time Fourier Transform (STFT), which is an extension to the classical Fourier transform as defined by Gabor (Bentley and McDonnell, 1994):
where

$$STFT \ (\tau, \omega) = \int s(t)g(t - \tau)e^{-j\omega t} \ dt$$

$$= \int s(t)k_{\tau,\omega}(t) \ dt \quad (2.5)$$

This function can be described as the Fourier transform of the signal $s(t)$, previously windowed by the function $g(t)$ around time $\tau$. As the window function is shifted in time over the whole signal, and consecutive overlapped transforms are performed, a description of the evolution of the signal spectrum with time is achieved. This method assumes signal stationarity over the limited window $g(t)$.

If the window is relatively short this assumption of local stationarity is often valid. As the window function $g(t)$ is shifted in time, repeated Fourier transforms are performed on overlapped data sets. Arranging these transforms, chronologically and on a common frequency axis, provides a time-frequency description of the signal which is commonly called the signal spectrogram. But introducing such a window into the Fourier transform has a detrimental effect upon frequency resolution. It leads to the 'leakage' of spectral energy to the surrounding frequencies. That is, it results in a reduced number of samples used in the Fourier transform calculation, which yields a reduced number of discrete frequencies that can be represented in the frequency domain.

With a reduced number of discrete frequency intervals, the ability of the transform to discriminate between sinusoids of different frequencies is significantly reduced. The relationship, between resolution in time and in frequency, is a concept shared by many areas of science and is commonly referred to as the "uncertainty principle" (Colestock, 1993). If $\Delta t$ is the transform resolution in the time domain, and $\Delta f$ is the transform resolution in the frequency domain, then the two sinusoids will be
discriminated only if they are more than $\Delta f$ apart in frequency, or $\Delta t$ apart in time. The uncertainty principle can be written as:

$$\Delta t \Delta f \geq \frac{1}{4\pi}$$  \hspace{1cm} (2.6)

Equation 2.6 implies that both time and frequency resolution cannot be made arbitrarily small, one must be traded for the other. The time and frequency resolution of the STFT is dependent upon the shape and length of the window function. Both these factors remain constant throughout an analysis. Hence the time-frequency resolution also remains constant throughout an analysis. This constant joint time-frequency resolution results in the STFT covering the time-frequency plane with a uniform array of resolution squares. That means, the time-frequency plane of STFT is tiled by a fixed size rectangular window.

In order to resolve the "scale-invariable" imperfection for STFT, wavelet analysis is used. The fundamental idea behind wavelet analysis is to produce a time-frequency representation of a given signal so that salient information are made available for further processing. Indeed, some researchers feel that using wavelets means adopting a whole new mind-set, or perspective, in processing data (Graps, 1995). A discussion of wavelets and multiresolution analysis is presented in the next section.

2.4 Characteristics of Wavelet and Multiresolution Analysis

2.4.1 Wavelet

The wavelet theory and techniques have been applied in many fields. In this thesis, wavelet technique is used to analyze the miners' heart rates. Because of the characteristics of "zoom" and "microscope", wavelets have a marvellous appropriateness for nonstationary signal analysis (Colestock, 1993).
The wavelet transform (WT) is described in terms of its basis functions, known as wavelets (literally “little waves”). Wavelets are composed of a family of basic functions, which are capable of describing signals in a localized time and frequency (or scale) format. The set of basis functions has compact support, meaning all their energy is localized to a finite space in time. Wavelet analysis starts with a basic wavelet function, then shifts and scales (or dilates) the prototype function to generate a family of orthonormal basis functions. All functions defined in the space spanned by the wavelet family can then be modeled by a linear combination of shifted and scaled prototype wavelets (Colestock, 1993).

Wavelet transform has many similarities with the Short Time Fourier Transform. It also maps the time function into a two-dimensional function of the scale variable $a$, and the time-shift variable $\tau$ (instead of $\omega$ and $\tau$) (Chan, 1995). The STFT achieves time-frequency description of signals by using appropriately selected windows. However, the fact that the window size is fixed does not permit a multi-resolution analysis as offered by wavelet transform.

In general, wavelet transform can be classified as continuous wavelet transform and discrete parameter wavelet transform.

The continuous wavelet transform (CWT) of $s(t)$ is defined by (Chan, 1995)

\[ CWT(a, \tau) = \frac{1}{\sqrt{a}} \int s(t) \psi\left(\frac{t-\tau}{a}\right) dt \]  

(2.7)

where $\psi(t)$ is the basic (or mother) wavelet:

\[ \psi_{\tau,a}(t) = \frac{1}{\sqrt{a}} \psi\left(\frac{t-\tau}{a}\right), \quad -\infty < \tau < +\infty, \quad a > 0 \]  

(2.8)

and the integration of $\psi(t)$ is equal to zero:

\[ \int_{-\infty}^{+\infty} \psi(t) dt = 0 \]  

(2.9)
The discrete parameter wavelet transform (DPWT) is defined by

\[ DPWT(m, n) = \int s(t) \psi_{mn}(t) dt \quad (2.10) \]

\[ \psi_{mn}(t) = a_0^{-\frac{m}{2}} \psi(a_0^{-m} t - n \tau_0) \quad (2.11) \]

where

\[ a_0, \tau_0 \] are constants that determine the sampling intervals.

It is of interest to study the type of \( \psi(t) \) and sampling intervals for \((a, \tau)\) that permit perfect reconstruction of the signal:

\[ s(t) = c \sum_m \sum_n DPWT(m, n) \psi_{mn}(t) \quad (2.12) \]

where \( c \) is some constant dependent only on \( \psi(t) \).

Since the Fourier transform of \( \psi(at) \) is \( \Psi(\omega / a) \), the centre frequency and bandwidth of a wavelet are both scaled by \( 1/a \) for a time scaling of \( a \). Thus, the ratio of centre frequency and bandwidth of all baby wavelets is (Chan, 1995):

\[ Q = \frac{\text{centre frequency}}{\text{bandwidth}} = \text{constant} \quad (2.13) \]

giving rise to the so-called constant-\( Q \) analysis capability of wavelets. The frequency resolution decreases (increasing bandwidth) with increasing centre frequencies. This is one advantage of wavelets.

When implemented on the computer, the discrete parameter wavelet transform is more useful than the continuous wavelet transform, as in the case of the continuous wavelet transform, the parameters \( a \) and \( \tau \) must be known before reconstructing. In practice, the parameters \( a \) and \( \tau \) are not known a priori but can be "characterised" by
means of their "wavelet coefficients", that is, $\alpha$ and $\tau$ can be limited in different discrete frames.

Daubechies (1992) applied the theory of frames to put down formally the reconstruction conditions for the discrete parameter wavelet transform. The theory of frames provides the representation of a vector in terms of a set of basis vectors that are not necessarily orthonormal basis, nor linearly independent. The coefficients are still inner products of the vector with the basis vectors. The following is a summary of the results of applying frame theory to the study of the DPWT, in particular to its invertability:

(a) Choice of $(a_0, \tau_0)$ in sampling the continuous variables $a = a_0^m$, $\tau = n \tau_0 a_0^m$ determines the invertability of a DPWT. Too coarse a sampling grid obviously will not allow perfect reconstruction.

(b) There are threshold values $(a_0, \tau_0)$, for a given $\psi(t)$, below which the $\psi_{mn}(t)$ will always form a frame, frame bounds $A > 0$, $B < \infty$. Then reconstruction is possible via Equation 2.12. However, computation of the $\psi_{mn}(t)$ in general requires recursion, unless the two frame bounds $A \approx B$.

(c) It is possible to select $(a_0, \tau_0)$ so that $A \approx B$ and Equation (2.14) is satisfied

$$s(t) = \frac{1}{A + B} \sum_m \sum_n <s(t), \psi_{mn}(t) > \psi_{mn}(t)$$

(2.14)

The closer $A$ is to $B$, the better is this approximation. If $A = B$, a frame is tight, and if $A = B = 1$, then the $\psi_{mn}(t)$ are orthonormal basis functions.

There are many different wavelets that can be created. Several families of wavelets that have proven to be especially useful are Haar, Daubechies, Biorthogonal, Coiflets, Symlets, Morlet, Mexican Hat, and Meyer, of which simple explanations

1) **Haar**

   This is the simplest of all the wavelets. Haar is discontinuous, and resembles a step function (Fig. 2.1). It represents the same wavelet as Daubechies db1.

   ![Fig. 2.1: Haar wavelet](image)

2) **Daubechies**

   Daubechies (1988) provided what are called compactly-supported orthonormal wavelets. This made discrete wavelet analysis practicable. The names of the Daubechies family wavelets are defined as dbN, where N is the order, and db the "surname" of the wavelet. The db1 wavelet is identical to the Haar. One of the Daubechies wavelets is shown in Fig. 2.2.
3) Coiflets

Coiflet wavelets were proposed by Daubechies for Coifman (Misiti et al, 1996). The wavelet function has $2N$ moments equal to 0 and the scaling function has $2N - 1$ moments equal to 0. The two functions have a support of length $6N - 1$. A Coiflet wavelet is shown in Fig. 2.3.
4) Biorthogonal
This family of wavelets exhibits the property of a linear phase, which is needed for signal and image reconstruction. By using two wavelets, one for decomposition and the other for reconstruction, instead of the same single one, interesting properties are derived (Misiti et al, 1996). Fig. 2.4 shows one of the Biorthogonal wavelets.

![Biorthogonal Wavelet Display](image)

**Fig. 2.4: Biorthogonal 3.9 wavelet**

5) Symlets
The symlets are nearly symmetrical wavelets proposed by Daubechies as modifications to the db family. The properties of the two wavelet families are similar. Fig. 2.5 shows one of the symlets.
6) Morlet

This wavelet has no scaling function, but is explicit. Fig.2.6 shows the morlet
7) Mexican hat
This wavelet has no scaling function and is derived from a function that is proportional to the second derivative function of the Gaussian probability density function. Fig. 2.7 shows a Mexican hat wavelet.

![Fig. 2.7: Mexican hat wavelet](image)

8) Meyer
The Meyer wavelet and scaling function are defined in the frequency domain. Fig. 2.8 shows the Meyer wavelet.

![Fig. 2.8: Meyer wavelet](image)
2.4.2 Multiresolution Analysis

Mallat developed the theory of Multiresolution Analysis (MRA) in 1989 (Zhang, 1995). This theory is based on the DPWT. Mallat theory not only unifies the existing wavelet basis functions but can also be used for constructing other wavelets basis functions. MRA can be used for constructing the compact support orthogonal wavelets, which have an inner product preserving property.

The multiresolution analysis is the essence of the wavelet transform. According to the concept of multiresolution, our main approach to wavelets is through 2-channel filter banks that contain two types of coefficients namely, approximation coefficients and detail coefficients. The idea of MRA is similar to subband decomposition and coding, where for coding efficiency, a signal is divided into a set of frequency bands. In this thesis the concept of MRA of the WT was used to decompose the miners’ heart rate data in order to obtain a higher resolution in the time-frequency domain by decomposing a sequence of signal \( s(n) \). With lowpass \( (\tilde{g}(l)) \) and highpass \( (\tilde{h}(l)) \) filters and decimation, the scheme in Fig. 2.9 decomposes signal \( s(n) \) into its subband components of \( d_1, d_2, \ldots, d_n \) and \( c_n \), representing the coarsest, conceivably the \( dc \), as \( L \rightarrow \infty \), component (Chan, 1995).

![Fig. 2.9: Multiresolution analysis decomposition](image-url)
The symbols $\downarrow 2$ and $\uparrow 2$ stand for subsampling and upsampling by two, respectively.

The outputs of the highpass filters $\tilde{h}(l)$ and $d_n^1, d_n^2, \ldots$ are called detail coefficients and the outputs of the lowpass filters $\tilde{g}(l)$ and $c_n^1, c_n^2, \ldots$ are called approximation coefficients (Chan, 1995), where,

$$
c_n^1 = \sqrt{2} \sum_{l=0}^{p-1} \tilde{g}(l)s(2n + p - 1 - l) \tag{2.15}
$$

$$
d_n^1 = \sqrt{2} \sum_{l=0}^{p-1} \tilde{h}(l)s(2n + p - 1 - l) \tag{2.16}
$$

In the two equations above, there is a delay of $p-1$ samples in the output $c_n^1$ and $d_n^1$.

There is no output $c_n^1$ until space $s(2n+p-1)$ is obtained.

The first stage of the MRA decomposition produces a lowpass component $c_n^1$, referred to as the smoothed or approximated version of $s(n)$, since its resolution is half of $s(n)$. The other component $d_n^1$ is the detail or difference. It contains the high frequency details of $s(n)$ that are not in $c_n^1$.

The next step decomposes $c_n^1$ into its approximation $c_n^2$ and detail $d_n^2$, following identical steps as previously taken. Thus

$$
\sum_n c_n^1 \phi_1(n) = \sum_n c_n^2 \phi_2(n) + \sum_n d_n^2 \psi_2(n) \tag{2.17}
$$

with

$$
c_n^2 = \sqrt{2} \sum_{l=0}^{p-1} \tilde{g}(l)c_{2n-l+p-1}^1 \tag{2.18}
$$

$$
d_n^2 = \sqrt{2} \sum_{l=0}^{p-1} \tilde{h}(l)d_{2n-l+p-1}^1 \tag{2.19}
$$
The reconstruction of $s(n)$ from the $dc$ components is:

$$s(n) = \sqrt{2} \sum_{l=0}^{p-1} g(l)c_{(n-l)/2}^l + \sqrt{2} \sum_{l=0}^{p-1} h(l)d_{(n-l)/2}^l$$  \hspace{1cm} (2.20)$$

Fig. 2.10 gives the structure for multi-stage reconstruction.

---

2.5 Comparison between the Wavelet Transform and the Short Time Fourier Transform

In the above sections, it was found that wavelet transform offers two major advantages, multiresolution analysis and time-frequency localization. This is in contrast to the STFT, which uses a single analysis window. The WT uses short windows at high frequencies and long windows at low frequencies (so-called “constant-Q” or constant relative bandwidth frequency analysis) in order to obtain a multiresolution analysis. For time-frequency localization, wavelets offer a different compromise. The frequency localization is logarithmic, that is, proportional to the frequency level. As a consequence time localization get finer in the higher
frequencies. In this thesis, the multiresolution analysis of the wavelet transform is applied to decompose heart rate data to obtain feature vectors for further classification.

Table 2.1 lists the similarities and the differences between STFT and WT.

**Table 2.1 Comparison between short time Fourier transform and wavelet transform**

<table>
<thead>
<tr>
<th>No.</th>
<th>Short time Fourier transform</th>
<th>Wavelet transform</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>For short time signal</td>
<td>For short time signal</td>
</tr>
<tr>
<td>2</td>
<td>For the analysis of non-stationary signal, the signal through a window over which the signal is approximately stationary.</td>
<td>For the analysis of non-stationary signals.</td>
</tr>
<tr>
<td>3</td>
<td>Using a single window.</td>
<td>Using short windows at high frequencies and long windows at low frequencies.</td>
</tr>
<tr>
<td>4</td>
<td>Localisation by windowing.</td>
<td>Localisation by scaling function and wavelet function.</td>
</tr>
<tr>
<td>5</td>
<td>Mapping into a time-frequency plane.</td>
<td>Mapping into a time-frequency plane.</td>
</tr>
<tr>
<td>6</td>
<td>Analysis with fixed resolution in the time-frequency plane. i.e., the signal can be analyzed with good time resolution or frequency resolution but not both. Has a ‘leakage’ of spectral energy to surrounding frequencies: $\Delta t \Delta f \geq 1/(4\pi)$</td>
<td>A multiresolution analysis in time-frequency plane, i.e., the time resolution becomes arbitrarily good at high frequencies while the frequency resolution becomes arbitrarily good at low frequencies. Has no ‘leakage’ of spectral energy to surrounding frequencies: $Q = (\text{centre frequency}/\text{bandwidth}) = \text{constant}$</td>
</tr>
</tbody>
</table>
Chapter 3

Pattern Recognition and Classification

3.1 Introduction

Pattern recognition and classification involve systematic means of placing abstract objects into categories, with the eye-brain computer as one model (Nadler and Smith, 1993). The techniques of pattern recognition have been applied in many fields including statistics, communication theory, biology, psychology, geophysics, and linguistics (Ciaccio, Dunn and Akay, 1993).

The three basic approaches to pattern recognition and classification are "statistical", "syntactic" and "neural networks" (Dickhaus and Heinrich, 1996).

Statistical pattern classification uses measurements and transforms of the pattern structure as feature vectors. The classifiers used are commonly dependent on particular probability distributions of the features (or properties) and feature vectors (or property vectors). Usually these techniques treat the pattern as a random vector, and assume a statistical distribution. Linear techniques are often used for clustering features or properties of the underlying structure.

Syntactic pattern recognition techniques base classification on descriptions or graphs of the pattern structure. So-called primitives, like straight lines, arcs, or
corners, are regarded as features that are chained together in a serial fashion as in a string. A typical class of patterns is represented by a distinct grammar. The classifying process can be performed by string matching or, frequently, by parsing.

Artificial intelligence (AI) is another technique applied to pattern classification. As one of the main parts of AI, artificial neural network (ANN) methods are widely used in many fields. Neural networks consist of an input and an output layer, and one or more hidden (middle) layers, consisting of weighted connections and nodes. These networks are trained by presenting a library (example) of patterns to the network input and iteratively adjusting the middle layer weights to provide a desired output.

In this thesis, the “statistical method” is used to classify the miners' heart rates.

The pattern recognition system is based on the statistical method and involves four steps (see Fig. 3.1):

---

![Fig. 3.1: Statistical pattern recognition system flowchart](image-url)

---

25
Pattern Recognition and Classification

1) Input data

In general, the three basic types of input data are:

i. Two-dimensional images, such as characters, fingerprints, maps, and photos;

ii. One-dimensional waveforms, such as electroencephalogram (EEG),
electrocardiogram (ECG), vibration waveform, etc;

iii. Physical parameters and Boolean values, such as the temperature data of the
patient, laboratory test data, and 0/1 Boolean values.

2) Data preprocessing

The aims of data preprocessing is to denoise, to enhance the useful information, and
to recover the data contaminated by the operating error of the measurement
instrument or other factors.

3) Feature extraction

In general, the number of image pixels or waveform data is very large.
Transformation of the original data is necessary to obtain more concise data which
can embody the essential features for classification. This is the process of feature
extraction.

4) Classification decision

Classification decision relies on statistical methods to classify the recognised object
into some type. Based on the sample training set, one of the decision rules has to be
determined in order to get the optimised result by using the appropriate decision
approach.
The data to be analysed in this thesis had been gathered in the form of a one dimensional time series, by Mackenzie-Wood et al (1997). This thesis therefore, ignores the first two steps and concentrates on "feature extraction" and "classification decision".

3.2 Feature Extraction

In pattern recognition, features are used to distinguish one class of objects from another, they represent patterns with a minimal loss of important information (Nadler and Smith, 1993). Features are functions of the measurements performed on a class of objects that enable that class to be distinguished from other classes in the same general category.

Features can be divided into two categories for statistical pattern recognition system (Ciaccio, Dunn and Akay, 1993):

(i) Time domain structural characteristics, such as moments, power, phase information, and model parameters.

(ii) Transform domain structural characteristics, such as frequency spectra and subspace mapping methods.

In general, features are combinations of the measurements (possibly preprocessed) that summarise the information in a useful way. Features are generally designed using the experience, intuition and cleverness of the designer.

Certain types of features defined for a given problem can be arranged as an ordered set. Such a set is called a "feature vector." A feature vector is therefore a reduced-dimensional representation of that pattern. One purpose of the dimensionality reduction is to meet the constraints of computing software and hardware
complexities, the computing cost, and for purposes of data transmission, the desirability of compressing pattern information. In addition, classification is often more accurate (the criteria for accuracy may be, for example, the percent of input patterns classified correctly) when the pattern is simplified through representation by important features or properties only (Ciaccio, Dunn and Akay, 1993). There is, however, a tradeoff between too few and too many features (termed the peaking phenomenon). According to Ciaccio, Dunn and Akay (1993), the choice of features used in classification is governed by:

1) Hardware and software constraint,
2) The peaking phenomenon, and
3) The permissible information loss.

Generally speaking, it is easy for computers to extract the mathematical features of an object. Such mathematical features can be obtained by measurements and transformations. By using multiresolution analysis of WT, this thesis uses the following six feature vectors to statistically classify the heart rates of miners in escapeways:

a) Entropy

Entropy is defined as the measure of the information content of a source (Young, 1986). There are some different entropies such as 'shannon', 'threshold', 'norm', 'log energy', 'sure', 'user', etc. (Misiti et al, 1996). In this thesis, the Equation 3.1 (named "shannon entropy") was used:

\[
Entropy(s) = -\sum_i x_i^2 \log(x_i^2)
\]  

(3.1)

where,

\[x_i\] is the \(i^{th}\) signal in a finite-length signal segment.
b) Energy

The signal energy is defined as the sum of the squares of the signal values over the analysis frame. This is expressed by Equation 3.2.

\[ Energy = \sum_{i=1}^{N} x_i^2 \]  

\hspace{1cm} (3.2)

c) Mean Value

The mean value (Equation 3.3) is similar to the energy expression (Equation 3.2) but without the squared weighting (which may cause the energy function to be sensitive to large signal amplitudes):

\[ Mean = \frac{1}{N} \sum_{i=1}^{N} x_i \]  

\hspace{1cm} (3.3)

d) Accelerations of Heart Rate

In calculating the acceleration of the heart rate, the approach, suggested by Dyer, Cooke and Nunn (1995), is used in this thesis (Fig. 3.2). In a specific period of time (such as a 10 sample time window), acceleration occurs if the heart rate of the right boundary in the window is greater than the heart rate of the left boundary in the same window by a definite value (such as in excess of 10 bpm).

![Fig. 3.2: The feature "Acceleration"](image)
e) **Zero-Crossing Rate**

Zero-crossing rate is defined as the number of sign changes occurring in the neighborhood of the signals along the axis of the analysis frame. The zero-crossing rate gives a general indication of frequency content as higher-frequency signals give a higher zero-crossing rate. The thesis uses the following method: if signal $x_i$ multiplied by $x_{i+1}$ ($i = 1 \ldots N-1$) happens to be a negative sign, then one number of zero-crossing rate is counted in, until the end of the signal. The zero-crossing rate is only used in detail levels of multiresolution analysis. The analysis frame of signals, for calculating the zero-crossing rates, is shown in Fig. 3.3.

f) **Peak Value**

Peak value is simply the largest absolute amplitude value occurring in the analysis frame, such as d2 level in Fig. 3.3.

---

**Fig. 3.3: The decomposition of discrete signals**
In this thesis, the features that are commonly used in pattern recognition were selected. No attempt has been made to optimise the features.

### 3.3 Pattern Classification

The fundamental approach chosen is to consider the pattern as having two different views, like the two sides of a coin (Schurmann, 1997). A pattern is a pair comprising an observation and a meaning. Pattern classification systems infer meaning from observation. Designing a pattern classification system is establishing a mapping from the measurement space into the space of potential meanings, whereby the different meanings are represented in this space as discrete target points. In artificial intelligence terms, pattern classification marks the step from the subsymbolic to the symbolic level of representation.

The very core of the problem lies in the fact that the observations—describing the appearance of the pattern—may widely change without affecting the pattern meaning. The patterns to be encountered in a given application task, and hopefully to be correctly recognised by the pattern classifier, are modelled as coming from a stochastic source.

Statistical techniques for pattern classification fall into several categories (Ciaccio, Dunn and Akay, 1993; Nadler and Smith, 1993; Schurmann, 1997):

1) **Bayes linear classifier**, which assumes normal distributions and is one of the most commonly used approaches;

2) **Maximum likelihood estimation**, which optimises a parameter based on likelihood;

3) **Fisher's linear discriminant**, which reduces the dimensionality of a feature vector in such a way as to improve classification;

4) **Entropy criteria**, which classifies a pattern based on minimising uncertainty.
In this thesis only the **Bayes linear classifier**, **Euclidean distance classifier** and **LBG classifier** are briefly discussed.

### 3.3.1 Bayes Linear Classifier (BLC)

For two normal distributions \( \omega_1 \) and \( \omega_2 \), the Bayes decision rule can be expressed as a quadratic function of the sample vector \( \mathbf{x} \) as:

\[
\frac{1}{2} (\mathbf{x} - \mathbf{\mu}_1)^T \left( \Sigma_1^{-1} \right) (\mathbf{x} - \mathbf{\mu}_1) - \frac{1}{2} (\mathbf{x} - \mathbf{\mu}_2)^T \left( \Sigma_2^{-1} \right) (\mathbf{x} - \mathbf{\mu}_2) + \frac{1}{2} \ln \left| \Sigma_1 \right| - \frac{1}{2} \ln \left| \Sigma_2 \right| + \ln \left[ \frac{P(\omega_1)}{P(\omega_2)} \right] \leq 0 \quad \text{then} \quad \mathbf{x} \in \{ \omega_1 \}
\]

(3.8)

where,

- \( \mathbf{\mu}_1 \) and \( \mathbf{\mu}_2 \) are mean vectors for class 1 and 2, \( P(\omega) \) is the probability of \( \mathbf{x} \),
- \( \Sigma_1^{-1} \) and \( \Sigma_2^{-1} \) are the inverses of the covariance matrices \( \Sigma_1 \) and \( \Sigma_2 \), and

This denotes class membership of \( \mathbf{x} \) in \( \omega_1 \) or \( \omega_2 \), dependent upon the direction of the inequality. The equation 3.8 can be simplified if the covariance matrices \( \Sigma_1 = \Sigma_2 = \Sigma \):

\[
(\mathbf{\mu}_2 - \mathbf{\mu}_1)^T \left( \Sigma^{-1} \right) - \frac{1}{2} \left( \mathbf{\mu}_1^T \left( \Sigma^{-1} \right) \mathbf{\mu}_1 - \mathbf{\mu}_2^T \left( \Sigma^{-1} \right) \mathbf{\mu}_2 \right) + \ln \left[ \frac{P(\omega_1)}{P(\omega_2)} \right] \leq 0 \quad \text{then} \quad \mathbf{x} \in \{ \omega_1 \}
\]

(3.9)

Further, if the observation vector \( \mathbf{x} \) is corrupted by white noise, \( \Sigma^{-1} = \mathbf{I} \) (i.e. the identity matrix):

\[
(\mathbf{\mu}_2 - \mathbf{\mu}_1)^T \mathbf{x} + \frac{1}{2} \left( \mathbf{\mu}_1^T \mathbf{\mu}_1 - \mathbf{\mu}_2^T \mathbf{\mu}_2 \right) + \ln \left( \frac{P(\omega_1)}{P(\omega_2)} \right) \leq 0 \quad \text{then} \quad \mathbf{x} \in \{ \omega_1 \}
\]

(3.10)
Now the product $\mu_i^T x$ is the correlation between $\mu_i$ and $x$, which can be written for a time sampled process as:

$$\mu_i^T x \approx \sum_{j=1}^{n} \mu_j(t_j) x(t_j)$$

(3.11)

where,

$i$ is the class number, and $j$ is the sample number in a multiple normal distributions sample set.

### 3.3.2 Euclidean distance classifier

If $P(\omega_1) = P(\omega_2) = 0.5$, the decision boundary is the perpendicular bisector of a line joining $\mu_1$ and $\mu_2$. The **Euclidean distance** measure is determined by:

$$d_i^2 = \| x - \mu_i \|^2$$

$$= (x - \mu_i)^T (x - \mu_i)$$

(3.12)

The Euclidean distance could be chosen by Equ. 3.13:

$$d_i = \min_i (d_i^2)$$

(3.13)

which allow $x$ to be classified in $\omega_i$. Equation 3.12 and 3.13 are equivalent to the linear distances. A distance function can be written as:

$$d_i^2 = x^T x - 2 (x^T \mu_i - \frac{1}{2} \mu_i^T \mu_i)$$

(3.14)

Ignoring the first term, which is a constant for all distances, a distance function can be written as:

$$d_i(x) = x^T \mu_i - \frac{1}{2} \mu_i^T \mu_i$$

(3.15)
where,

vector $\mathbf{x}$ is assigned to the cluster whose mean is closest to $\mathbf{x}$.

The cluster centers are found by averaging, which can be performed adaptively.

### 3.3.3 LBG Classifier for Pattern Classification

Lloyd proposed an iterative non-variational technique known as "Method I" for the design of scalar quantizers. Linde, Buzo, and Gray, (1980), extended Lloyd’s basic approach to the general case of vector quantizers by using a clustering approach. Their algorithm is commonly referred to as the LBG algorithm.

The LBG algorithm is based upon the minimisation of $d_i^2$ (defined in Equation 3.12) using a training set as the signal. The goal in designing an optimal vector quantizer is to obtain a quantizer (commonly termed codebook) consisting of $N$ reproduction vectors (reference vectors), that minimises the expected distortion. Optimisation is said to be achieved if there is no other quantizer that can achieve the minimum expected distortion.

Let the expected distortion be approximated by the time-averaged square error distortion given by the equation:

$$D(\chi, P(\chi)) = \frac{1}{N} \sum_{j=1}^{N} d(\chi_j, \mu_j)$$ \hspace{1cm} (3.16)

The LBG algorithm for an unknown distribution training sequence is shown in the following steps (Linde, Buzo, and Gray, 1980):

1) Let $N =$ number of levels; distortion threshold $\varepsilon \geq 0$. Assume an initial $N$ level reproduction vector $\hat{\mathbf{A}}_0$ and a training sequence $(\chi_j ; j = 1, 2, ..., N )$, and $m =$ number of iterations, initialised to zero.
2) Given \( \hat{A}_m = (\mu_i; i = 1, 2, \ldots, N) \), find the minimum distortion partition 
\( P(\hat{A}_m) = (S_i; i = 1, 2, \ldots, N) \) of the training sequence:

\[ \chi_j \in S_i \quad \text{if} \quad d(\chi_j, \mu_i) \leq d(\chi_j, \mu_l), \quad \text{for all} \ l \]

where,

\( l \) is the number of the reproduction vector set, \( l = 1, \ldots, N \).

Compute the average distortion:

\[
D_m = D\left(\hat{A}_m, P\left(\hat{A}_m\right)\right) = \frac{1}{N} \sum_{j=1}^{N} \min_{\mu \in \hat{A}_m} d(\chi_j, \mu) \tag{3.17}
\]

3) If \( (D_{m-1} - D_m) / D_m \leq \varepsilon \), stop the iteration with \( \hat{A}_m \) as the final reproduction vector, 
otherwise continue.

4) Find the optimal reproduction vector \( \mu(P(\hat{A}_m)) = (\mu(S_i); i = 1, \ldots, N) \) for \( P(\hat{A}_m) \)
where

\[
\mu(S_i) = \frac{1}{||S_i||} \sum_{j=1}^{m} \chi_j \quad \chi_j \in S_i \tag{3.18}
\]

5) Set \( \hat{A}_{m+1} = \mu(S_o) \), increment \( m \) to \( m+1 \), and go to step 2).

In the above iterative algorithm, an initial reproduction vector \( \hat{A}_0 \) was assumed in order to start the algorithm.
Chapter 4
Classification of the Miners' Heart Rates

4.1 Field Simulation Data

The heart rate data of the miners used in this thesis were monitored and collected at mines in New South Wales and Queensland by the research team of the ACARP project, No.C5039 (MacKenzie-Wood, et al, 1997). The objectives of the underground investigations were to gather in-mine data on escape times, distances travelled and average heart rates, and to develop a technique to predict how much oxygen was actually needed for an average miner to escape from an underground mine. The field simulated escape trials were conducted at South Bulli, Elouera and Myuna collieries in New South Wales and the Crinum colliery in Queensland. The mines were selected to represent the variety of conditions that are normally encountered in the actual escapeways of Australian coal mines. The escape routes were selected by the mine and based on the following requirements:

- A distance which would require the volunteers to walk for a minimum of one hour.
- An established escapeway to simulate typical underground escape route conditions.

Attempts were made to ensure that the profiles of the volunteers represented those of the current workforce in Australian underground coal mines. Prior to participating in the field trials, all the volunteers were assessed by an occupational physician to identify those with significant medical conditions or those who may have problems
walking out of the mine because of significant musculoskeletal problems (MacKenzie-Wood, 1997).

During the simulated escape trials, 37 volunteers walked along the escape route at their respective mines on Day 1 carrying the SCSR units on their belts. The walk was repeated on Day 2 with the same subjects wearing the SCSR units. The walking pace on each day was kept at a constant rate of about 2 km/hr. The heart rates of each subject were recorded by a Polar Vantage NV™.

At the end of Day 2 each SCSR unit's breathing bag was monitored by an observer to enable the oxygen “run out” time to be determined. Normally, the end of the trial could be defined for each individual as the point of complete collapse of the breathing bag, which may be accompanied by increased breathing resistance. If carbon dioxide builds up in the breathing circuit headache and light-headedness may also occur. This is most likely to be caused by inhaled concentrations of CO₂ of 2-3%. The duration of the SCSR unit was taken from the time the individual started to breathe oxygen via the SCSR units ending with the complete collapse of the breathing bag. The record of Day 1, dynamic heart rate of field subject 1 is provided in Fig 4.1; the dynamic heart rates of the remaining 36 subjects are provided in Appendix C. The summary of field data from the three collieries is provided in Table 4.1 through Table 4.4.

**Fig. 4.1: Time versus heart rate of subject No.1**
### Table 4.1 Summary of South Bulli Colliery trials

<table>
<thead>
<tr>
<th>Subject ID</th>
<th>Age (yrs)</th>
<th>Weight (kg)</th>
<th>Heart Rate on Day 1 (HR₁) Minimum</th>
<th>Average (bpm)</th>
<th>Maximum (bpm)</th>
<th>Heart Rate on Day 2 (HR₂) Minimum</th>
<th>Average (bpm)</th>
<th>Maximum (bpm)</th>
<th>Obsₚ</th>
<th>ObsᵥO₂</th>
<th>Consumption of Cigarette (g/wk)</th>
<th>Consumption of Alcohol (g/wk)</th>
<th>Exercise Ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>47</td>
<td>84</td>
<td>66</td>
<td>88.0</td>
<td>112</td>
<td>59</td>
<td>90.0</td>
<td>110</td>
<td>70.25</td>
<td>1.42</td>
<td>140</td>
<td>180</td>
<td>6</td>
</tr>
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<td>2</td>
<td>40</td>
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<td>117</td>
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<td>168</td>
<td>109</td>
<td>136.7</td>
<td>167</td>
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<td>2.23</td>
<td>49</td>
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<td>98</td>
<td>122.0</td>
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<td>93</td>
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<td>138</td>
<td>80</td>
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<td>132</td>
<td>54.25</td>
<td>1.84</td>
<td>0</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>43</td>
<td>91</td>
<td>99</td>
<td>118.8</td>
<td>141</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>67.50</td>
<td>1.48</td>
<td>0</td>
<td>45</td>
<td>7</td>
</tr>
<tr>
<td>6</td>
<td>43</td>
<td>88</td>
<td>108</td>
<td>135.1</td>
<td>154</td>
<td>95</td>
<td>127.0</td>
<td>152</td>
<td>67.25</td>
<td>1.49</td>
<td>0</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>29</td>
<td>92</td>
<td>88</td>
<td>107.4</td>
<td>131</td>
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<td>N/A</td>
<td>N/A</td>
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<td>1.79</td>
<td>0</td>
<td>150</td>
<td>6</td>
</tr>
<tr>
<td>8</td>
<td>49</td>
<td>85</td>
<td>94</td>
<td>118.4</td>
<td>145</td>
<td>80</td>
<td>109.6</td>
<td>134</td>
<td>48.00</td>
<td>2.08</td>
<td>140</td>
<td>2</td>
<td>420</td>
</tr>
<tr>
<td>9</td>
<td>44</td>
<td>89</td>
<td>89</td>
<td>106.9</td>
<td>125</td>
<td>83</td>
<td>107.4</td>
<td>128</td>
<td>66.00</td>
<td>1.52</td>
<td>28</td>
<td>140</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>49</td>
<td>87</td>
<td>97</td>
<td>129.4</td>
<td>157</td>
<td>77</td>
<td>101.4</td>
<td>132</td>
<td>57.25</td>
<td>1.75</td>
<td>0</td>
<td>75</td>
<td>1</td>
</tr>
</tbody>
</table>

| Minimum    | 29        | 78          | 66                               | 88.0          | 112           | 59                                | 90.0          | 110           | 44.75| 1.42  | 0                             | 5                      | 1                |
| Mean       | 43.1      | 90.3        | 94.7                             | 119.0         | 141.8         | 85.1                              | 112.7         | 138.4         | 59.65| 1.71  | 35.7                          | 133.5                  | 3.6              |
| Median     | 43.5      | 88.5        | 95.0                             | 119.8         | 143.0         | 81.5                              | 108.5         | 133.0         | 61.25| 1.64  | 0                             | 130.0                  | 3.5              |
| Maximum    | 49        | 116         | 117                              | 143.7         | 168           | 109                               | 136.7         | 167           | 70.25| 2.23  | 140                           | 420                    | 7                |

Where:

- \( \text{Obs}_T \) is the observed oxygen “run out” time via the SCSR unit.
- \( \text{Obs}_vO₂ \) is the observed oxygen consumption using 100 litres divided by \( \text{Obs}_T \).
### Table 4.2 Summary of Elouera Colliery trials

<table>
<thead>
<tr>
<th>Subject ID</th>
<th>Age (yrs)</th>
<th>Weight (kg)</th>
<th>Heart Rate on Day 1 (HR1)</th>
<th>Heart Rate on Day 2 (HR2)</th>
<th>ObsT (min)</th>
<th>ObsVO2 (litres/min)</th>
<th>Consumption of Cigarettes (g/wk)</th>
<th>Consumption of Alcohol (g/wk)</th>
<th>Exercise Ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>51</td>
<td>76</td>
<td>91 (bpm) 116.3 (bpm) 130</td>
<td>N/A N/A N/A</td>
<td>64.00</td>
<td>1.56</td>
<td>0</td>
<td>360</td>
<td>2</td>
</tr>
<tr>
<td>12</td>
<td>57</td>
<td>69</td>
<td>71 (bpm) 102.1 (bpm) 118</td>
<td>71 (bpm) 105.8 (bpm) 127</td>
<td>75.50</td>
<td>1.32</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>13</td>
<td>50</td>
<td>78</td>
<td>81 (bpm) 109.9 (bpm) 132</td>
<td>111 (bpm) 124.0 (bpm) 135</td>
<td>64.50</td>
<td>1.55</td>
<td>0</td>
<td>60</td>
<td>5</td>
</tr>
<tr>
<td>14</td>
<td>51</td>
<td>89</td>
<td>86 (bpm) 108.0 (bpm) 124</td>
<td>101 (bpm) 111.1 (bpm) 127</td>
<td>58.50</td>
<td>1.71</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>15</td>
<td>36</td>
<td>83</td>
<td>74 (bpm) 98.9 (bpm) 111</td>
<td>73 (bpm) 106.7 (bpm) 123</td>
<td>63.00</td>
<td>1.59</td>
<td>0</td>
<td>540</td>
<td>7</td>
</tr>
<tr>
<td>16</td>
<td>42</td>
<td>77</td>
<td>114 (bpm) 128.3 (bpm) 137</td>
<td>110 (bpm) 135.7 (bpm) 147</td>
<td>63.00</td>
<td>1.59</td>
<td>0</td>
<td>360</td>
<td>2</td>
</tr>
<tr>
<td>17</td>
<td>51</td>
<td>72</td>
<td>81 (bpm) 100.4 (bpm) 113</td>
<td>76 (bpm) 105.4 (bpm) 120</td>
<td>72.00</td>
<td>1.39</td>
<td>0</td>
<td>180</td>
<td>3</td>
</tr>
<tr>
<td>18</td>
<td>45</td>
<td>66</td>
<td>87 (bpm) 109.2 (bpm) 124</td>
<td>90 (bpm) 118.7 (bpm) 162</td>
<td>78.00</td>
<td>1.28</td>
<td>0</td>
<td>220</td>
<td>3</td>
</tr>
<tr>
<td>19</td>
<td>46</td>
<td>80</td>
<td>83 (bpm) 108.0 (bpm) 121</td>
<td>78 (bpm) 106.7 (bpm) 117</td>
<td>69.25</td>
<td>1.44</td>
<td>0</td>
<td>150</td>
<td>6</td>
</tr>
</tbody>
</table>

Minimum: 36 66 71 98.9 111 71 105.4 117 58.50 1.28 0 0 2

Mean: 47.7 76.7 85.3 109.0 123.3 88.8 114.3 132.3 67.53 1.49 0 207.8 4.2

Median: 50.0 77.0 83.0 108.0 124.0 84.0 108.9 127.0 64.50 1.55 0 180.0 4.0

Maximum: 57 89 114 128.3 137 111 135.7 162 78.00 1.71 0 540 7

Where:

- ObsT is the observed oxygen “run out” time via the SCSR unit.
- ObsVO2 is the observed oxygen consumption using 100 litres divided by ObsT.
Table 4.3 Summary of Myuna Colliery trials

<table>
<thead>
<tr>
<th>Subject ID</th>
<th>Age (yrs)</th>
<th>Weight (kg)</th>
<th>Heart Rate on Day 1 (HR₁)</th>
<th>Heart Rate on Day 2 (HR₂)</th>
<th>ObsT (min)</th>
<th>ObsVO₂ (litres/min)</th>
<th>Consumption of</th>
<th>Exercise Ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Minimum</td>
<td>Average</td>
<td>Maximum</td>
<td>Minimum</td>
<td>Average</td>
<td>Maximum</td>
</tr>
<tr>
<td>20</td>
<td>45</td>
<td>85</td>
<td>73</td>
<td>109.6</td>
<td>134</td>
<td>83</td>
<td>110.5</td>
<td>137</td>
</tr>
<tr>
<td>21</td>
<td>30</td>
<td>78</td>
<td>68</td>
<td>101.6</td>
<td>140</td>
<td>79</td>
<td>108.9</td>
<td>145</td>
</tr>
<tr>
<td>22</td>
<td>35</td>
<td>77</td>
<td>96</td>
<td>125.4</td>
<td>152</td>
<td>96</td>
<td>127.1</td>
<td>154</td>
</tr>
<tr>
<td>23</td>
<td>47</td>
<td>91</td>
<td>102</td>
<td>126.7</td>
<td>155</td>
<td>107</td>
<td>130.8</td>
<td>171</td>
</tr>
<tr>
<td>24</td>
<td>37</td>
<td>72</td>
<td>68</td>
<td>98.6</td>
<td>126</td>
<td>77</td>
<td>104.8</td>
<td>128</td>
</tr>
<tr>
<td>25</td>
<td>42</td>
<td>76</td>
<td>113</td>
<td>130.2</td>
<td>147</td>
<td>130</td>
<td>140.3</td>
<td>156</td>
</tr>
<tr>
<td>26</td>
<td>38</td>
<td>92</td>
<td>75</td>
<td>100.2</td>
<td>128</td>
<td>74</td>
<td>98.6</td>
<td>129</td>
</tr>
<tr>
<td>27</td>
<td>41</td>
<td>87</td>
<td>70</td>
<td>107.8</td>
<td>166</td>
<td>56</td>
<td>110.1</td>
<td>143</td>
</tr>
<tr>
<td>28</td>
<td>32</td>
<td>115</td>
<td>81</td>
<td>123.2</td>
<td>163</td>
<td>85</td>
<td>119.7</td>
<td>162</td>
</tr>
</tbody>
</table>

| Minimum    |           |             | 30      | 72      | 68      | 98.6   | 126     | 56      | 98.6   | 128     | 49.00   | 1.47    | 0       | 0                  | 2              |               |
| Mean       | 38.6      | 85.9        | 82.9    | 113.7   | 145.7   | 87.4   | 116.8  | 147.2   | 60.39   | 1.68    | 0       | 88.9                | 3.0             |               |
| Median     | 38.0      | 85.0        | 75.0    | 109.6   | 147.0   | 83.0   | 110.5  | 145.0   | 63.50   | 1.57    | 0       | 60.0                | 3.0             |               |
| Maximum    | 47        | 115         | 113     | 130.2   | 166     | 130    | 140.3  | 171     | 68.25   | 2.04    | 0       | 160                | 5              |               |

Where:

- ObsT is the observed oxygen “run out” time via the SCSR unit.
- ObsVO₂ is the observed oxygen consumption using 100 litres divided by ObsT.
### Table 4.4 Summary of Crinum Colliery trials

<table>
<thead>
<tr>
<th>Subject ID</th>
<th>Age (yrs)</th>
<th>Weight (kg)</th>
<th>Heart Rate on Day 1 (HR₁)</th>
<th>Heart Rate on Day 2 (HR₂)</th>
<th>Obsᵀ</th>
<th>ObsVO2</th>
<th>Consumption of</th>
<th>Exercise Ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Minimum (bpm)</td>
<td>Average (bpm)</td>
<td>Maximum (bpm)</td>
<td>Minimum (bpm)</td>
<td>Average (bpm)</td>
<td>Maximum (bpm)</td>
</tr>
<tr>
<td>29</td>
<td>29</td>
<td>31</td>
<td>96</td>
<td>92</td>
<td>125.9</td>
<td>156</td>
<td>75</td>
<td>108.9</td>
</tr>
<tr>
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<td>30</td>
<td>36</td>
<td>94</td>
<td>125</td>
<td>164.8</td>
<td>200</td>
<td>126</td>
<td>147.8</td>
</tr>
<tr>
<td>31</td>
<td>31</td>
<td>32</td>
<td>83</td>
<td>82</td>
<td>114.0</td>
<td>141</td>
<td>79</td>
<td>114.5</td>
</tr>
<tr>
<td>32</td>
<td>32</td>
<td>39</td>
<td>130</td>
<td>94</td>
<td>131.1</td>
<td>169</td>
<td>80</td>
<td>109.0</td>
</tr>
<tr>
<td>33</td>
<td>33</td>
<td>38</td>
<td>88</td>
<td>85</td>
<td>107.9</td>
<td>133</td>
<td>81</td>
<td>102.2</td>
</tr>
<tr>
<td>34</td>
<td>34</td>
<td>27</td>
<td>77</td>
<td>92</td>
<td>123.4</td>
<td>156</td>
<td>79</td>
<td>109.2</td>
</tr>
<tr>
<td>35</td>
<td>35</td>
<td>30</td>
<td>84</td>
<td>89</td>
<td>125.5</td>
<td>162</td>
<td>90</td>
<td>110.1</td>
</tr>
<tr>
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<td>36</td>
<td>33</td>
<td>74</td>
<td>92</td>
<td>124.5</td>
<td>157</td>
<td>83</td>
<td>120.8</td>
</tr>
<tr>
<td>37</td>
<td>37</td>
<td>33</td>
<td>77</td>
<td>100</td>
<td>129.6</td>
<td>156</td>
<td>93</td>
<td>115.5</td>
</tr>
<tr>
<td>Minimum</td>
<td>27</td>
<td>74</td>
<td>82</td>
<td>107.9</td>
<td>133</td>
<td>75</td>
<td>102.2</td>
<td>123</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>33.2</strong></td>
<td><strong>89.2</strong></td>
<td><strong>94.6</strong></td>
<td><strong>127.4</strong></td>
<td><strong>158.9</strong></td>
<td><strong>87.3</strong></td>
<td><strong>115.3</strong></td>
<td><strong>144.4</strong></td>
</tr>
<tr>
<td>Median</td>
<td>33.0</td>
<td>84.0</td>
<td>92.0</td>
<td>125.5</td>
<td>156.0</td>
<td>81.0</td>
<td>110.1</td>
<td>143.0</td>
</tr>
<tr>
<td>Maximum</td>
<td>39</td>
<td>130</td>
<td>125</td>
<td>164.8</td>
<td>200</td>
<td>126</td>
<td>147.8</td>
<td>184</td>
</tr>
</tbody>
</table>

Where:
- Obsᵀ is the observed oxygen "run out" time via the SCSR unit.
- ObsVO2 is the observed oxygen consumption using 100 litres divided by Obsᵀ.

41
4.2 Classification of the Miners' Heart Rates

The classification of the miners' heart rate data was implemented by the following four steps:

1) Preprocessing of the heart rate data.
2) Wavelet selection.
3) Decomposition of the heart rate and extraction of feature vectors.
4) Classification of feature vectors.

The implementation procedure is summarized in Table 4.5 with the application software.

<table>
<thead>
<tr>
<th>Step</th>
<th>Scope</th>
<th>Tasks</th>
<th>Application Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Data preprocessing</td>
<td>Original ASCII file is converted to &quot;<em>.txt&quot; and &quot;</em>.mat&quot; format files for MATLAB software.</td>
<td>Microsoft Excel; MATLAB.</td>
</tr>
<tr>
<td>2</td>
<td>Wavelet selection</td>
<td>Using the &quot;*.mat&quot; select the appropriate wavelet to decompose the miners' heart rates</td>
<td>MATLAB (Wavelet tool box)</td>
</tr>
<tr>
<td>3</td>
<td>Decomposition of the heart rate and extraction of feature vectors</td>
<td>Using the &quot;*.txt&quot; file of the heart rate data, code MATLAB m-files to decompose the heart rates and extract the feature vectors.</td>
<td>MATLAB</td>
</tr>
<tr>
<td>4</td>
<td>Classifying the feature vectors</td>
<td>Use a classifier to divide the feature vectors into different groups.</td>
<td>Microsoft C++</td>
</tr>
</tbody>
</table>

The details for the above four steps are discussed below:

**Step 1: Data Preprocessing**

The data-preprocessing phase involves converting the original heart rate data to a text file using Microsoft Excel. The 37 heart rates were in the spread sheet column.
Classification of the Miners' Heart Rates

per subject and saved as one *.txt file. Each column of the text file was further saved as a MATLAB *.mat binary file using MATLAB software (mat-file hr_1 contained information for subject 1 etc.).

Step 2: Wavelet Selection

Wavelets and multiresolution analysis were discussed in Chapter 2 of this thesis. In practice, there are different families of wavelets which may suit different processes. Among the wavelet families considered were Haar, Daubechies, Biorthogonal, Coiflets, Symlet, Morlet, Mexican Hat and Meyer.

The following steps were adopted in determining the suitable wavelet for the miners' heart rates:

1) Load MATLAB and at MATLAB prompt, type "wavemenu" (plus enter key) to load wavelet toolbox.

```
>> wavemenu
```

and the Wavelet Toolbox Main Menu appears (Fig. 4.2).

![Wavelet Toolbox Main Menu](image)

Fig. 4.2: Wavelet toolbox main menu
2) From Wavelet Toolbox Main Menu (Fig. 4.2), click the Wavelet 1-D menu item because the heart rate data is in 1-D domain. The discrete wavelet analysis tool for one-dimensional signal data appears.

3) From the File menu (Fig. 4.3), choose the Load signal option. When the Load Signal dialog box appears, select one of the "*.mat" files (e.g. hr_1 for subject 1). Click the Open button to display the analysis window (Fig. 4.4).

4) In the upper right portion of the Wavelet 1-D tool menu (Fig. 4.4), select a wavelet and the number of levels for decomposition (e.g. Haar, level 5). The level number represents the number of subband components for decomposition of the signal in detail levels. MATLAB provides one to eight (1-8) levels for the multiresolution of the signal. In this thesis, five (5) levels were used for decomposition of the heart rate. Click the Analyze button. After a few seconds MATLAB displays the decomposition levels of the original signal (Fig. 4.5).
Classification of the Miners' Heart Rates

Fig. 4.4: Wavelet 1-D analysis window

Fig. 4.5: Decomposition of the subject No. 1 data using Haar Wavelet
5) Print a hard copy of the multiresolution of the heart rates for visual analysis.

The above procedures were repeated for Haar, db4, bior2.2, coiflet3 and symlet4 wavelets for each of the 37 heart rates.

Fig. 4.5 through Fig. 4.9 show the typical decompositions of the heart rates of subject 1 using Haar, db4, bior2.2, coiflet3 and symlet4 wavelets. The numbers 4, 2.2, 3 and 4 in wavelet window indicate the order of filters.
Fig. 4.7: Decomposition of the subject No. 1 data using bior2.2 wavelet

Fig. 4.8: Decomposition of the subject No. 1 data using coiflet3 wavelet
6) Wavelet selection
Since this thesis deals with finite data sets, the wavelets with compact support might be preferred. According to Graps (1995), Kocur et al (1996) and Ogden (1997), the adopted wavelet should have smoothness and symmetry properties. Daubechies (1992) introduced a family of wavelets that are not only orthonormal, but also have compact support. The development of the Daubechies wavelet family made a profound impact, and these wavelets are used extensively in practice.

After a visual comparison among the wavelet decomposition outputs, the wavelet of Daubechies 4 (db4) was found to have "reasonable smoothness and symmetry" properties in the decomposition graphs. In this thesis, the db4 wavelet was selected for decomposing and extracting the features of the miners' heart rate data.
Step 3: Decomposition of the Heart Rate and Extraction of Feature Vectors

MATLAB functions "WAVEDEC" and "WRCOEF" were used to decompose the time series data of the miners' heart rates.

"WAVEDEC" is a multi-level 1-D wavelet decomposition function with the syntax:

\[ [C, L] = \text{WAVEDEC}(X, N, 'wname') \]

where,

- \text{WAVEDEC}: function name.
- \(X\): signal name, or input-file name.
- \(N\): decomposition level, strictly positive \(N\) is required.
- \(C\): decomposition output vector.
- \(L\): the bookkeeping output vector.

\text{WRCOEF} is a reconstruction function from the coefficients of a 1-D signal. \text{WRCOEF} computes the vector of reconstructed coefficients, based on the wavelet decomposition output \([C, L]\) of \text{WAVEDEC}, at level \(N\). The syntax of \text{WRCOEF} is

\[ X = \text{WRCOEF}('type', C, L, 'wname', N) \]

where,

- \('wname\)': a string containing the name of the wavelet.
- \('type\)': whether approximation (\('type' = 'a'\)) or detail (\('type' = 'd'\)) coefficients to be reconstructed.
  - When \('type' = 'a'\), \(N\) is allowed to be 0, otherwise
- \(N\): Level \(N\) must be an integer such that \(N \leq \text{length}(L)-2\).
- \(C\): decomposition vector.
- \(L\): the bookkeeping vector.
The extraction of the feature vectors was implemented with MATLAB software. MATLAB also provides various intrinsic functions and options to create user's m-file functions.

The five feature vectors extracted from the decomposed heart rates were:
1) Entropy, 2) Energy and Mean Value, 3) Acceleration, 4) Zero-Crossing, and 5) Peak Value.

1) Extracting entropy
For the calculation of entropy, the MATLAB function "wentropy" was used. The syntax of the function is:

\[
\text{Entropy} = \text{wentropy}(X, T, P)
\]

where,

\[
\text{Entropy} = \text{the output entropy of the vector or matrix input } X.
\]

In both cases, output Entropy is a real number.

\[
T \text{ is a string containing the type of entropy:}
\]

- T = 'shannon', 'threshold', 'norm', 'log energy', 'sure', 'user'

\[
P \text{ is an optional parameter depending on } T \text{ value:}
\]

- If T = 'shannon' or 'log energy', P is not used.
- If T = 'threshold' or 'sure', P is the threshold and must be a positive number.
- If T = 'norm', P is the power and must be such that \(1 \leq P < 2\).
- If T = 'user', P is a string containing the M-file name of the user's entropy function, with a single input parameter X.

In this thesis, the 'shannon' wentropy function was used to calculate the feature vector of "entropy" of the heart rates.
2) Extracting Energy and Mean Value

The energy of time series data is given by the Equation 4.1

\[
E_{nergy} = \sum_{i=1}^{N} x_i^2
\]  \hspace{1cm} (4.1)

where

\( x_i \) is the reconstruction signal of a level of approximation, or a level of detail.

The calculation of the signal's energy uses the algorithm of multiplication of matrices, that is, the transpose of the \( n \times 1 \) column matrix multiplying the \( n \times 1 \) row matrix equals to a scalar, or a real value. The real value is the energy of the heart rate data.

The extraction of the mean value of the heart rate data uses the MATLAB function "mean (X)", \( X \) is the vector of \( x_i, i = 1 \ldots N \).

3) Extracting Acceleration

In this thesis, the variation times of the waveform of the heart rate data were obtained by a window (Fig. 4.10) of a definite duration and computed as follows:

![Acceleration definition](image)

**Fig. 4.10: Acceleration definition**
In Fig. 4.10, the window width $k$ is the interval between signal $x_i$ and signal $x_{i+k}$, $x_i$ is the reconstruction signal of approximation or details,

- if $x_{i+k} - x_i \geq dv$
  
  where,

$dv$ was a predefined value (e.g. $dv=10$ bpm),

then there is an acceleration.

- Count up the acceleration, and move the window to the position between signal $x_{i+k}$ and signal $x_{i+2k}$.

- If $x_{i+k} - x_i < dv$, there is no acceleration. The window is moved forward to the position between signal $x_{i+k}$ and $x_{i+2k}$.

- Continue the judgement in the new window until the window is moved to the end of the signal.

4) Extracting Zero-Crossing

The algorithm used to extract the feature of zero-crossing from the detail levels of multiresolution is based on the signs of the product $x_{i+j} \cdot x_i$ ($x_i$ is the reconstruction signal of the level $j$ details, $j = 1, 2, \ldots, 5$).

If $x_{i+j} \cdot x_i \leq 0$ then a zero-crossing appears. If $x_{i+j} \cdot x_i > 0$, there is no zero-crossing.

This is illustrated in Fig. 4.11. In Fig. 4.11, $x_1 \cdot x_2 < 0$, therefore there is a zero-crossing, and $x_3 \cdot x_4 > 0$, and there is no zero-crossing.

![The reconstruction signal $x$ of level $j$ detail versus amplitude](image)

**Fig. 4.11: The reconstruction signal $x$ of level $j$ detail versus amplitude**
5) Extracting Peak-Value and Location

The m-function "pickpeak.m" was used to extract the feature vector of the peak-value and it's location (refer to Fig. 4.5).

The "pickpeak.m" function outputs the top N peak values and their location in each subband level.

Below is the algorithm of the function "pickpeak.m":

1. In a reconstruction signal of a subband level (approximation or detail), let \( \text{Max} = x_1 \).
2. Compare the Max with the next signal \( x_2 \), if \( x_2 > \text{Max} \), then let \( \text{Max} = x_2 \), otherwise, Max is still the \( x_1 \).
3. Repeat the above until the end of the series.

The m-file for extracting the above feature vectors is listed in Appendix A-1.

The total feature vectors extracted from the sublevel signal were reorganized up to 9 files (Appendix B). Each file contained 5 feature vectors per line (one line represented one subject, that is, total of 37 lines). In feature vector files, the first 4 columns were the same, only the column 5 (e.g. zcross_d1) is changed to some other feature vector in order to be read by the classification program. Table 4.6 is part of the final results of the feature vectors.

Table 4.6 The composition of the feature vectors in an Excel file

<table>
<thead>
<tr>
<th>Subject No.</th>
<th>energy_a5</th>
<th>entropy_a5</th>
<th>mean_a5</th>
<th>acceleration_a5</th>
<th>zcross_d1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2294191.42</td>
<td>25970.63</td>
<td>86.57</td>
<td>10</td>
<td>200</td>
</tr>
<tr>
<td>2</td>
<td>5989657.33</td>
<td>42009.09</td>
<td>140.03</td>
<td>17</td>
<td>214</td>
</tr>
<tr>
<td>3</td>
<td>4335528.82</td>
<td>35725.04</td>
<td>119.08</td>
<td>13</td>
<td>208</td>
</tr>
<tr>
<td>4</td>
<td>4238353.36</td>
<td>35306.55</td>
<td>117.69</td>
<td>11</td>
<td>194</td>
</tr>
<tr>
<td>5</td>
<td>4141383.88</td>
<td>34974.80</td>
<td>116.58</td>
<td>11</td>
<td>202</td>
</tr>
<tr>
<td>6</td>
<td>5367465.41</td>
<td>39794.64</td>
<td>132.65</td>
<td>19</td>
<td>202</td>
</tr>
<tr>
<td>7</td>
<td>3347499.35</td>
<td>31464.26</td>
<td>104.88</td>
<td>10</td>
<td>200</td>
</tr>
</tbody>
</table>
Step 4: Feature Vectors Classification

In this thesis, a statistical classification program (Ogunbona, 1998) based on the LBG algorithm was used for classification of feature vectors. The source code of the C program is listed in Appendix A-2.

The methodology of the classification system is based on the LBG algorithm (see section 3.4).

The classification system is composed of three parts, they are:

1) Generate training set,
2) Generate and train a codebook,
3) Classify the feature vectors.

1) Generate training set
This is the first part of the classification system. It is used for generating a binary file of training vectors to be used in the LBG algorithm. The training vectors, or the training set, contain a collection of pattern representatives.

At the DOS prompt, the user types:

"D:\> gen_training_set files.txt train.set"

where, the “files.txt” contains the names of feature vectors files (one per line) which act as training samples. The feature vector files are the output from Step 3 (page 58) that is, the step "Decomposition of the Heart Rate and Extraction of Feature Vectors".
Generated text files are:

features1.txt
features2.txt
features3.txt
features4.txt
features5.txt
features6.txt
features7.txt
features8.txt
features9.txt

A sample of the feature vector file is shown in Table 4.6.

The "train.set" is the output file, which is used to train codebook by lbg_codebook in the next phase.

2) Generate and train a codebook

The second part of the classification system is the "lbg_codebook" program. It is used for generating and training the codebook. The codebook is called the reference pattern or template. The size of the codebook is also called the number of groups or classes.

The procedure is discussed as followings:

(i) Create a codebook.

(ii) Open the training set file, or train.set, and create a linked list of training vectors. The organization of the data set into a linked list reduces the overhead in traversing the training file several times for processing.

(iii) Initialize the codebook by using a small set of feature vectors.

(iv) Start LBG algorithm iteration: find the optimum partition based on the current codebook; compute the overall distortion resulting from this partition; if the percentage decrease in distortion is not good enough upgrade the codebook. Average the codebook to obtain the updated centroids.

(v) Write the final codebook to text file.

At DOS prompt type the following to execute the lbg_codebook program:
where, the "train.set" is the name of the input file containing the training set (the output from step one).

the "5" is the size of the feature vector used in this thesis.

the "initial.txt" is the name of the text file which contains the codebook. In this thesis, the "initial.txt" file was created by extracting some of the feature lines from any result file from step 3 (see Table 4.6).

the "4" is the size of the codebook or groups to be classified for the feature vectors, which can be changed to be any positive number.

3) Classify the feature vectors

The third part of the classification system is to execute the "classify" program. It is used for classifying each feature vector into a proper pattern class. The user supplies a text file containing a trained codebook and another text file of vectors to be classified. The program returns a text file containing the vectors and their classes.

This phase follows the following steps:

(i) Build and maintain the codebook internally.

(ii) Build data buffer (get the size of the feature vectors).

(iii) Classify the feature vectors.

Output the classification results to a text file.

To execute the classification program, type the following command at DOS prompt:

D:\>classify initial.txt 4 5 result2.txt 37 output.txt

where, the "classify" is the classification tool for feature vectors,

the "initial.txt" is the same with the second part of the program package,

the "4" is the size of the codebook or groups to be classified.
Classification of the Miners' Heart Rates

the "5" is the feature vector size.

the "result2.txt" is one of the feature vector files to be classified,

the "37" is the feature vector numbers (in this thesis, there are 37 subjects), the "output.txt" is the output file which contains the result of the classification and their feature vectors.

Part of the result of the classification, which has been reorganised in Table 4.7, is shown in the following:

Class: 1
2294191.500000 25970.630859 86.570000 10.000000 29.000000

Class: 4
5989657.500000 42009.089844 140.029999 17.000000 29.000000

Class: 3
4335529.000000 35725.039062 119.080002 13.000000 29.000000

Class: 2
4238353.500000 35306.550781 117.690002 11.000000 27.000000

Class: 2
4141384.000000 34974.800781 115.800003 17.000000 27.000000

Class: 4
5367465.500000 39794.640625 132.649994 19.000006 25.000000

Class: 2
3347499.250000 31464.259766 104.879997 10.000000 27.000000

Class: 2
4098166.250000 34740.148438 115.80003 17.000000 27.000000
Table 4.7 The classification result of the miners' heart rates

<table>
<thead>
<tr>
<th>subject ID</th>
<th>Work Place</th>
<th>Age (yrs)</th>
<th>Weight (kg)</th>
<th>Classification</th>
<th>Obst</th>
<th>Obs vo2</th>
<th>min/100 lrs</th>
<th>liter/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>South-Bulli</td>
<td>47</td>
<td>84</td>
<td>1</td>
<td>70.25</td>
<td>1.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>South-Bulli</td>
<td>40</td>
<td>116</td>
<td>4</td>
<td>44.75</td>
<td>2.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>South-Bulli</td>
<td>38</td>
<td>78</td>
<td>3</td>
<td>65.25</td>
<td>1.53</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>South-Bulli</td>
<td>49</td>
<td>93</td>
<td>2</td>
<td>54.25</td>
<td>1.84</td>
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<td></td>
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<td>1.48</td>
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<td></td>
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<tr>
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<td>1.49</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>56.00</td>
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<td></td>
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<td>1.56</td>
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<td></td>
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<td>1.54</td>
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<td></td>
</tr>
<tr>
<td>25</td>
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<tr>
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<td>64.00</td>
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<td>94</td>
<td>4</td>
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<td>88</td>
<td>2</td>
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<td>77</td>
<td>3</td>
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<td>1.59</td>
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<td>35</td>
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<td>84</td>
<td>3</td>
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<td>1.96</td>
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</tr>
<tr>
<td>36</td>
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<td>58.25</td>
<td>1.72</td>
<td></td>
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<tr>
<td>37</td>
<td>Crinum</td>
<td>33</td>
<td>77</td>
<td>3</td>
<td>64.50</td>
<td>1.55</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.3 Discussion of the Classification Result

The classification result (see Table 4.6) may be summarized as follows:

A total of 37 samples of the miners' heart rates were classified into four groups.

- 18.9 percent of the total samples are in group 1.
- 37.9 percent of the total samples are in group 2.
- 32.4 percent of the total samples are in group 3.
- 10.8 percent of the total samples are in group 4.

The association between groups and oxygen consumption, body mass, age, and workplace are shown in Figs 4.12 through 4.15.

1) Group versus oxygen consumption rate

![Group versus oxygen consumption rate](image)

*Fig. 4.12: Group versus oxygen consumption rate*

Fig. 4.12 shows that

1. The group 4 members are associated with relatively higher oxygen consumption rates (minimum 1.49, maximum 2.23, average 1.91),
2. The group 1 members are characterized by relatively lower oxygen consumption rates (minimum 1.32, maximum 1.59, average 1.48).

In general, the average group oxygen consumption rate increases from group 1 through to group 4 (1.48, 1.64, 1.70, 1.91, respectively).
2) Group versus body mass

Fig. 4.13 Group versus body mass

Fig. 4.13 shows that
(1) The group 4 numbers are associated with relatively higher body masses (minimum 88, maximum 130, average 107).
(2) The group 1 numbers are associated with relatively lower body masses (minimum 69, maximum 92, average 78.57).

In general, the average group body mass also increases from group 1 to group 4 (78.57, 84.03, 84.42, 107, respectively). Groups 1 and 2 have similar body mass distributions.

3) Group versus age

Fig. 4.14: Group versus age
Classification of the Miners’ Heart Rates

Fig. 4.14 shows that

(1) The group 4 members have relatively lower average age.
(2) Group 1-3 members have wide spread age distributions.

4) Group versus Mine

![Graphs showing group distribution by mine](image)

Fig. 4.15: Group versus mine

Fig. 4.15 shows that

(1) Most of South-Bulli subjects belong to group 2.
(2) Most of Crinum subjects belong to group 3.
(3) Group 4 members were at South-Bulli and Crinum coalmines.
Chapter 5

Summary and Conclusions

5.1 Summary

The simple linear model suggested by MacKenzie-Wood et al (1997) was found inappropriate since the original heart rate data used was nonstationary. Hence, the techniques of signal processing and pattern classification have been explored in this thesis to determine the classification of the heart rates of miners during a rescue operation.

The results of the classification of miners' heart rates may be summarised as in the following:

(1) Daubechies 4 (db4) wavelet was selected to decompose the heart rates into different sub-levels. The results were further used for extracting the feature vectors.

(2) The feature vectors and their extracting methods were determined. Several feature vectors were extracted from the data of the sub-levels of the heart rates.

(3) Based on the results of the feature vectors of the heart rates, the classification result of the miners' heart rates was obtained by using the classifier based on the LBG algorithm.

(4) A discussion was made regarding the classification result of the heart rates and the field trial result of the oxygen consumption rate, and the personal related factors.

5.2 Conclusions

(1) Compared with the traditional statistics method to cope with a nonstationary process, such as the miners' heart rates during rescue operation, the techniques of
signal processing and pattern classification have proved to be suitable in analysing the nonstationary heart rates of the miners during the rescue operation.

(2) The db4 wavelet and the multiresolution technique were proven to be appropriate for analysing the nonstationary heart rates of miners in escapeway.

(3) The classification software package, based on the LBG algorithm, was successfully applied in this thesis to classify the miners' heart rates into four groups.

(4) Group 4 members are associated with relatively higher oxygen consumption rates.

5.3 Recommendations for Further Work

This thesis has produced encouraging results in spite of the limited sample size. Areas of further research are identified below:

(1) Gather more trial data of the miner's heart rates during the rescue operation.

(2) Extract more feature vectors and optimize these feature vectors by using the feature vector selection technique, which is one of the important subjects in pattern classification.

(3) Analyse the two factors (heart rate and body mass) in combining form. This is because the heart rate and the body mass affect the oxygen consumption rate at the same time.

(4) Explore the use of different pattern classification techniques to classify the miners' heart rates.
References


Appendices
APPENDIX A-1: The m-file for extracting the feature vectors

$\text{PROGRAM: calcu_features.m}$

% Revised data 06/08/1998
% AUTHOR: RUIBAO FENG

load heart.txt
for i=1:37
    [c(:,i),l(:,i)]=wavedec(heart(:,i),5,'db4');
    a5(:,i)=wrcoef('a',c(:,i),l(:,i),'db4',5);
    d1(:,i)=wrcoef('d',c(:,i),l(:,i),'db4',1);
    d2(:,i)=wrcoef('d',c(:,i),l(:,i),'db4',2);
    d3(:,i)=wrcoef('d',c(:,i),l(:,i),'db4',3);
    d4(:,i)=wrcoef('d',c(:,i),l(:,i),'db4',4);
    d5(:,i)=wrcoef('d',c(:,i),l(:,i),'db4',5);
end

%%%%%%%%%%%%%%%%%%%%%%%
% calcu entropy of signals
%%%%%%%%%%%%%%%%%%%%%%%

% en_shannon_aj(i): the entropy of the i'th detail signals at level j with entropy type of 'shannon'
for i=1:37
    en_shannon_a5(i)=wentropy(a5(:,i),'shannon');
end

entropy=en_shannon_a5;
fid=fopen('entropy_a5.txt','w');
fprintf(fid,'%8.2f\n',entropy);
status=fclose(fid);

%%%%%%%%%%%%%%%%%%%%%%%
% calculate the energy and mean value of a5
%%%%%%%%%%%%%%%%%%%%%%%
for i=1:37
    energy_a5(:,i) = a5(:,i)'*a5(:,i);
    mean_a5(:,i) = mean(a5(:,i));
end

fid=fopen('mean_a5.txt','w');
fprintf(fid,'%12.2f\n',mean_a5);
status=fclose(fid);

% calculate energy and mean value of d5
fid = fopen('energy_a5.txt','w');
fprintf(fid,'%12.2f\n',energy_a5);
status=fclose(fid);
% Calculate the acceleration of heart rate a5
v=10;
% v is the variability between the signal a5(k+9,i) and a5(k,i).
for i=1:37
    acce_a5(i)=0;
    for k=1:291
        if (a5(k+9,i)-a5(k,i)) >= v
            acce_a5(i)=acce_a5(i)+1;
            k=k+10;
        end
    end
acce_a5(i)=acce_a5(i)+1;
end
accel = acce_a5';
fid = fopen('acceleration.txt', 'w');
fprintf(fid, '%8.0f
', accel);
status=fclose(fid);

% calculate the zero crossing numbers of signal series
% for i=1:37
    nd1(i)=0; nd2(i)=0; nd3(i)=0; nd4(i)=0; nd5(i)=0;
    % ndk(i) are the zero-crossing number in k level of subject i data
    for j=1:300-1
        if d1(j,i)*d1(j+1,i)<=0
            nd1(i)=nd1(i)+1;
        end
        if d2(j,i)*d2(j+1,i)<=0
            nd2(i)=nd2(i)+1;
        end
        if d3(j,i)*d3(j+1,i)<=0
            nd3(i)=nd3(i)+1;
        end
        if d4(j,i)*d4(j+1,i)<=0
            nd4(i)=nd4(i)+1;
        end
        if d5(j,i)*d5(j+1,i)<=0
            nd5(i)=nd5(i)+1;
        end
    end
end
zero_crossing=[nd1' nd2' nd3' nd4' nd5'];
% zero_crossing=zero_crossing';
fid = fopen('zero_crossing_d1_d5.txt', 'w');
fprintf(fid, '%12.2f%12.2f%12.2f%12.2f%12.2f\n', zero_crossing);
status=fclose(fid);

% pick up the peak values and location
% nb: the number of top peaks to be calculated.
nb=5;
for i=1:37
    [loc_a5(:,i),val_a5(:,i)]=pickpeak(a5(:,i),nb,3);
    [loc_1(:,i),val_1(:,i)]=pickpeak(d1(:,i),nb,3);
    [loc_2(:,i),val_2(:,i)]=pickpeak(d2(:,i),nb,3);
    [loc_3(:,i),val_3(:,i)]=pickpeak(d3(:,i),nb,3);
    [loc_4(:,i),val_4(:,i)]=pickpeak(d4(:,i),nb,3);
    [loc_5(:,i),val_5(:,i)]=pickpeak(d5(:,i),nb,3);
    ya5(:,i)=sort(loc_a5(:,i));
    y1(:,i)=sort(loc_1(:,i));
    y2(:,i)=sort(loc_2(:,i));
    y3(:,i)=sort(loc_3(:,i));
    y4(:,i)=sort(loc_4(:,i));
    y5(:,i)=sort(loc_5(:,i));
    for j=1:nb-1
        dis_dlp(j,i)=y1(j+1,i)-y1(j,i);
        dis_d2p(j,i)=y2(j+1,i)-y2(j,i);
        dis_d3p(j,i)=y3(j+1,i)-y3(j,i);
        dis_d4p(j,i)=y4(j+1,i)-y4(j,i);
        dis_d5p(j,i)=y5(j+1,i)-y5(j,i);
    end
    dis_dlp(nb,i)=0;
    dis_d2p(nb,i)=0;
    dis_d3p(nb,i)=0;
    dis_d4p(nb,i)=0;
    dis_d5p(nb,i)=0;
    for k=1:nb
        for j=1:nb
            if y1(k,i)==loc_1(j,i)
                re_val_1(k,i)=val_1(j,i);
            end
            if y2(k,i)==loc_2(j,i)
                re_val_2(k,i)=val_2(j,i);
            end
            if y3(k,i)==loc_3(j,i)
                re_val_3(k,i)=val_3(j,i);
            end
            if y4(k,i)==loc_4(j,i)
                re_val_4(k,i)=val_4(j,i);
            end
            if y5(k,i)==loc_5(j,i)
                re_val_5(k,i)=val_5(j,i);
            end
        end
        k=3*(i-1)+1;
    end
    disp1(:,k:k+2)=[y1(:,i),dis_dlp(:,i),re_val_1(:,i)];
    disp2(:,k:k+2)=[y2(:,i),dis_d2p(:,i),re_val_2(:,i)];
    disp3(:,k:k+2)=[y3(:,i),dis_d3p(:,i),re_val_3(:,i)];
    disp4(:,k:k+2)=[y4(:,i),dis_d4p(:,i),re_val_4(:,i)];
    disp5(:,k:k+2)=[y5(:,i),dis_d5p(:,i),re_val_5(:,i)];
end
%%
value3=[val_1(3,:) ' val_2(3,:) ' val_3(3,:) ' val_4(3,:) ' val_5(3,:)];
value3_verse=value3';
value3_pos=[loc_1(3,:) ' loc_2(3,:) ' loc_3(3,:) ' loc_4(3,:) ' loc_5(3,:)];
value4=[val_1(4,:) ' val_2(4,:) ' val_3(4,:) ' val_4(4,:) ' val_5(4,:)];
value4_pos=[loc_1(4,:) ' loc_2(4,:) ' loc_3(4,:) ' loc_4(4,:) ' loc_5(4,:)];

value_aS=[val_aS(1,:) ' val_aS(2,:) ' val_aS(3,:) ' val_aS(4,:) ' val_aS(5,:)];

fid=fopen('peak_loc_a5.txt', 'w');
fprintf(fid, ' % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f
', value_a5');
status=fclose(fid);

fid=fopen('peak_loc_d1.txt', 'w');
fprintf(fid, ' % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f
', value_d1');
status=fclose(fid);

fid=fopen('peak_loc_d2.txt', 'w');
fprintf(fid, ' % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f
', value_d2');
status=fclose(fid);

fid=fopen('peak_loc_d3.txt', 'w');
fprintf(fid, ' % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f
', value_d3');
status=fclose(fid);

fid=fopen('peak_loc_d4.txt', 'w');
fprintf(fid, ' % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f % 8.2f
', value_d4');
status=fclose(fid);
fid=fopen('peak_loc_d5.txt','w');
fprintf(fid,’%0.2f%0.2f%0.2f%0.2f%0.2f%0.2f%0.2f%0.2f%0.2f
’,
value_d5’);
status=fclose(fid);

function [loc,val]=pickpeak(spec, npicks, rdiff)
%PICKPEAK Picks peaks
%spec--data vector or matrix
%npicks--number of peaks desired [default=2]
%rdiff--minimum spacing between picked peaks [default=5]
%loc--vector of locations (indices) of the picked peaks
%val--vector corresponding valueS
%A 0 in location (i,j) of array loc (or a NaN in array val)
%indicates that the j-th data vector has less than i peaks
%with a separation of rdiff or more
%-----------parapeter checks-----
if (exist('rdiff') ~=1) rdiff=5; end
if (exist('npicks')~=1) npicks=2; end
%--------convert row vectors to col vectors
[mrows,ncols] = size(spec);
if (mrows==1) mrows=ncols; ncols=1; spec=spec(:); end
%-----edit out NaNs and Infs------
good=find (finite(spec));
rmin=min(spec(good))-1;
bad =find(-finite(spec));
if (~isempty(bad))
spec(bad) = ones(size(bad))*rmin;
end
%----find a peak, zero out the data around the peak, and repeat
for k=1:ncols
    dx=diff([rmin;spec(:,k);rmin]);
    lp=find(dx(1:mrows) >=0 ... & dx(2:mrows+l) <=0);
    vp =spec(lp,k);
    for p=1:npicks
        [v,l]=max(vp);
        loc(p,k)=l;p(1);
        ind=find(abs(l-1-l)>rdiff);
        if (~isempty(ind))
            break
        end
        vp=vp(ind);
        l=l(ind);
    end
end
%% end of the program
APPENDIX A-2: C++ programs for Feature Vectors Classification

/*
PROGRAM: gen_training_set.c
VERSION: 1.0 (March 1998)
AUTHOR: Philip Ogunbona
124 Carters Lane
Fairy Meadow 2519

DESCRIPTION: The program generates a binary file of training vectors for use by the LBG algorithm.

USAGE: gen_training_set [text file listing files to be processed] [output file] Example::> gen_training_set files.txt train.set
*/
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <math.h>
void usage(void);

int main (int argc, char *argv[])
{
    char *p, file_name[30], out_file[30], text_file[30], line_buffer[80];
    int feature_vector_size = 15;
    int count;
    static FILE *file_ptr1, *file_ptr2, *file_ptr3;
    float *feature_vector;

    if(argc == 1){
        usage();
        exit(1);
    }

    strcpy(text_file, argv[1]);
    strcpy(out_file, argv[2]);

    feature_vector = (float *)calloc(feature_vector_size, sizeof(float));
    if (!feature_vector ) {
        fprintf(stderr, "Error: Unable to allocate memory \n");
        exit(1);
    }

    /* open output file for writing */
/* create the file if it does not already exist; write to it if it exists */

    file_ptr2 = fopen(out_file, "ab+");
    if(file_ptr2 == NULL) {
        fprintf(stderr, "Error opening output file : : > %s for writing.", out_file);
        exit(1);
    }

/* open the text file containing the list of files to be processed */

/* open the input file for reading*/

    file_ptr1 = fopen(text_file, "rt");
    if(file_ptr1 == NULL) {
        fprintf(stderr, "Error opening text input file : : >%s for reading.", text_file);
        exit(1);
    }

while (!feof(file_ptr1)) {

/* get a line of the file to process */

    fscanf(file_ptr1, "%s\n", file_name);
    file_ptr3 = fopen(file_name, "rt");
    if (file_ptr3 == NULL) {
        fprintf(stderr, "Error: Cannot open file file name);
        continue;
    } else {
        printf("Processing: %s\n", file_name);
        while ( !feof(file_ptr3)) {
            fgets(line_buffer, 80, file_ptr3);
            /* get the features into a vector */
            count = 0;
            p = strtok(line_buffer, ",\t");
            feature_vector[count] = (float)atof(p);
            #ifdef DEBUG
            printf("feature_vector[ %d]= %f \n",count,
                    feature_vector[count]);
            #endif
            while (p = strtok(NULL, ",\t") ){
                feature_vector[++count] = (float)atof(p);
                #ifdef DEBUG
                printf("feature_vector[ %d]= %f \n",count,
                        feature_vector[count]);
                #endif
            };
            fwrite(feature_vector, sizeof(float), count+1, file_ptr2);
        }
    }
}
fclose(file_ptr1);
fclose(file_ptr2);
free(feature_vector);
return 0;
}

void usage(void)
{
    printf("\n\ngen training set :utility program to generate
training set for use with LBG algorithm\n");
    printf("\nUSAGE: gen_training_set [text file containing file
names to be processed] [output file]\n");
    printf("\n\nExample::> gen_training_set files.txt
train.set\n\n");
    printf("files.txt contains the names of feature files (one per
line)\n");
    printf("The program assumes that the feature files have one
feature vector per line\n");
    printf("There can be as many features (separated by space, tab or
comma) as needed per line\n");
    printf("There can also be as many lines as needed per file\n");
}

*/

#define LBG_CODEBOOK.C

REFERENCE: The program is based on the algorithm contained in:

for Vector
No.1,

VERSION: 1.0
DATE: 3/98 -- (evolving)
DESCRIPTION: Program implements the LBG algorithm
AUTHOR: P. O. Ogunbona
124 Carters Lane
Fairy Meadow 2519

#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <math.h>
#include <values.h>

struct listelem{
    float *vector; /* vector of descriptors e.g pixels */
Appendices

```c
int codeword; /* the assigned codeword number */
struct listelem *next;

char buffer[80], infile[45];
int *cbk_usage;
float **codebook;
struct listelem list_head, *temp, *vector_node;
char reply, codebk_file[45];
float epsilon = 0.001, new_m_dist, old_m_dist = MAXFLOAT, buf;
float new_dist, old_dist, criterion, feature;
float *buffer2, templ;

/* function prototype */
float dist(float *vecl, float *vec2, int v_size);

int main(int argc, char **argv)
{
    FILE *file_ptr;
    int vec_size, book_size, min;
    int m, i, j, k;

    if (argc < 5) {
        printf("\n\t	LBG training algorithm by P.O.Ogunbona\n\n");
        printf("Correct Usage:\n");
        printf("lbg_codebook training_input_file feature_size,
codebook_name codebook_siz\n\n" );
        printf("training_input_file : name of input file
containing training set\n\n");
        printf("feature_size: size of the feature vector \n" );
        printf("codebook : name of text file to contain codebook
(or initial codebook)\n\n" );
        printf("codebook_siz : size of the codebook\n\n");
        exit(1);
    }

    vec_size = atoi(argv[2]);
    book_size = atoi(argv[4]);
    strcpy(codebk_file, argv[3]);
    strcpy(infile, argv[1]);

    cbk_usage = (int *)calloc(book_size, sizeof(int));
    /* keep track of cell usage */

    /* Get the training file and form a linked list.
    The training file is a binary file supplied by the user
    and can be generated by the program
    MAKE_TRAINING_SET file_list training_file
    */
```
/* Initialisation:
(1) Get all the feature vectors organised into a linked list.
(2) Initialize the codebook

The organisation of the data set into a linked list reduces the overhead in traversing the training file several times for processing.
*/

file_ptr = fopen(infile, "rb");
if( !file_ptr ){
    fprintf(stderr, "Error opening training set: %s \n", infile);
    exit(1);
}

printf("\n\nCreating a linked list of training vectors ...\n");
temp = &list_head;
while( !feof(file_ptr)){
    /* get the vec_size long feature vector*/
    buffer2 = (float *)calloc(vec_size, sizeof(float));
    if( !buffer2 ) {      
        fprintf(stderr, "Error: Cannot allocate memory.\n");
        exit(1);
    }

    fread(buffer2, sizeof(float), vec_size, file_ptr);
    vector_node = (struct listelem *)calloc(1, sizeof(struct listelem ));

    temp->next = vector_node;
    vector_node->codeword = 0;
    vector_node->vector = buffer2;
    vector_node->next = 0;
    temp = vector_node;
}
fclose(file_ptr);

fprintf(stdout, "\n\nReading in the initial codebook ...\n");
/* create codebook */

codebook = (float**)calloc(book_size, sizeof(float*));
if(!codebook){
    fprintf(stderr, "Error: Cannot allocate memory.\n");
    exit(1);
}
for ( i = 0; i < book_size; ++i) {
    codebook[i] = (float*)calloc(vec_size, sizeof(float));
    if(!codebook[i]) {
        fprintf(stderr, "Error: Cannot allocate memory.\n");
        exit(l);
    }
}
/* read initial codebook from file */

file_ptr = fopen(codebk_file, "rt");
if (!file_ptr){
    fprintf(stderr, "Error opening: %s as initial codebook\n",codebk_file);
    exit(l);
}
for ( i = 0; i < book_size; ++i){
    for(j = 0; j < vec_size; ++j) {
        fscanf(file_ptr, "%f", &codebook[i][j]);
    }
    fscanf(file_ptr, "\n");
}
fclose(file_ptr);

fprintf(stdout, "\n\nLBG algorithm iterations \n\n");
/* start LBG algorithm iteration */

do{
/* step 1: find the optimum partition based on the current codebook */
    fprintf(stdout, "# "); fflush(stdout);
/* initialize the codebook usage buffer. */
    for (i = 0; i < book_size; ++i) cbk_usage[i] = 0;
    vector_node = &list_head; /* start from the head of the list */
    do {
        temp = vector_node->next;
        old_dist = dist(temp->vector, &codebook[0][0], vec_size);
        min = 0;
        for (i = 1; i < book_size; ++i) {
            new_dist = dist(temp->vector,
                             &codebook[i][0], vec_size);
            if (new_dist < old_dist) {
min = i;
old_dist = new_dist;
}

temp->codeword = min;
cbk_usage[min] += 1; /* increment the usage frequency of the cell */

vector_node = temp;
)
} while (vector_node->next != 0);

/* step 2: compute the overall distortion resulting from this partition */

vector_node = &list_head; /* start from the head of the list */
new_m_dist = 0.0;
k = 0;
do {

temp = vector_node->next;
m = temp->codeword;
buf = dist(temp->vector, &codebook[m][0], vec_size);
new_m_dist = ((new_m_dist * k) + buf)/(k+1); /* recursive update of the mean */
vector_node = temp;
k++;
} while (vector_node->next != 0);

criterion = (old_m_dist - new_m_dist)/old_m_dist;
old_m_dist = new_m_dist;

/* step 3: if the percentage decrease in distortion is not good enough update the codebook. */

if ( criterion > epsilon ) {
    for( i = 0; i < book_size; ++i) {
        if( cbk_usage[i] == 0) continue; /* retain old codeword by skipping */
        for ( j = 0; j < vec_size; ++j)
            codebook[i][j] = 0.0;
    }

    vector_node = &list_head; /* start from the head of the list */
do {
        temp = vector_node->next;
m = temp->codeword;
        if (cbk_usage[m] != 0) {
            /* ensure that only the used cells are updated */
            for (i = 0; i < vec_size; ++i)
                codebook[m][i] += temp->vector[i];
        }
} while (vector_node->next != 0);
Appendices

```c
vector_node = temp;

while (vector_node->next != 0);

/* average the codebook to obtain the updated centroids */

for (i = 0; i < book_size; ++i) {
    for(j = 0; j < vec_size; ++j) {
        if (cbk_usage[i] != 0)
            codebook[i][j] = codebook[i][j]/cbk_usage[i];
    }
}

/* else the current codebook is the "best" under the present conditions. */

} while (criterion > epsilon); /* goto step 1: */

/* write the final codebook to text file */

fprintf(stdout, "Creating the final codebook ...
");

file_ptr = fopen(codebk_file, "wt");
if(!file_ptr) {
    fprintf(stderr, "Error opening: %s \n", codebk_file);
    exit(1);
}
for (i = 0; i < book_size; ++i) {
    for (j = 0; j < vec_size; ++j) {
        fprintf(file_ptr, "%f\t",
            codebook[i][j]);
    }
}
fprintf(file_ptr, "\n");
fclose(file_ptr);

fprintf(stdout, "Finito ! \n\n");
return(1);

}

float dist(float *vecl, float *vec2, int v_size)
{
    int i;
    float ret_val = 0.0;
    for (i = 0; i < v_size; ++i)
        ret_val += (*((vecl+i) - vec2[i]) * (vecl[i] - vec2[i]));
    ret_val = sqrt(ret_val);
    return(ret_val);
}
```

80
PROGRAM: classify.c
VERSION: 1.0
DATE: March 1998
DESCRIPTION: Program implements feature vector classification using the codebook generated from an LBG algorithm. The user supplies a text file containing a trained codebook and another text file of vectors to be classified. The program returns a text file containing the vectors and their classes. For ease of identification, the classes are labeled 0, 1, 2, 3, etc.

AUTHOR: Philip Ogunbona
124 Carters Lane,
Fairy Meadow 2519
Australia

float dist(float *vecl, float *vec2, int v_size);

int main( int argc, char **argv)
{
  int i, j, k, count, code_book_size, vector_size, data_size,
      vector_class;
  char in_file[30], out_file[30], cbk_file[30],
      line_buffer[128], *p;
  FILE *file_ptr;
  float **data_buffer, **code_book, min_dist, distance;

  if (argc < 6) {
    fprintf(stderr, "classify: classification tool for feature vectors.\n"");
    fprintf(stderr, "\nUSAGE: classify [codebook file] [book size] [vector size] [feature vector file] [num of vectors] [output file]\n"");
    fprintf(stderr, "\nif the feature vector size does not match the code vector size\n"");
    fprintf(stderr, "\nthe result generated is not reliable. The program's behaviour is unpredictable.\n"");
    fprintf(stderr, "\nExample usage: classify codebook.txt 10 5 feature.txt 30 classes.txt\n"");
    exit(1);
  }

strcpy(cbk_file, argv[1]);
code_book_size = atoi(argv[2]);
vector_size = atoi(argv[3]);
strcpy(in_file, argv[4]);
data_size = atoi(argv[5]);
strcpy(out_file, argv[6]);

    /* build and maintain the codebook internally */

code_book = (float **)calloc(code_book_size, sizeof(float*));
if (!code_book) {
    fprintf(stderr, "Error: Unable to allocate memory\n");
    exit(1);
}
for (i = 0; i < code_book_size; ++i) {
    code_book[i] = (float*)calloc(vector_size, sizeof(float) );
    if (!code_book[i]) {
        fprintf(stderr, "Error: Unable to allocate memory.\n");
        exit(1);
    }
}

file_ptr = fopen(cbk_file, "r");
if (file_ptr == NULL) {
    fprintf(stderr, "Error: Unable to open codebook file : %s\n", cbk_file);
    exit(1);
}
i = 0;
while (!feof(file_ptr)) {
    fgets(line_buffer, 128, file_ptr);
    count = 0;
p = strtok(line_buffer, " ,\t" );
    code_book[i][count] = (float)atof(p);
    while (p = strtok(NULL, " ,\t" ))
        code_book[++i][++count] = (float)atof(p);
fclose(file_ptr);

    /* build data buffer */
data_buffer = (float **)calloc(data_size, sizeof(float*));
if (!data_buffer) {
    fprintf(stderr, "Error: Unable to allocate memory\n");
    exit(1);
}
for (i = 0; i < data_size; ++i) {
    data_buffer[i] = (float*)calloc(vector_size, sizeof(float) );
    if (!data_buffer[i]) {
        fprintf(stderr, "Error: Unable to allocate memory.\n");
        exit(1);
    }
}
file_ptr = fopen(in_file, "r");
if (file_ptr == NULL) {
    fprintf(stderr, "Error: unable to open input file: %s ", in_file);
    exit(1);
}

i = 0;
while (!feof(file_ptr)) {
    fgets(line_buffer, 128, file_ptr);
    count = 0;
    p = strtok(line_buffer, ",\t");
    data_buffer[i][count] = (float)atof(p);
    while (p = strtok(NULL, " ,\t"))
        data_buffer[++i][++count] = (float)atof(p);
}
fclose(file_ptr);

/* open the output file for writing */

file_ptr = fopen(out_file, "wt");
if (file_ptr == NULL) {
    fprintf(stderr, "Error: Unable to open output file: %s ", out_file);
    exit(1);
}

for (i = 0; i < data_size; ++i) {
    min_dist = 1.0E7;
    for (j = 0; j < code_book_size; ++j) {
        distance = dist(&data_buffer[i][0], &code_book[j][0], vector_size);
        if (distance < min_dist) {
            min_dist = distance;
            vector_class = j;
        }
    }
    fprintf(file_ptr, "Class: %d\n", vector_class);
    for (k = 0; k < vector_size; ++k)
        fprintf(file_ptr, "%f\t", data_buffer[i][k]);
    fprintf(file_ptr, "\n\n");
}
fclose(file_ptr);
return(0);

float dist(float *vec1, float *vec2, int v_size)
{
    float ret_val = 0.0;
    int i;
for (i = 0; i < v_size; ++i) {
    ret_val += (vec1[i] - vec2[i]) * (vec1[i] - vec2[i]);
}
ret_val = sqrt(ret_val);
return(ret_val);
# Appendix B

## APPENDIX B-1: A list of feature vectors (features1.xls)

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Appendix C: Time versus heart rate of subjects

Subject 2

Subject 3

Subject 4

Subject 5
Appendix C: Time versus heart rate of subjects ctd.
Appendix C: Time versus heart rate of subjects ctd.
Appendix C: Time versus heart rate of subjects ctd.
Appendices

Appendix C: Time versus heart rate of subjects ctd.

Subject 18

Subject 19

Subject 20

Subject 21
Appendix C: Time versus heart rate of subjects ctd.

Subject 22

Subject 23

Subject 24

Subject 25
Appendix C: Time versus heart rate of subjects ctd.

Subject 26

Subject 27

Subject 28

Subject 29
Appendix C: Time versus heart rate of subjects ctd.

Subject 30

Subject 31

Subject 32

Subject 33
Appendix C: Time versus heart rate of subjects ctd.