Estimation of Extent Damage Tissue by Multi Resolution Analysis of the Electrocardiogram and Arterial Blood Pressure

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Abstract

Introduction: *Coronary artery congestion is a heart disease which causes a lack of oxygen and nutrients in the heart, and is felt as chest pain (ischemia disease). Prolonged ischemia can continue until the cells start to dye, which is called myocardial infraction.*
Aims: *We aim to determine the amount of cardiac tissue damage by multi resolution analysis of electrocardiogram (ECG) and atrial blood pressure (ABP) signals.*
Methods: *In this study 39 Wistar rats were used, and ECG and ABP signals were recorded to estimate the extent of tissue damage. The signals were recorded for 30 minutes during normal heart function and for 30 minutes during ischemia and myocardial infraction (MI) which was induced by artificial complete blockage of the left anterior descending coronary artery (LAD). Additionally the vasopressin (AVP) in various doses was injected to 39 rats. Afterwards, the wavelet packet transform (WPT) wad applied to the recorded ECG and ABP signals for decomposition into dyadic scales. 50 dyadic scales which were more informative for discrimination of different ischemic phases among each other and from the healthy phase were chosen, and a feature vector as the entropy of corresponding wavelet coefficients was selected. As a reference measurement of the extent of damage tissue, images of the heart sections were additionally extracted, and the extent of damage tissue was assessed by image processing technique. Finally, the amount of damage tissue was classified with artificial neural networks (ANN) based techniques.*
Results: *The extent of tissue damage was estimated based on the ANN and multi-resolution analysis of the synchronic electromechanical signals with the average error of the 2.17% for the normal and ischemic tissue in all the AVP doses.*

1. Introduction

Coronary occlusion deprives cardiac cells of oxygen and nutrients (ischemia disease). When prolonged it leads to cardiac cells death that is irreversible damage to the heart tissue known as myocardial infraction (MI). Myocardial ischemia might also cause serious abnormal heart rhythms [1]. When ischemia is in its mild phase, ischemic conditions can be reversed without tissue damage, but presence of ventricular arrhythmias accelerates cell death as it creates others forms of tissue injury [2, 3].

In the published literature there are many different methods for detection and estimation of the extent of infarcted region, where predictions and measurements are done before and after the MI is induced. Cardiovascular magnetic resonance imaging (CMRI) is commonly used as a reference tool for detection of infarction area, but it is an expensive procedure compared to echocardiography and potentially ECG measurement. For example, for detection of the lateral MI, CMRI is commonly applied method [7]. Some other methods combine ECG with MRI as in [5], where detection is based on correlation between QRS score and delayed enhancement magnetic resonance imaging (DE-MRI).

Doppler echocardiography is an approach that applies ultrasound technology for evaluation in general of heart condition, blood vessels status or blood flow (speed and direction) [10]. Measurement of the ventricular global longitude strain is a very effective procedure to determine the extent of damage [4]. In reference [11] ischemic and myocardial size and location is quantified by combining CMRI and strain Doppler echocardiography.

In reference [8], identification of Q waves and ST-segments from infarcted region are obtained from body surface potential mapping. Also, it should be emphasized that body surface potential mapping is an accurate analysis tool for scoring of ECG signals in the clinical scenarios [9], followed with CMRI for accurate determination of the area of infarcted region. QRS scoring study that investigates Q and R wave and $\frac{R}{Q}$ and $\frac{R}{S}$ amplitude ratios from a 12 lead ECG is studied in [6], and in this study only ECG signal is used for detection and estimation of infracted region.

Listed approaches use 12 to 80 lead ECG for feature extraction which makes these algorithms very computationally expensive. Also, in some of these methods signal is obtained from across a certain spatial domain, and ability to obtain the multi lead ECG is not assessed. In this paper we used 1-lead ECG, and by injection of different doses of vasopressin an artificial MI region of different sizes is created. Features of ECG and ABP signals are extracted with wavelet analysis, and additionally both healthy and tissue damage regions are obtained with image processing approach. Finally, extracted features are classified and normalized with ANN. The outline of this paper is as follows: Data conditioning and overall structure of the processing algorithm is outlined in the material and method section. Next, details of feature extractions from haemodynamic signals are explained followed with additional feature extraction from 2D heart images. For classification of the feature vector, four ANNs were created and discussed. In the discussion section estimated damage and normal tissue values obtained intelligent networks are compared with 2D heart images.

2. Material and Method

2.1. Data preparation

Male rats were housed and cared accordingly to the institutional guidelines of Tehran University of medical sciences. During surgical procedure, heparinized saline (100 U/ml) with polyethylene tubing catheter was implanted for haemodynamic monitoring and blood sampling and the Evans blue dye is injected. Arterial haemodynamic parameters and ECG signal are recorded continually. Pericardium is incised, around the region of left anterior descending coronary artery (LAD) and in right of left atrial appendage a silk thread is placed. By applying tension to the suture regional ischemia is induced leading to a regional deep ischemia and MI. With this intervention basal haemodynamic parameters and ECG signal are elicited [12].

2.2. Entropy

For indexing and measuring the irregularity in signal, entropy can be used and calculated as follows:

Shannon method: $E(s) = -\sum_i s_i^2 \log(s_i^2)$

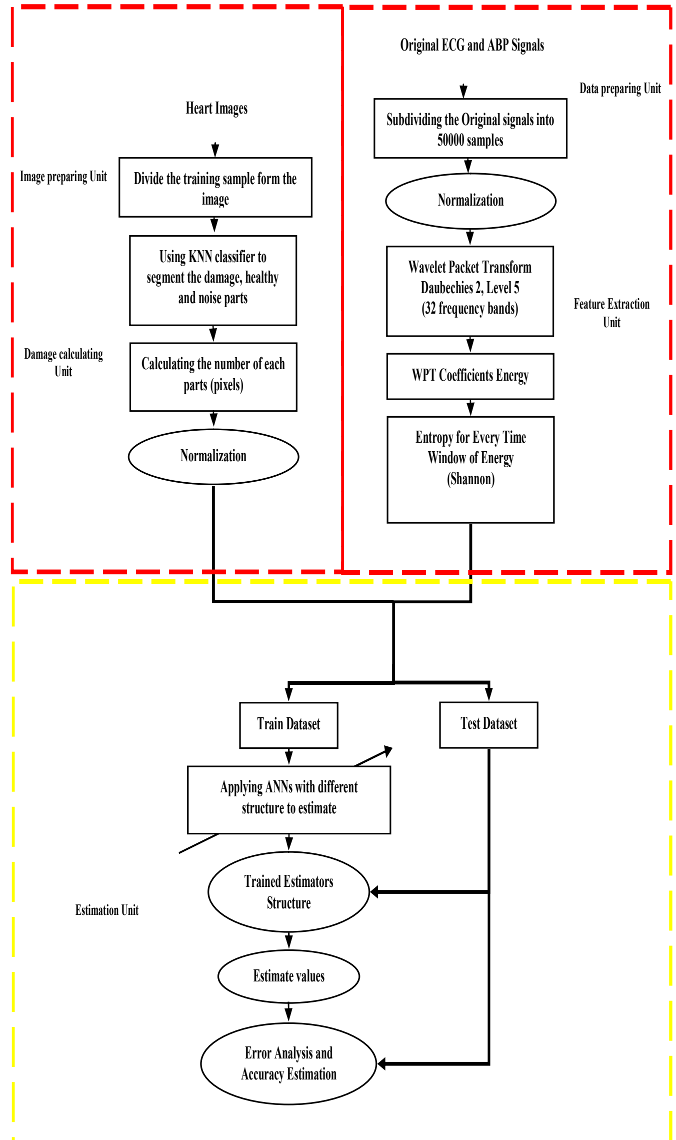

Figure. 1 The overall block diagram of the proposed approach

2.3. Feature extracting from haemodynamic signals

As features are elicited among the rats having different doses of AVP, for feature extraction from the disordered ECG signals from damaged tissue, wavelet packet transform is implemented. Wavelet packet transform has better separation in high and low frequency regions and more details can be extracted from a signal that if Fourier transformation is used. Wavelet packet transform in the 5th level with basis wavelet function of db2 is applied for signal decomposition. Number of frequency bands is determined with trial and error procedure.

Table 1. Structures related to each ANN classifier

ANN classifier number	Classifier Type	Number of hidden layers	Number of neurons	Activation function of hidden and output layers	Training epoch number
1	MLP-BP	1	20	tansig - logsig	50
2	MLP-BP	1	25	logsig - tansig	100
3	MLP-BP	1	25	tansig - tansig	150
4	MLP-BP	1	30	logsig - logsig	120

For discrimination of signal disorder value in each frequency band, entropy function is applied to wavelet coefficient. To enhance recognition of the extent of damage tissue, ABP signal is additionally used. Entropy function and calculated entropy value is computed for each rat and feature space with dimension of 32 is extracted.

2.4. Feature extracting from heart scan image

Images of rat's hearts, are divided into two classes representing healthy and damaged tissue. These two classes are separated based on the different image colors of the normal and damaged tissue. Since the normal and damaged regions were not clustered as distinct and separated areas, we used a k-nearest neighbor classifier to discriminate these two classes.

To create a relationship between the images and the extent of damaged tissue, areas were determined as follows:

a) Images were converted from RGB to LAB space as in the LAB space image component are independent of the light intensity changes.

b) Since there were five colors in the processed images, they were decomposed to 5 clusters as: white, red, blue, dark red and dark blue.

2.5. Intelligent networks testing and training

After determination and extraction of the feature vector, four artificial neural networks (ANN) were established, and for network training the acquired data from 30 rats was used. The data of 9 of the rats which were did not participate in training was employed for testing of the networks. The detail information of employed ANN networks is presented in Table 1. In this step, estimation was applied via four estimators with different data used for testing and training. This hybrid network consisted of four MLP neural networks (MLP-BP) with different topology parameters in order to increase the estimation accuracy.

3. Results

30 rats out of 39 were used for training, and 9 rats were used for testing. The results for estimation step of algorithm for 9 rats is shown in Table 2. For each rat estimated and fault error rate is plotted in Figure 2 and average error of 2.17% is obtained for these estimators.

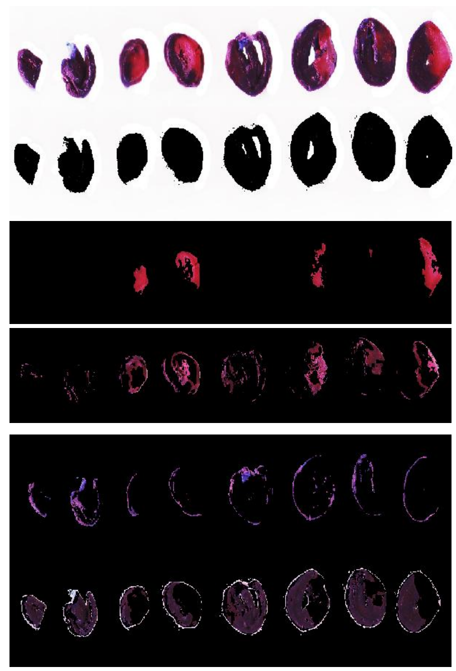

Figure. 2 Clustering of images of rat heart based on their color

Table 2. Results of estimated fault parts of 9 rats

Rat Number	Estimated Fault Parts	Real Fault Parts	Error
Rat #1	0.6948	0.6835	1.66
Rat #2	0.7616	0.6509	1.7
Rat #3	0.6647	0.7899	1.59
Rat #4	0.789	0.6856	1.5
Rat #5	0.7889	0.7604	3.74
Rat #6	0.773	0.7623	1.4
Rat #7	0.7425	0.8972	1.72
Rat #8	0.8318	0.8502	2.17
Rat #9	0.7581	0.7282	4.1
		Average error	2.17

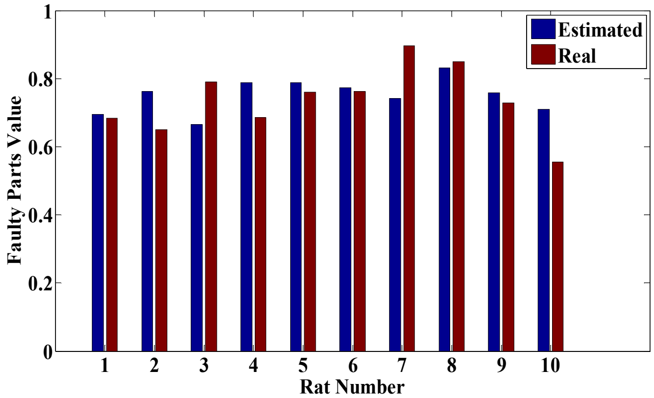

Figure 3. Comparison of the faulty parts value for each rat.

4. Discussion and conclusion

The aim of this study was to develop the algorithm for estimation of the extent of damaged tissue during and after the MI. To reach this goal, the desired features were extracted from ECG and APB signals, and finally, they were estimated. The data was recorded for duration of surgical operations from the animal researches quarters of Medical Sciences faculty of Tehran University under standardized conditions according to institutional guidelines of this university. In this study, for feature space extraction there was no need to delineate the rats' signal events since the morphology of the signal during the MI was changed. Consequently, such morphological features may not lead to a promising performance. On the other hand, by employing the multi-resolution analysis high performance is achievable. In this study, by using energy of the entropy of the coefficients obtained by wavelet packet decomposition the desired feature space was extracted and used for estimation. The extent of the damaged tissue of the rats' heart was elicited by image processing techniques. The estimation step was conducted by training and testing of the four neural networks estimators. The proposed approach predicted the extent of the damaged and normal tissues with an average error of 2.17%. The results indicate that myocardial infarction can be distinguished with the critical signals, such as ECG and ABP.

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