Abstract—ECG is an electric signal which is generated from human heart. It is used for investigating some abnormal heart functions. In this paper, the shape of ECG is used to classify ECG beat in four types: normal beat (N), left bundle branch block beat (L), right bundle branch block beat (R), and ventricular premature beat (V). To extract the shape of ECG, the discrete wavelet transform with level 3 of Daubechies 1 is used after digital filter is applied to remove noise from ECG signal. Then PCA (Principal Components Analysis) and SVM (Support Vector Machines) are adapted to create a model of classifier for use with paper-based ECG printout. The ECG image from ECG printout is processed by some image processing techniques such as red grid removing, noise rejection, image thinning, and time-series ECG extraction to obtain the time-series ECG signal before classification. Based on MIT-BIH arrhythmia database which is used for SVM training and evaluation, the performance of this classifier is 99.6367% with LIBSVM.

Keywords-component: ECG printout, ECG classification, Principal Components Analysis, Support Vector Machines

I. INTRODUCTION

The electrocardiogram (ECG) is a vital sign signal for heart functional investigation. This electric signal is generated from the heart to create the cardiac cycle which generates the blood circulation. It is composed of three basic components: the P wave, QRS complex, and T wave as shown in Figure 1. The P wave is generated when the atrium depolarizes. After that, the QRS complex is generated when the ventricle depolarizes, and the T wave is generated when the ventricle recovers. The cardiovascular disease is one of the leading causes of death around the world. While the lack of medical expertise in analyzing an ECG signal is a significant problem, especially in rural areas. Therefore, the research on ECG classification methods for ECG printout is aimed at relieving this problem. The example of paper-based ECG printout is depicted in Figure 2.

The ECG classification method for ECG printout consists of three basic components. The first component is the time series ECG beat detection from ECG printout. The second is data preprocessing such as discrete wavelet transform and PCA. The last component is ECG beat classification with SVM.

Previous work for ECG printout digitization is referred in [1-7]. For ECG classification with SVM with different detail on feature space is referred in [8-15]. Furthermore, Fourier transform [16] and shape-based matching algorithm [17] are also used for ECG beat classification from ECG printout.

II. ECG BEAT DETECTION FROM ECG PRINTOUT

This section is dedicated to ECG beat retrieval method from ECG printout.
A. **ECG paper scanning**

The image is scanned with 300 dpi which is equivalent to 295 Hz (3.4 msecs/pixel) sampling rate for data recorded with speed of 25 mm/sec.

B. **Select area of interest**

An interesting ECG beat is then selected from the image for image and signal processing.

C. **ECG image binarization**

The selected segment of ECG image is loaded as gray scale because the color of ECG signal from the original paper is black and the color of paper grid is red. Threshold selection (130/255) is used for create binary image. But noise will appear in sometimes as shown figure 3. Then it needs to eliminate noise after binarizing the image.

D. **Noise rejection**

To remove the noise on the image after binarization process, the following process of noise rejection is applied to the binary image. The process starts by scanning vertically to find out the black pixel. If the black pixel is found and all adjacent pixels around it are white background color, then this black pixel will be considered and treated as a noise which will be replaced with white background color.

E. **Image thinning**

Since the line of ECG trace of original scanned image from ECG printout has a thickness which is a redundant of data in time series domain. Then thinning process with moving average algorithm is used to eliminate this redundant of data. Moving average in top-down fashion is used for thinning binary ECG images. When applying 5-point moving average to the binary image after noise rejection, the location of maximum value within 5-point window is used to determine the position of the thinning output pixel. This concept is illustrated in figure 4. The result of thinning process and noise rejection is shown in figure 5.

F. **Time series data extraction**

Time series data extraction is started from black pixel searching on each column with bottom-up style. After black pixel is found, its row index is used as the data value. This process is repeated on every column of image.

G. **Time series data preprocessing**

For classification ECG beat, the classifier use its shape for classify. Then data preprocessing is required. This preprocessing comprises of normalization and mean subtraction for generate zero-mean signal. The equation for normalization is shown in (1).

\[
 x[n] = \frac{x[n] - \min(x)}{\max(x) - \min(x)}
\]

H. **QRS complex detection**

After we create zero-mean normalized ECG signal. The absolute value of zero-mean normalized signal is used to find its envelope with Hilbert transform (green line on figure 6). The equation below is a Hilbert transform of real function \(x(t)\) when \(x(t)\) is ECG time series data.
Finally the peak of QRS complex is located by looking for the top of its envelope. The result of QRS detection after plotting the peak location of the QRS complex together with zero-mean normalized data and the envelope of its absolute value is shown in figure 6.

$$H[x(t)] = \frac{1}{\pi} \int_{-\infty}^{\infty} x(\tau) \frac{1}{t-\tau} d\tau$$  \hspace{1cm} (2)

I. ECG beat extraction

After the position of QRS complex in selected beat is located. ECG beat is extracted with 185 samples where the peak of QRS complex is the 93th sample. After that downsampling method with rational fraction M/L is applied to ECG beat for generate 200 Hz ECG signal. M is a downsample factor and L upsample factor which is 59 and 40 respectively.\n
The linear interpolation is used for upsampling method.

III. SVM TRAINING

SVM is a supervised learning method for linear separable data with maximum margin value. Our work focus only on 4 types of signals: Normal beat, Left bundle branch block beat, Right bundle branch block beat and premature ventricular contraction. Single lead is used for training (MLII or limb lead II).

A. Data preprocessing

High quality of feature vector will yield the better result of classification. Then data preprocessing is applied for this purpose. Digital filtering is used for eliminate noise on ECG signal. After that Discrete Wavelet Transform and PCA is used for enhance features of filtered ECG signal.

1) ECG signal downsampling

Because ECG signal from MIT-BIH database is sampling at 360 Hz then downsample to 200 Hz is required for compatible with sampling frequency of signal for ECG when implementation. Downsampling factor is 9 and upsampling factor is 5.

2) Digital filtering and database construction

Digital filter is used on this work base on design of Hamilton and Tompkins work [22]. This filter aim to reduce the influence of noise, such as muscle noise, power line and baseline wonder. After filtering, we construct the same size of database for SVM training and evaluation (45686). Each data in new database is compose with its labels for each type of beat annotations such as -1 for Normal, -2 for Left bundle branch block beat, 1 for Right bundle branch block beat and 2 for Premature ventricular contraction.

Data in each database is ECG beat with 225 samples where the peak of QRS complex is the 113th sample which normalized and removed DC component as describe in section Time series data extraction.

3) Features extraction

Discrete wavelet transform (DWT) and principle components analysis (PCA) is used for create vector space. Daubechies wavelets level 1 is used as wavelet packet. Each beat is decomposed to level 3. Then cD1, cD2, cD3 and cA3 are output of DWT. After that we reconstruct new ECG shape with cD3 and cA3 component and ignore 5 samples from the most of each end (left and right). Then PCA is used for find 20 principle components.

Finally, output of features extraction is 20 dimensions of principle components. And database of reconstruct ECG signal with its classification label.

B. SVM training

This work use LIBSVM for train and validate SVM model. Gaussian RBK is used as kernel function. 5-fold cross validation is used for find parameters of kernel function and SVM model. After training, we know each parameter for kernel function and SVM model which is 32.0 and 2.0 for C and γ respectively.

Data from database will be transform with principle component before SVM training or evaluation.

C. SVM evaluation

This SVM classifier has a good performance because its accuracy is 99.6367% (correct classification 45520 beats from 45686 beats).

IV. IMPLEMENTATION

When SVM classifier model is already train and evaluate. It integrate with ECG beat detection method from section 2 for evaluate with real ECG image. The performance is good. But if quality of ECG printouts is low then error due to simple thinning will decrease performance of SVM classifier.

V. CONCLUSION

Support vector machine with discrete wavelet transform and principle component analysis is a good performance ECG beat classifier. For integrate this classifier with ECG beat detection for ECG printout, the improvement of image processing techniques is required.
REFERENCES


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