Automatic Detection of Heart Disease from Twelve Channel Electrocardiogram Waveforms

TG Zimmerman[1], T Syeda-Mahmood[2]

[1]IBM Almaden Research Center, San Jose CA, USA
[2]IBM Almaden Research Center, San Jose CA, USA

Abstract

A statistical means to automatically detect heart disease from twelve channel ECG waveforms is reported. Patient ECG records from the PTB Diagnostic ECG Database are assigned to one or more of 18 heart disease groups. A single heart beat cycle near the beginning of the record is used to measure eight temporal intervals (e.g. QT, ST, PR, QS) for each of the twelve channels, resulting in 96 parameters for each patient record. The average and standard deviation of the 96 parameters for 63 non-disease patients are used as a control reference. The number of parameters that exceed two times the standard deviation of the control reference is used as a disease indicator. Using ten or more out-of-bound parameters as the disease criteria, 72% of disease patient records are correctly identified while 8% of control patient records are falsely identified as having a heart disease.

1. Introduction

Twelve channel electrocardiograms (ECG) provide a non-invasive spatial perspective on the electrical activity of the heart. Cardiologists are trained to look at temporal features in the waveforms to detect anomalies indicative of heart disease [1]. Previous work uses automatic waveform shape-based retrieval of ECG recordings to infer similarity in diagnosed diseases [3]. Others have used wavelets, Fourier transforms, neural networks and expert systems to automatically detect heart diseases. This work examines statistical variations in the temporal intervals of ECG waveforms in a single cardiac cycle to classify patients as disease or non-disease. The goal is to create computationally simple metrics to screen large ECG databases to detect records that suggest heart disease.

2. Methods

The PTB Diagnostic ECG Database [2] provides a test set to determine the accuracy of the disease/non-disease classifier.

Each twelve channel record includes a patient diagnosis with one or more disease conditions (or no disease for the control group). The numerous disease conditions are grouped into eighteen conditions, listed in Table 1.

Table 1. Disease categories and true positive (TP) disease detection rate for two different detection sensitivities. The TP-10 and TP-6 columns are the TP rates when the out-out-bound count exceeds 10 and 6, respectively. The false positives (healthy control patients incorrectly classified as having heart disease) are 8% and 21% for TP-10 and TP-6, respectively.

Condition	TP-10	TP-6
AV Node 1	69%	84%
MI; infero-posterior	100%	100%
MI; antero-septal	79%	85%
MI; inferior	55%	74%
MI; anterior	89%	97%
MI; infero-lateral	67%	81%
MI antero-lateral	81%	95%
Bundle branch block	57%	86%
Cardiomyopathy	93%	93%
Cardiomyopathy; atrial frib	100%	100%
Valvular heart disease	83%	100%
Atrial fibrillation	100%	100%
Ventricular fibrillation	57%	76%
Dysrhythmia	86%	93%
Arterial hypertension	72%	82%
Arterial hypertension; MI	72%	80%
Hypertrophy	71%	86%
Coronary artery disease	80%	90%

Each twelve channel record is first filtered to remove a wandering zero-volt baseline. Waveform markers (P, Q, R, S, T) for one cardiac cycle are detected by synchronizing on the S or R wave, defined as the largest negative and positive peaks in a 3 second sample window, respectively. Three temporal intervals referenced to the S wave (QTs, STs, PRs) and five

temporal intervals referenced to the R wave (RRr, QSr, QTr, STr, PRr) are calculated.

The eight temporal intervals are calculated for each of the twelve channels, producing 96 interval measurements for each patient. The average and standard deviation of each interval from the control group (63 patients with no disease) establishes the control value for each interval. It is observed that disease patients have intervals that often exceed the control values by more than two standard deviations. By counting the number of intervals that exceed the control value by two standard deviations, a single scalar metric ("out-of-bound count") is established to indicate disease state. A patient is classified as having heart disease if the out-of-bound count exceeds a sensitivity threshold. The sensitivity threshold is selected to optimize the tradeoff between false positive and negatives.

2.1. Algorithm details

Each channel of the 549 ECG records from 294 patients is filtered by a 6 pole low pass filter to restore the zero-volt base line, implemented by running a three pole low pass filter forward through the record, then backwards thru the record, reducing the temporal lag introduced by the filter.

Waveforms are detected in each channel by establishing a model of an ECG waveform, shown in Figure 1. The S and R wave are detected as the largest negative and positive peaks, respectively, occurring in a 3 second sample window. The time of the S and R wave peaks are used as temporal reference points to find the rest of the waves (P, Q, R, T), based on the search windows listed in Table 2, established by inspecting a composite of control and disease waveforms.

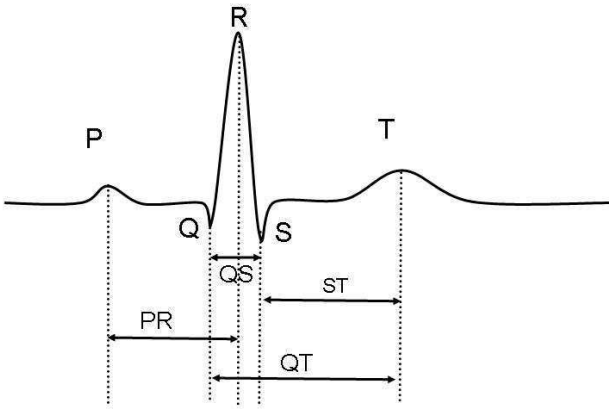

Figure 1. Model waveform is defined by wave peaks that occur within temporal search windows referenced to the S and R wave peaks. Time intervals are measured between wave peaks for each ECG channel.

The wave peaks are expected to occur within the temporal search window and are maximum negative (Q) or positive (P, T) peaks. For example the P wave is expected as a positive peak occurring 100 to 500 samples before the S wave peak, and 1000 and 80 before the R wave peak.

Table 2. Temporal search windows for wave peaks (in milliseconds) referenced to either the S or R peak. S and R waves are defined as the maximum negative and positive peaks, respectively, occurring within a 3 second sample window.

WAVE PEAK	MIN	MAX	MIN	MAX
P	-100	-500	-1000	-80
Q	-100	-40	-600	-25
R	-200	0	Ref=0	Ref=0
S	Ref=0	Ref=0	0	100
T	65	400	100	440
R-R	500	1200	500	1200

To calculate the time interval between R waves (RRr) the R wave is detected as the maximum value occurring in the 3 second window. The R of the next waveform is detected as the first peak that exceed ½ the previous R peak and falls within 0.5 and 1.2 seconds of the previous R peak.

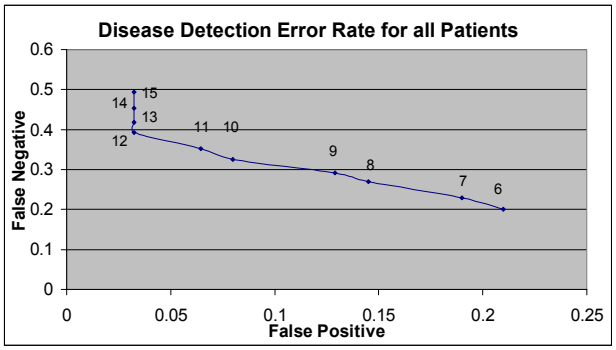

Figure 2. ROC curve for discriminating between disease and non-disease state of ECG waveforms based on temporal analysis of 96 interval parameters (8 intervals per ECG channel). Disease state is determined by counting the number of parameters that exceed two standard deviations of the control average ("out-of-bound count").

3. Results

The out-of-bound counts are calculated for each patient ECG record. By varying the disease threshold

(minimum number of out-of-bound counts to qualify as a disease) an ROC curve is generated (Figure 2). An equal error rate (EER), the sensitivity when false positives equals false negatives, is most closely achieved with a sensitivity of 6 (EER ~ 0.20). The true positive detection rate for each disease category for sensitivity values of 6 and 10 is shown in Table 1.

4. Discussion and conclusions

The statistical method of classifying a patient as disease or non-disease presented here offers a simple means of automatically screening large numbers of patients. The method does not distinguish the type of disease. Rather, it is a blunt screening tool to determine if an ECG suggests a patient might have heart disease.

The method works by establishing a model of an ECG waveform, measuring waveform peak intervals, and comparing them to a set of control values. If a waveform does not comply with the model assumptions (e.g. the S wave is not the largest negative value), the remaining waves will most likely be erroneously labeled, creating errors in the temporal interval measurements. The assumption is that waveforms that break the basic rules belong to patients with heart disease. The assumption appears to be correct most of the time, as demonstrated by the performance of the method for the test database.

Temporal intervals are measured between waveform peaks, compared to prior work that measures some intervals at zero-crossing which are very susceptible to errors from wandering base lines.

Examining the deviations of the interval measurements from the control values for each interval and patient reveals some interesting patterns (Figure 3 and Figure 4). Most striking is the significant role a few channels play in distinguishing non-disease from disease patients. Specifically channels ii, iii, v3, v5 are the most active channels in detecting disease. This suggests that a special harness containing precordial leads (v1 thru v6), combined with simple statistical methods taught here may be sufficient to screen large populations for heart diseases.

The present method is blunt for it does not associate particular rule deviations with specific diseases. Further research may find correlations between temporal intervals and specific heart diseases. This matter is complicated, however, by patients that manifest multiple heart diseases.

Acknowledgements

The authors would like to thank Professor Hans Koch and his colleagues at the Physikalisch-Technische Bundesanstalt for making the ECG dataset publicly available.

References

[1] Dubin, D.. *Rapid Interpretation of EKG's* Dale B. Dubin Cover Publishing Company October 2000

[2] Physikalisch-Technische Bundesanstalt (PTB), Diagnostic ECGDatabase, http://physionet.org/physiobank/database/ptbdb/

[3] Syeda-Mahmood T, Beymer D, Wang F. *Shape-based Matching of ECG Recordings.* to appear in International IEEE Conference on Engineering in Medicine and Biology (EMBC2007), Lyon, France, August 23-26, 2007.

Address for correspondence;
IBM Almaden Research Center
650 Harry Road
San Jose CA 95014

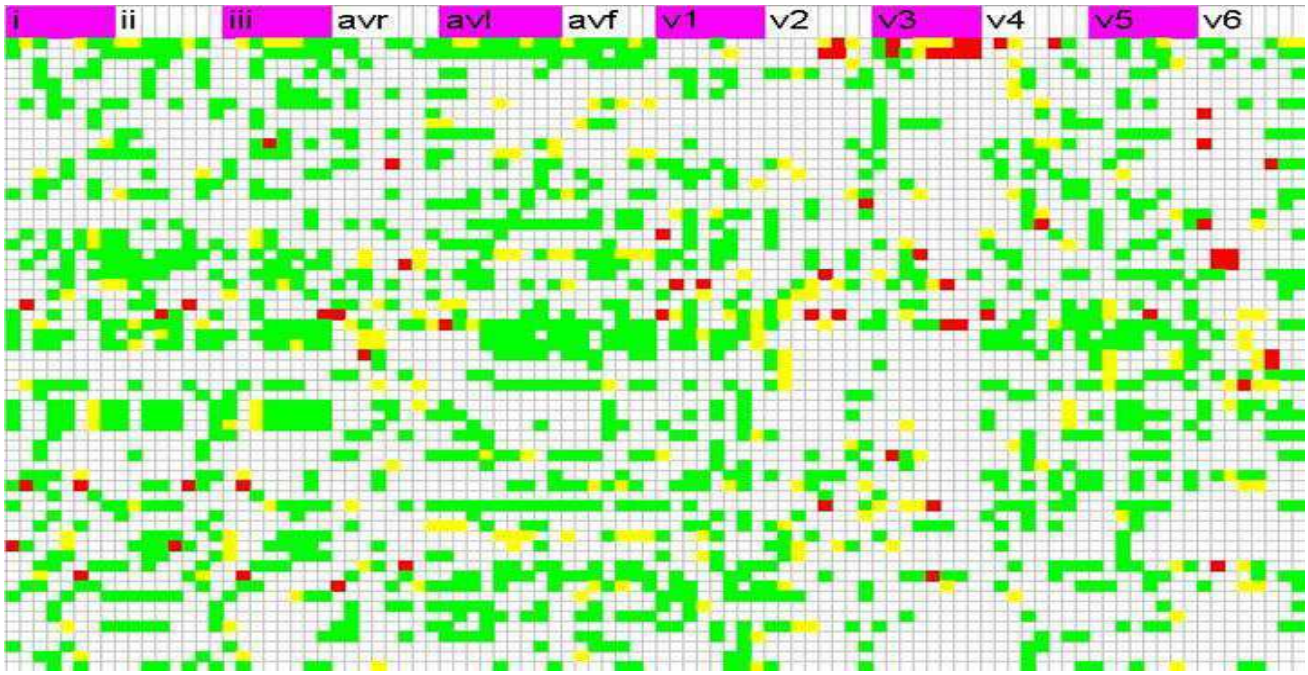

Figure 3. Deviation of 96 intervals (8 intervals per ECG channel) for 64 control (non-disease) patients. Each row is the parameters derived from a heart beat cycle from an individual non-disease patient. Each column is one of the 96 interval parameters; QTs STs PRs RRr QSr QTr STr PRr, respectively, for each of the twelve ECG channels (i, ii, iii, avr, avl, avf, v1, v2, v3, v4, v5, v6). The color of the square indicates how many standard deviations the measured interval is from the average for all control patients; white <1 SD, green <2 SD, yellow<3 SD, red>= 3 SD.

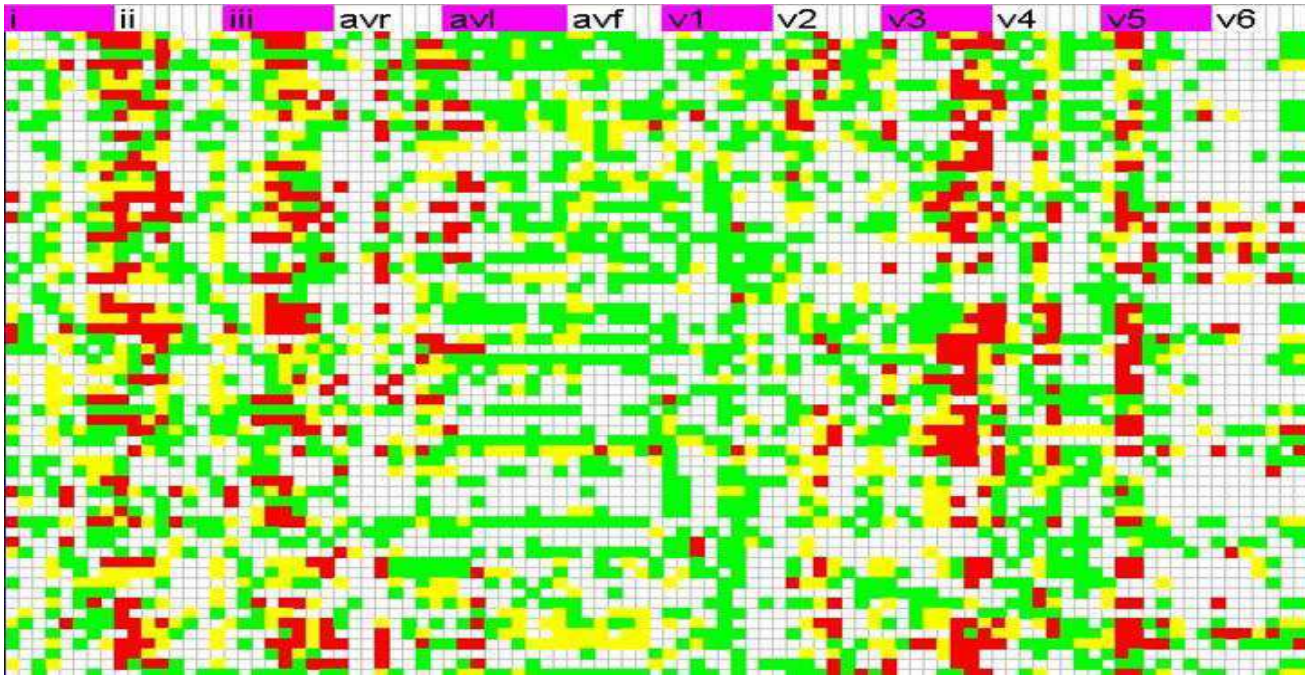

Figure 4. Deviation of 96 intervals (8 intervals per ECG channel) for patients diagnosed with Anterior Myocardial Infarction. Intervals measured from ECG channels ii, iii, v3 and v5 show particular deviation from the parameter average of the control group.