Realtime Wireless Monitoring of Abnormal ST in ECG Using PC Based System

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Abstract: The ST-segment that the beginning part of T wave is the important diagnostic parameter to finding myocardial ischemia. Abnormal ST appears in two types. One is the level change, and the other is the pattern change. In this paper, we describe the monitoring of abnormal ST using PC based system. Hardware of this system consists of transmitter, receiver and PC. The function of transmitter is measuring ECG in three channels which are selected manually and transmitting the data to receiver by digital radio way. Connection with receiver and PC is by RS232C, and the data received on the PC is analyzed automatically by ECG analysis algorithm and saved to file. In the algorithm part for detecting abnormal ST, ST-segments are approximated by a polynomial. This method can detect all of the deviation and pattern change of ST-segment regardless the change in the heart rate or sampling rate. To gain algorithm reliability, the method rejects distorted polynomial approximation by calculation the difference between the approximated ST-segment and original ST-segment. In pre-signal processing, the wavelet transformation separates high frequency bands including QRS complex from the original ECG. Consequently, the process improves the performance of detecting each feature points.

Keywords: ST-segment, myocardial ischemia, polynomial approximation, monitoring of abnormal ST

1. INTRODUCTION

Usually, people go to hospital and take ECG check when one take a medical examination or something wrong occurs in body. Lately, ECG is used on purpose to keep good health or monitor cardiac function of aged person as well as on purpose to diagnose the disease of heart patients. The ambulatory ECG monitoring system under guarantee of safety and accuracy is very efficient to prevent the progress of heart disease and sudden death. These systems can detect the temporary change of ECG that is very significant to diagnose heart disease such as myocardial ischemia, arrhythmia and cardiac infarction.

Myocardial ischemia is a disorder of cardiac function caused by insufficient blood flow to the muscle tissue of the heart. If this insufficient blood flow repeated for long time, although it appears temporarily, it might cause infarction of heart muscle or dangerous cardiac arrhythmias. That is, to find the symptom of myocardial ischemia is as important as to find cardiac infarction and arrhythmia. The main ECG symptom related with myocardial ischemia consists of ST level change episodes and ST pattern change lasting several seconds or sometimes some minutes. As mentioned above, since this symptom is related to sudden death and is very important for first-aid treatment, it is necessary to monitor and analyze the ECG of a person who is suffering from heart disease for 24 hours. Also, the ECG of an aged person who has a weak heart must be monitored continuously. The ambulatory ECG monitoring systems developed until now, the so-called holter systems consist of the portable ECG recorder, data reader, analysis software and PC or workstation. User measure and record ECG by oneself as carrying the portable ECG recorder, and analyze the recorded ECG using analysis software based on PC or send that to physician in hospital. ECG analysis process of most holter systems is off-line except several systems that detect QRS by real-time and make warning sound at dangerous situation. Memory capacity of recorder is one of important parameters in system performance. User can carry the recorder for a long time, if memory is big, but most recorders can be used about 3day. Event recording function of recorder is that user decides when ECG recording begin and when stop by operating event button. This function does to use memory efficiently, but user does not record ECG when feels nothing, because the change of ECG may appear without anything wrong physically. Also, user always checks memory capacity remained. Therefore, for measurement of ECG more efficiently for a long time, it is necessary to make automatically control signal that decides when ECG recording begin and when stop, and to send recording ECG data of recorder to PC by wireless communication. Wireless communication with recorder and PC guarantee that user is active freely. Event recording signal can be generated by auto-analysis algorithm. The algorithm analyzes measured ECG automatically, and detects abnormal part in ECG. Many feature points of ECG can be used by standard that detect abnormality in ECG. Using QRS complex, holter system can store the arrhythmia occurring part selectively, and using ST segment, that can store the cardiac ischemia occurring part selectively. The detection of ST segment change through continuous ECG monitoring is very important because it can find cardiac abnormality that patient may not feel or that may bring a emergency situation.

Until now, a number of measurement system[1-2] and algorithms[3-9] for ECG have been developed. Neural network and fuzzy are used most often in automatic detection of arrhythmia and ischemic episodes[10-13]. Although wavelet transform is also used, it is mainly used for noise reduction and detection of arrhythmia[14-16]. Most of algorithms that have been developed until now place importance on the detection of QRS complex and ST-segment elevation or depression, but the change of ST-segment pattern, especially, should be also considered. Although myocardial ischemia can be detected with only ST deviation, ST pattern change is also a very important parameter in this detection. Actually, the change of ST pattern means abnormal condition of ventricular, regardless of whether or not ST deviation exists.

In this paper, we design the potable ECG measurement device and develop ECG auto-analysis algorithm and software to compose the ambulatory ECG monitoring system. The portable ECG measurement device have three channels and communicate to PC by digital radio way. Channel selection is performed manually. ECG analysis algorithm detects abnormal ST using the polynomial approximation. We suggested that ST-segment could be approximated by a polynomial with the least square method to classify the ST-segment[17]. Polynomial approximation is applied in R-S and S-T to detect the depression or elevation of ST-segment and also to detect the change in ST-segment pattern. Consequently, ST-segment change can be classified into the depression or pattern type.

2. ECG MEASUREMENT DEVICE

The portable ECG measurement device consists of multiplexer, amplifier, filter, micro-controller and RF module. After amplification and filtering, the ECG signal is fed through micro-controller. Fig. 1 shows the hardware configuration and Fig. 2 shows measured ECG.

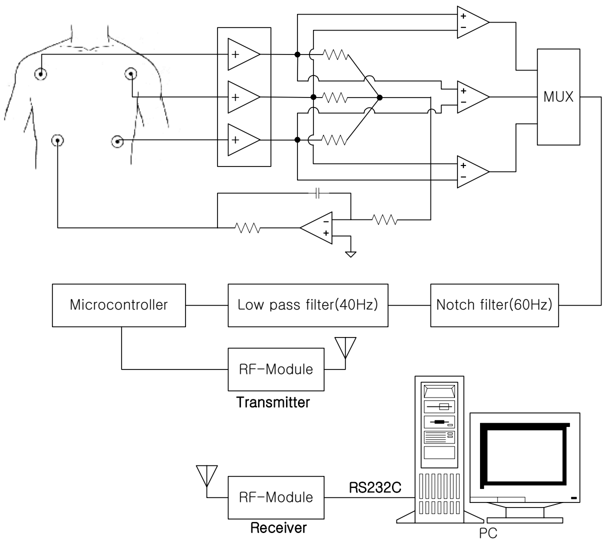

Fig. 1. Ambulatory ECG monitoring system

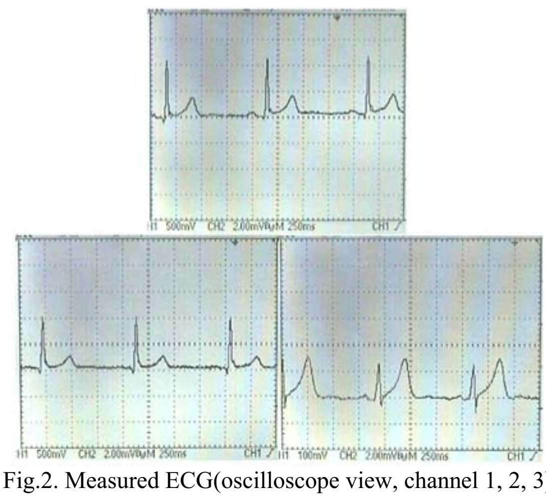

Fig.2. Measured ECG(oscilloscope view, channel 1, 2, 3)

We used PIC16C74 for micro-controller, BIM418 for RF module, AD621 for amplifier. And, we composed 40Hz high pass and 60Hz notch filter using OP amp. The device has three channels, and each channel is selected by manual operating. Sampling rate is 600Hz and A/D resolution is 8bit. Available distance of RF module is 30m in building and 120m in open ground, and communication with PC is performed through serial port. ECG analysis software display the measured ECG and the results of analysis.

3. ANALYSIS ALGORITHM

3.1 Pre-processing

ECG is analyzed by wavelet transformation, detection of feature points, approximation to polynomial, rejection of distorted ST-segment and classification. Fig. 3 shows ECG analysis process. R, S and T-waves have to be detected precisely to analyze the ST-segment accurately. S and T-wave are the base points for the polynomial approximation, and the P wave is the base point of reference point detection. The reference point means the end of the P wave and is used to obtain the level difference between ST-segments. The R wave must be precisely detected because it is used to find other feature points.

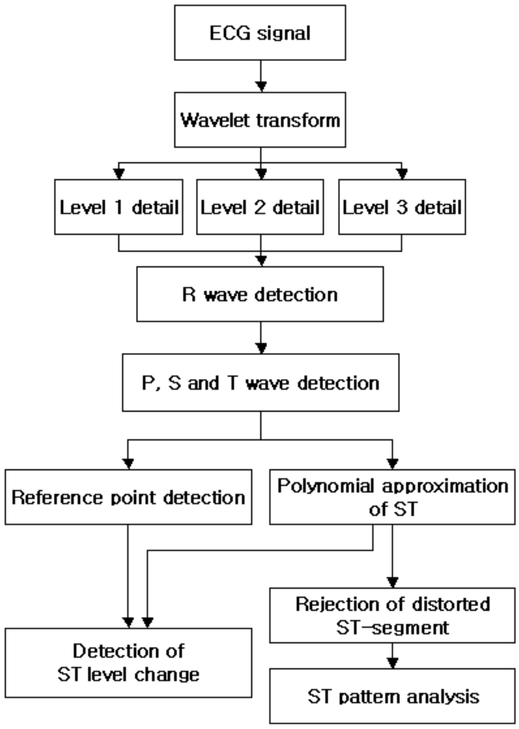

Fig.3. Block diagram of ECG analysis

The wavelet transform separates high frequency bands including QRS complex from the original ECG. Consequently, the process improves the performance of detecting R waves. The peak points of R waves are relatively higher than the other points in high frequency bands. Therefore, R waves can be detected by observing for noticeable decrease or increase of high frequency bands.

The polynomial approximation of ST-segment can detect any kind of change of ST-segment regardless of the heart rate or sampling rate. We need to know how much noise is included in the ST-segment before the pattern analysis because the noise may greatly distort the shape of the approximated ST-segment

1) Wavelet transform

The wavelet transform is used to analyze time-varying signal and compensates the weak point of the Fourier transform that divides the signal into frequency components. The wavelet transform divides input signal into high frequency bands(details) and low frequency bands using scaling function. In case of the ECG, using the wavelet transform is more effective than using the Fourier transformation, because the ECG is time varying signal which includes various frequency bands. The daubiech wavelet function is used and the decomposition level is 3 in this work

2) Detection of feature points

Fig. 4 shows the R-wave detection process. The details from the wavelet transform are used to detect the R wave, because the details disclose the QRS complex of the ECG distinctly, and the amplitudes of QRS complex in details are complementary to each other. To improve the detection accuracy of R waves, we make each maximum value of the details equal. The peak of the R wave is detected by observing the rapid increase or decrease of the detail. Before this searching process, we grouped the detail by 5 sampled data, and then we searched the noticeable increase or decrease of each maximum value of these groups for reducing R wave detection error caused by noise.

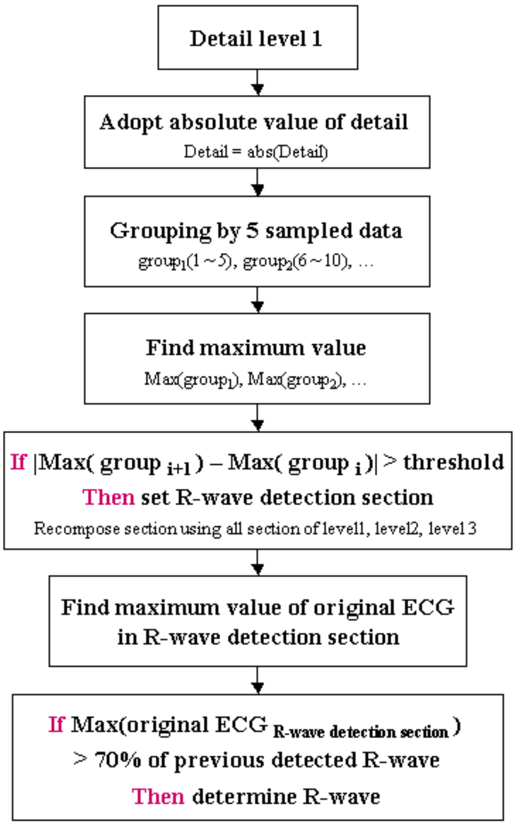

Fig. 4. R-wave detection algorithm

This process is applied to each detail respectively, and the results of each process are recomposed into the R wave detection sections. This R wave detection sections overlap with original ECG and the provisional peak points of R waves are detected by finding the maximum values of original ECG in the R wave detection section. The provisional points are taken as the true peak point of R wave to satisfy the preset criterion. P, Q, S and T wave are detected using the similar searching method based on the detected R wave, and the reference point used in ST level analysis is detected by finding a minimum slope point in the middle part of P and Q wave.

3.2 ST analysis algorithm

1) Polynomial approximation

All ST-segments are approximated by a polynomial with 9th order. In the analysis of the ST level and pattern change, the original ECG is not used. To detect a change of ST-segment, we compare between pseudo ST-segments that respectively consist of 15 data taken from the approximated ST-segment instead of comparing between original ST-segments. That is, only 15 data extracted from the approximated polynomial represent the original ST-segment

2) Rejection of distorted ST-segment

The amount of noise that affects to the process of polynomial approximation and the preciseness of polynomial approximation must be defined. The sum of error between the original ST-segment and its approximation is used to quantify the distortion of the polynomial approximation. A large error means the approximation has serious distortion due to the restriction of the approximation order or the effect of much noise. The ST-segment is rejected in the analysis process if the sum of error is larger than the pre-fixed criterion

3) ST level deviation

The monitoring of ST level deviation is performed by continuously calculating the difference between ST-segments. This work is valid under the equalization of each reference point level, because the baseline of the ECG is not constant. Fig. 5 shows an example of the equalization of reference point level. The 3 points in the middle part of ST-segment are used to compare between ST-segments

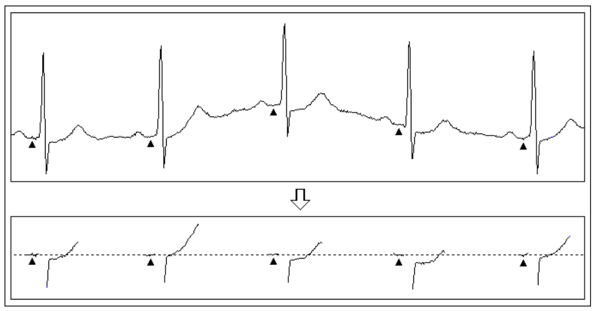

Fig. 5. Equalization of reference point level

4) ST pattern change

The detection of ST-segment pattern change is performed by continuously comparing the ST-segment pattern with the reference pattern. The difference between the ST-segment and the reference pattern becomes smaller if the pattern of any ST-segment approaches the reference pattern. The difference is calculated by the following equation,

$$D = \sum_{i=1}^{15} (ref_i - ST_i)^2 \quad , \qquad (1)$$

where, ST_i and ref_i means the pseudo ST-segment and the reference pattern respectively

4. RESULTS

Fig. 6 is the ECG measured by our device and the 'O' marks are the detected R-waves by real-time. PC software detects R-waves from the received ECG and saves ECG to file

Fig. 6. R-wave detection from designed software

The detection of feature points is performed by the proposed algorithm, and the result is shown in Fig 7. The 'O' marks represent the P, R, S and T waves. The '△' marks represent the reference points described in the previous section. The test ECG was measured from our device. We used more stable and typical shape part relatively in measured ECG, because our algorithm was designed to analyze the ECG that had positive P and T waves such as those of the ECG measured from Lead Ⅱ

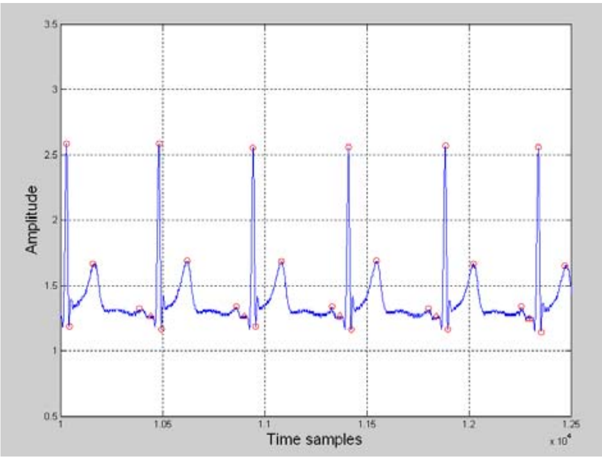

Fig. 7. Detection of feature points

Fig. 8 is the result of ST level analysis and shows the relative deviation between ST-segments. The test ECG is e0113 in European ST database, and the continuous ECG measured from one person for 2 hours. ST-segment levels of (D), (E) and (F) are higher than those of (A), (B) and (C). The noticeable level change starts in 16th heart beat of part (C).

The value of the first heart beat in (A) is zero, because of the relative deviation from the first measured ST-segment.

From the result of ST level monitoring, we can know that part (D), (E), (F) have to be saved automatically for using portable device more efficiently

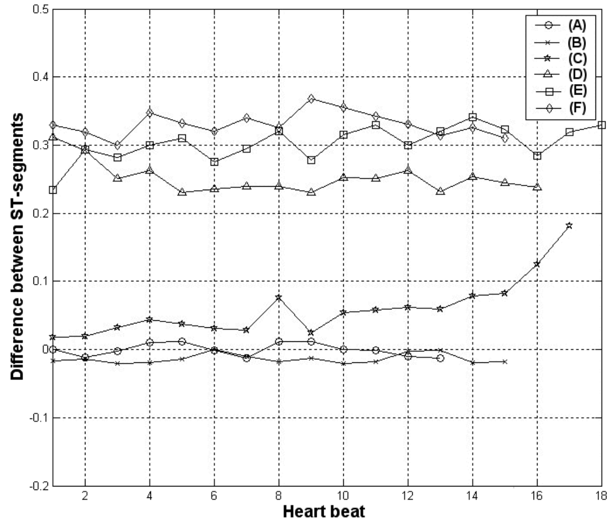

Fig. 8. ST level deviation

Fig. 9 and 10 show the reference pattern and the comparison result of the test ECG with the reference.

The test ECG is e0415 in European ST database and continuously measured from one person for 2 hours.

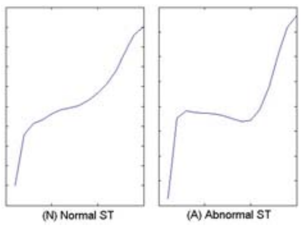

Fig. 9. Reference ST pattern

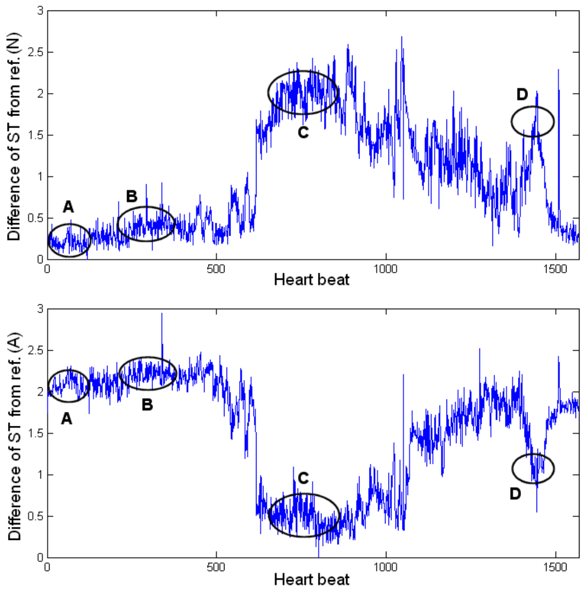

Fig. 10. The result of ST pattern analysis

There are two types in the reference pattern, one is the normal ST whose slope increases slowly, and the other is the abnormal ST whose slope decreases in the middle part. The top figure in Fig. 10 shows the comparison result of the test ECG with the normal ST and the bottom figure is the comparison result with the abnormal ST. The vertical axis is the difference between the original ST in test ECG and the reference ST. Small difference means that the approximated ST is similar to the reference in shape. From this figure, we can see that the ST-segment pattern changes from normal to abnormal in (C) and (D).

5. CONCLUSION

Ambulatory ECG monitoring system is very efficient to prevent the progress of heart disease and sudden death.

Myocardial ischemia is a disorder of cardiac function and a prime cause for the occurrence of cardiac infarction and dangerous cardiac arrhythmias. Myocardial ischemia causes the transient change in the pattern of the ST-segment. Since this symptom appears without anything wrong physically, it is necessary to record ECG automatically in time that abnormality appears in ECG.

We developed an analysis algorithm based on polynomial approximation that could compare ST-segments regardless of the heart rate or sampling period. Using this method, we found that when the ST level changes in whole ECG by calculating the relative deviation of ST levels from reference level. And, we found that when the ST pattern changes into an abnormal pattern by comparing the pattern with the reference pattern.

In addition, we minimized the noise effect and distorted approximation by rejecting the part of the ECG including much noise and distortion. Using the developed algorithm, we can determine the transient change in the pattern or level of the ST-segment.

We composed ambulatory ECG monitoring system using personal computer, and the device performed the measurement of three channels ECG.

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