ABSTRACT

A simple and efficient algorithm has been developed to detect QRS complexes at high speed (approximately 32x real time speed) from the single channel digitized ECG data records. This algorithm discriminates QRS complexes against various artifacts including those due to tape recorder amplifier saturation. Attenuation of noise (60 Hz power line frequency) is obtained in a systematic way by a suitable differentiation procedure. This algorithm successfully discriminates muscle artifacts from the distortion due to amplifier saturation. The QRS detection program has less than 5.2% type I error (misses), and less than 3.9% type II error (false detects) under extreme conditions. These errors are reduced to a negligible value in relatively artifact-free records.

INTRODUCTION

The artifacts found in the ECG records may have various sources of origin, such as the recording instruments, improper mounting of electrodes, and the patient or his immediate environment [1]. Saturation of the recorder amplifiers may lead to reduced sensitivity and signal waveform distortion. Loose electrodes can lead to an unstable ECG which may also be reduced in amplitude. Gross body movements, muscle artifacts, and contamination from the power line frequency are additional artifacts due to the patient and his immediate environment [2]. Some of the records infested with these artifacts are shown in Fig. 1. One has to identify the bonafide QRS complexes in the presence of artifacts and arrhythmias so as to minimize the type I (missing the detection of bonafide QRS complexes) and type II (false detection) errors.

QRS DETECTION SCHEME

A large number of methods based on digital filtering, matched filtering, approximation of the waveforms, feature extraction and pattern recognition have been reported in the literature. The most common parameters used are: QRS amplitude, slope, and duration. The absolute amplitude is a very unstable parameter when the data record is long, while the slope measurement may be influenced by high frequency noise. The QRS duration measurement can be erroneous in the case of a slurred T-wave. A window for slope is a good discriminatory parameter. The muscle and body movement artifacts and power-line frequency noise can be reduced by determining the slope as described in the next section. The determination of QRS duration is prone to error. This difficulty is overcome by measuring the time duration between maximum positive and negative slopes which is less variant with time and easy to measure. The parameters used in this work for the detection of QRS complexes are:

(1) The positive and negative slope windows
(2) The duration between maximum positive and negative slopes, and
(3) The maximum number of peaks (i.e. slope sign changes) within a time window.

The last criterion is used to discriminate artifacts due to the saturation of amplifiers.

DEVELOPMENT OF DETECTION ALGORITHM

SLOPE CALCULATION

The slope at any point is calculated as:

\[ s(n) = d(n+m) - d(n-m) \]  (1)

where \( s(n) \) = slope at data point \( n \) and \( d(n+m) \) = data value at \( (n+m) \)th sample point.
This successive differentiation can be viewed as a digital filter whose frequency response is obtained by taking the \( Z \)-transformation \([3]\) of (1). The system function of the filter is:

\[
S(z) = \frac{2mT}{z^m} \tag{2}
\]

The poles of the system function given by (2) are at the origin of the \( z \)-plane and the zeroes are at:

\[
z_k = \exp\left(\frac{j2\pi k}{2m}\right), \quad k = 0, 1, 2, \ldots, 2m-1
\]

The poles and zeroes of this system function are shown in Fig. 2. The sampling frequency \( f_s \), corresponds to \( 2m \) in the \( z \)-plane, and there are \( 2m \) zeroes on the unit circle for the function given by (3). Therefore, the frequencies at which the system function is zero are given by:

\[
f_k = \frac{kf_s}{2m} ; \quad k = 0, 1, 2, \ldots, 2m-1 \tag{4}
\]

The value of \( m \) is chosen so that the system function zero frequencies, given by (4), are in the vicinity of the power-line frequency. For \( m=2 \) and \( f_s = 256 \) Hz, the zeroes are at 0, 64, 128 and 192 Hz. Therefore, the 60 Hz power line frequency is expected to be attenuated for \( m=2 \). Fig. 2 shows the effect of various values of \( m \) on the derivative of the ECG signal. In the technique developed here, a suitable value of \( m \) can be selected depending upon the power-line frequency or any other frequency to be attenuated and the sampling rate.

![Fig. 2 The effect of various values of m on the differentiation of ECG recording](image)

### Recursive Updating of Positive and Negative Slope Thresholds

The QRS slope values differ from data record to data record. Therefore, the slope thresholds are updated when a new data segment is obtained from the digitized data tape. The updating is done by means of a recursive formula given as:

\[
T(n) = aT(n) + (1-a) . T(n-1) \tag{6}
\]

where IT = initial slope threshold for the nth data segment, \( T(n) \) = slope threshold for the nth data segment and \( a \) = recursive coefficient.

The value of \( a \) can be between 0 and 1. A value of \( a = 0.5 \) is found to be satisfactory.

### Duration Between Maximum Positive and Maximum Negative SLOPES, AND ELIMINATION OF HIGH-FREQUENCY ARTIFACTS

In the case of wide and abnormal QRS complexes, the QRS duration can be even up to 180 msec. Therefore, a maximum duration of 120 msec between maximum positive and maximum negative slopes has been chosen for this work. Normally, the duration between maximum positive and maximum negative slopes can be assumed to be about half the duration of the QRS complex.

Very deep notches were observed in the R wave in some of the recordings, which can be attributed to phase reversal due to saturation in the FM-recorder. However, the number of deep notches exceeding the slope thresholds were found to be less than or equal to 3. Moreover, these notches were absent during the ST segment, as shown in Fig. 1. The abnormal or distorted QRS complex is thus discriminated from noise by the absence of sharp peaks during 120 msec following a maximum of 3 peaks during the preceding 120 msec. Based on these criteria an interactive computer program for off-line QRS detection has been developed in the FORTRAN language.

### RESULTS AND DISCUSSION

Parts of 5 records representative of the observed spectrum of artifacts were used to study the reliability of the program developed. Those records were analyzed in the TEST mode of the computer program. In this mode, the ECG data and the computer detections are displayed on the Tektronix graphics terminal for visual verification. These records had from 0.03 to 3.9% type I (misses) and from 0.76 to 5.2% type II (false detection) errors. The type I errors were caused mainly by an excessively reduced slope at times. The records dominated by notched QRS complexes as well as ectopic beats and isolated artifact spikes led to the wrong detections.

The QRS detection algorithm attenuates the noise in a systematic way and discriminates the muscle artifact from the distorted QRS complexes. This algorithm recovers the recorded ECG data effectively, even in the presence of distortion due to amplifier saturation.

### REFERENCES


228