Fourier Descriptors for Morphological Analysis of Vectorcardiograms

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Abstract

The use of Fourier shape descriptors for morphological studies of vectorcardiograms (VCGs) is presented. The FDs can effectively be used as features for classification of VCGs of different clinical categories. In addition, they provide clinically significant qualitative shape information for use by the Cardiologist. The initial results of analysis of normal and abnormal VCGs are encouraging.

I. Introduction

Computer analysis of vectorcardiograms (VCGs) for morphological information has been performed using the features extracted from the spatial and planar vectors and orthogonal scalar leads [1,2,4]. Two methods of classification, namely, the logical decision-tree approach [2] and the multivariate statistical analysis [4] have extensively been employed and elaborate algorithms and programmes developed for their implementation. However, the inter-patient variability of the features and specificity and sensitivity of the methods often lead to overlap of clinical categories and resulting misclassification. A method based on the shape analysis of closed contours, namely, the Fourier descriptors (FDs), is presented in this paper for the analysis of morphology of vectorcardiograms. These descriptors can be normalized to reduce inter-patient variability. While the normalized FD features are used for diagnostic classification, the qualitative shape features derived from the unnormalized descriptors are used for report generation and for perusal by the Cardiologist. The qualitative features with their unique clinical significance have potential for effective mass screening and epidemiological studies.

The FDs have been used for recognition of handwritten alphanumeric characters and machine parts [3] and for 2- and 3-d tracking of aircraft [7]. Use of FDs of VCG loops for cardiac rhythm analysis has been demonstrated [5] and its application for data compression has shown encouraging results [6]. Thus the method has the advantage of combining rhythm monitoring and data compression with detailed analysis of morphology.

II. Method

The Fourier descriptors provide an efficient method for description and discrimination of closed contours like vectorcardiographic loops as most of the shape information is contained in a few descriptors of lower harmonics. The QRS events are identified from the spatial velocity of the axial leads. The loops are represented as a complex sequence of the corresponding axial signals and their descriptors obtained by a Fourier transform. Rhythm analysis is performed using the FDs of frontal plane QRS loops [5] and a representative beat is obtained by aligning and averaging the beats identified to be of similar shape and of sinus origin. The FDs of vector loops of the representative beat are obtained and used for morphological analysis. In this paper the results of analysis of planar QRS vector loops in the frontal, horizontal and sagittal planes are presented. As the FDs are global descriptors, the descriptors of partial loops defined over initial, middle and terminal portions of the QRS loop are also obtained. The significant descriptors of the complete and partial loops are analysed for their qualitative shape information and clinical classification. The following paragraphs describe the steps involved in this method.

A. Data Acquisition

Amplified orthogonal (X,Y,Z) lead ECG of normals and patients with ECG abnormalities is recorded on a 4-channel FM tape recorder. The analog signals are digitized on an ADS/PDP-11 Hybrid Computer. A sampling rate of 500 samples/sec and a 12-bit precision are used. Further processing is performed on the digital computer DEC-1090.
B. PREPROCESSING

The preprocessing of data involves filtering of axial signals, computation of spatial velocity and detection of component waves. The square of spatial velocity is defined as

\[
SV = (dx)^2 + (dy)^2 + (dz)^2
\]

where \(du = u(i) - u(i+1), u=X,Y,Z\). The QRS complex is identified first by a two level search on SV. P and STT vectors are then identified by searching backward and forward from the beginning and end of QRS respectively with a lower threshold 1.

C. DESCRIPTORS OF VCG LOOPS

The planar vectorcardiograms are represented as a complex sequence of the appropriate axial signals. The frontal plane QRS vector loop with its beginning at IBEG and of duration NDUR samples, for example, is represented as

\[
A(i) = \text{CMPLX}(X(IBEG+i), +Y(IBEG+i)), \quad i = 1, 2, \ldots, NDUR
\]

and

\[
A(NDUR+1) = A(1).
\]

This sequence is Foualgorithm nsformed using an inplace FFT algorithm. The resulting

\[
\text{FRONTAL QRS LOOP}
\]

\[
\text{NORMALIZED FDs OF COMPLETE LOOPS}
\]

The partial loops of the QRS are identified in accordance with the standard clinical practice. These are marked on the vector loops shown in Figures 1 and 2. The partial loops are also represented as closed contours for FD analysis by adding appropriate line(s) at the beginning and/or the end of that portion.

![Fig.1. Frontal plane QRS vector loops of a normal (above) and a patient with inferior wall myocardial infarction (MI) and their normalized descriptors. The partial loops are identified as INITIAL (first 30ms), TERMINAL (last 30ms) and MIDDLE (remaining).](image)

![Fig.2. Horizontal plane QRS loops of a normal (above) and a patient with anterolateral MI and their normalized descriptors. Note the reversal in the direction of rotation and grossly different partial loops who e descriptors (not shown here) are of high diagnostic value.](image)

III. QUALITATIVE SHAPE ANALYSIS

While the normalized FDs are useful for machine classification of VCGs into different clinical categories, the original descriptors provide qualitative shape information such as orientation, direction of rotation, rate of inscription and size of the vector loops for use by the
Cardiologist. These are described below.

**Orientation**: The orientation of the vector loop is the angle subtended by the line joining the centre of gravity C of the loop and the origin of the reference axis. The coordinates of C can approximately be obtained from the d.c. coefficient A(0) as

\[ C = 4 \times A(0)/LFFT \]

where LFFT is the length of the transform.

**Rotation**: The difference of sum of magnitudes of positive and negative descriptors, DSMPN, is computed as

\[ DSMPN = \sum_{j=1}^{K} MA(j) - \sum_{j=1}^{-K} MA(j) \]

where MA(j) is the magnitude of the descriptor A(j) and K is the number of descriptors considered on either side of A(0). If this difference in significantly positive the direction of rotation is counter clockwise and it is clockwise if significantly negative. If the magnitude of this difference is small, irrespective of its sign, the rotation is that of 'Figure of 8'.

**Inscription**: The rate of inscription of vector loops is determined by the conduction of impulses in the heart. As the rate of inscription is related to the frequency content of signals it is expected that the spectral distribution of FDs gives an idea about the conduction, facilitating localization of the portions with significant conduction delays.

**Size**: The magnitude of A(1) or A(-1), whichever is higher, indicates the size of the vector loop if the rate of inscription is uniform. Otherwise the magnitude of the largest descriptor other than A(0) gives an indication about the size.

IV. CLASSIFICATION

The real and imaginary parts of the normalized FDs are made use of for classification. The binary attributes of the qualitative shape features like orientation, rotation, inscription and size are also considered for assigning class labels. A measure of distance between the candidate descriptors and the prototypes of clinical categories is computed. If the descriptors match with one of the stored prototypes, the VCG is assigned to the class of that prototype. Otherwise, it is labelled as 'ABNORMAL' and recommended for further analysis by the Cardiologist.

V. RESULTS

The VCGs of normal subjects and patients with anterolateral, anteroseptal, inferior and posterior wall myocardial infarctions and right bundle branch blocks (complete and incomplete) have been analysed. The results are encouraging.

VI. CONCLUSION

The results of analysis of QRS vectorcardiograms indicate that the Fourier descriptors are useful for morphological studies. Further work is in progress to analyse P and STT vectors. The analysis can be extended to spatial vector loops.

REFERENCES