MULTILEAD SIGNAL PREPROCESSING BY LINEAR TRANSFORMATION TO DERIVE AN ECG LEAD WHERE THE ATYPICAL BEATS ARE ENHANCED

Chavdar Lev Levkov

Signa Cor Laboratory, Sofia, Bulgaria, info@signacor.com

ECG signal preprocessing for reliable detection and discrimination of atypical beats in electrocardiogram (ECG) is suggested. An optimal linear transformation from primary lead signals is derived which maximize certain criterion for discrimination of atypical beat from the typical one. This optimal transformation is assumed as a new ECG lead where the atypical beat is enhanced and can be discriminated easily from the typical one. The method is verified experimentally with 4 channel ECG data base of 27 records.

Keywords: ECG preprocessing, lead transformation, QRS recognition.

1. INTRODUCTION

1.1. Detection and discrimination of atypical beats

Reliable detection of atypical beats in electrocardiogram (ECG) has been a major task in automated electrocardiography the last 40 years. Numerous publications can be found [1, 2, 3]. At the moment there are quite reliable algorithms of detection based on different principles and methods most of them evristic. The problem can be described as follows: The shape (pattern) of the QRS complex of atypical beat in ECG is different from the shape of the typical beat and due to this feature it is possible to discriminate the two beats. The main problem in the automatic recognition algorithms is that they must be almost 100% reliable since rare cardiac disturbances can lead to important diagnostic conclusions. Two widely accepted methods for cardiac diagnosis – Bedside ECG monitoring and Holter recording will benefit very much if recognition reliability close to 100% will be reached.

1.2. Lead transformation

The surface ECG has spatial origin and a suitable model is a current dipole source changing its moment during different cycles of excitation of the myocardium. As a consequence of this model new leads with desired features can be obtained by simple linear transformations. Examples are the synthesis of 12-leads or orthogonal leads [4, 5, 6]. It is also possible to derive a non-standard leads which will be sensitive to some type of cardiac pathology [7, 8].

2. METHODS

2.1. Enhancement of atypical beat by lead transformation

As a general rule typical and atypical beats have different paths of excitation in the myocardium and hence the representative spatial dipole activity will be different. A logical step is to derive a lead signal which will be sensitive to atypical beat and insensitive to the typical one. This preprocessing should be performed before application of any QRS recognition and feature extraction procedure.

2.2. Transformation

The signal of each lead will be denoted as $\boldsymbol{L_i}$. A simple linear transformation can be used to derive a new signal $\boldsymbol{V}$:

$$\boldsymbol{V = a_1L_1 + a_2L_2 + a_3L_3 + a_4L_4} \,. \quad (1)$$

Here $\boldsymbol{a_i}$ are rational number coefficients.

Two quantities are derived:

$$\boldsymbol{A_{atyp}} = \Sigma \,|\, \boldsymbol{V_i} \,|\,, \quad \text{for } \boldsymbol{i} \text{ in atypical QRS time interval ;} \quad (2)$$

$$\boldsymbol{A_{typ}} = \Sigma \,|\, \boldsymbol{V_i} \,|\,, \quad \text{for } \boldsymbol{i} \text{ in typical QRS time interval .} \quad (3)$$

These quantities represent the unsigned signal area in the QRS zone.

A discrimination coefficient $\boldsymbol{D}$ is defined as:

$$\boldsymbol{D = A_{atyp} \; / A_{typ}} \,. \quad (4)$$

The best transformation (Equation (1)) must be found for each record where this ratio $\boldsymbol{D}$ reaches maximal value. For the simplicity the values of $\boldsymbol{a_i}$ were limited in the range of [$-1<\boldsymbol{a_i}<1$] and this range was divided in 32 equal discrete steps.

All possible $\boldsymbol{a_i}$ values give $\boldsymbol{32^4}$ different combination transformations. All transformations must be tested and the combination giving maximal $\boldsymbol{D}$ is the optimal one. This optimal transformation is individual for given patient record but can be applied for the whole record irrespective of the fact that it is obtained from only two beats.

2.3. Experiments

An ECG database of 27 Holter recordings from different patients was used. Each record consists of 4 linearly independent channels (leads CS4, CX6, CS6, CS3) [6]. The length is 5 s with 200 Hz sampling rate and 10 bits resolution. There is at least one atypical beat in each record. A program was written to process the signals in convenient way. The QRS time intervals in atypical and typical beats were determined manually by positioning a cursor on the screen in visually determined start and end points of the QRS. The signal in these intervals must be clean from noise. Then the easiest dumb optimization procedure was performed – for each $\boldsymbol{a_i}$ combination, the $\boldsymbol{D}$ value was computed and at the end the coefficients where the best $\boldsymbol{D}$ was obtained were used to compute the optimal $\boldsymbol{V}$ signal according to Equation (1).

3. RESULTS

The result of one of the optimized transformations (record #24) in graphical form is given on Fig. 1. The first 4 lines are the original signals from Holter recording. The bottom ECG is the V signal – the result from the transformation where the atypical beat is enhanced. This is one of the best results obtained.

Fig. 2 represents a case (record #9) where the discrimination between two beats is not so good. Three different transformations were tested and the results are denoted as V(T1), V(T2) and V(T3). Fig. 3 represents the results of individual optimal transformations applied on several records from the ECG data base.

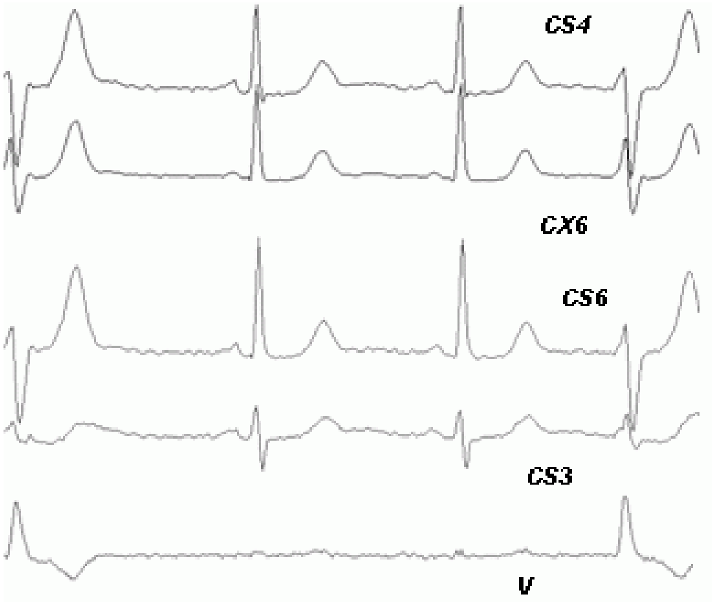

Fig.1. Result of one of the optimized transformations (record #24).

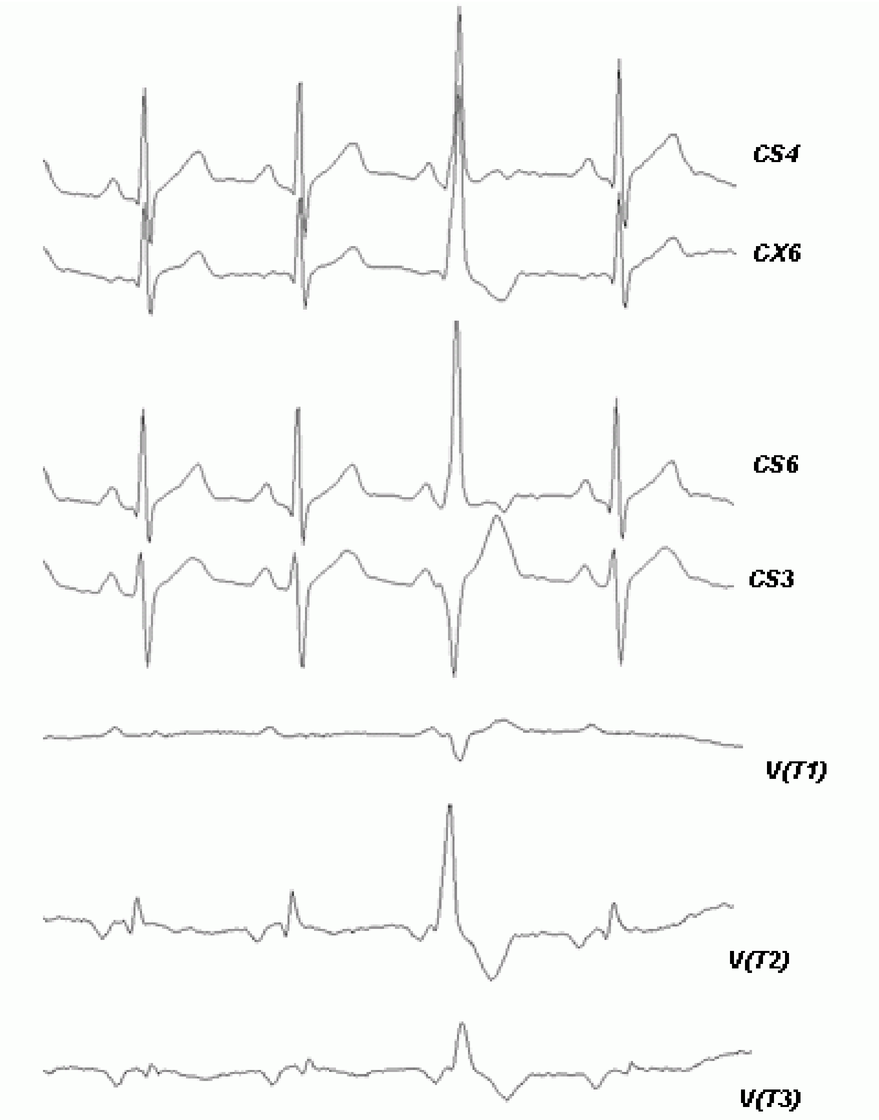

Fig. 2. Case (record #9) with not so good discrimination between two beats.

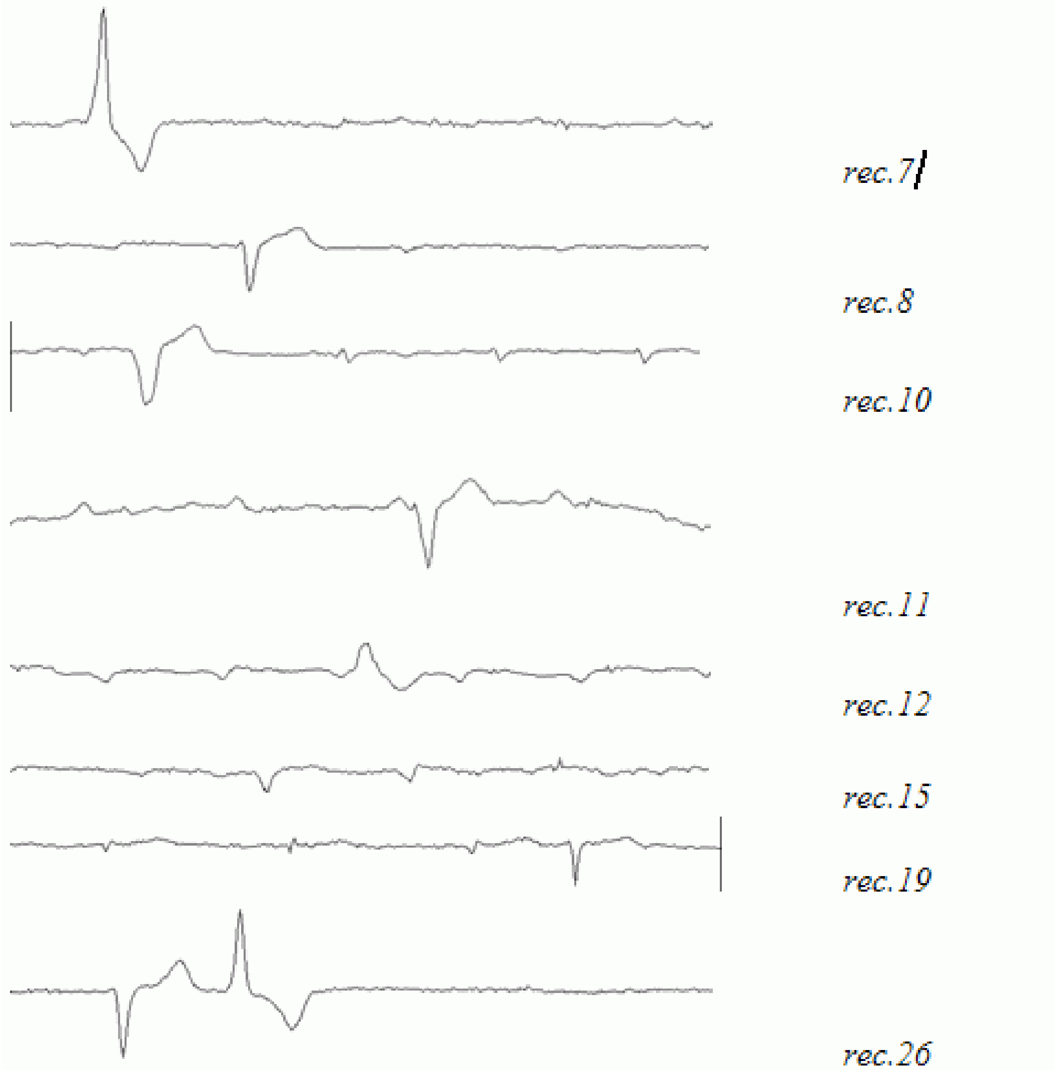

Fig. 3. Results of individual optimal transformations applied on several records from the ECG data base.

4. CONCLUSIONS AND DISCUSSION

On Fig. 1 there is nothing to expect anymore. On Fig. 2 there is significant improvement compared to primary leads. Three different transformation coefficients were tested with this record with different D criteria. T1 transformation eliminates typical beat totally but with the price of significant reduction of atypical QRS amplitude. Note that in T1 the P-wave can also be separated from the typical complex easily. T2 gives sufficient atypical QRS amplitude but the typical complex is still present.

As can be seen from Fig. 3 good results can be obtained in most of the records – the typical QRS complex almost disappears and very reliable discrimination is possible. As a conclusion in all 26 records the D ratio of atypical to typical beat was improved significantly.

4.1 Any linear transformation from mathematical point of view is a rotation and stretching of the spatial curve in multidimensional space versus coordinate system origin. The coordinates of this spatial curve are primary lead voltages as a function of time. But the optimal transformation has also a physical meaning. It can be assumed as procedure to find the best coordinate axis (or view angle) where the atypical beat voltage has a maximal value and typical beat has small value. Since the spatial orientation of two excitation processes are physically different it is very likely that such a view angle can be found and the atypical beat will be enhanced. This phenomenon is very well seen in 12 –standard leads which can be assumed as a linear transformations from the heart vector components. In some leads the atypical beats are with much higher amplitude than typical beats.

4.2 The results can be improved if other criteria for discrimination are used. It is not clear in the moment whether the worst case results are due to improper discrimination criterion and hence the transformation is not optimal, or the two beats can not be separated due to similar spatial excitation process.

4.3 The primary leads should be physically orthogonal for best results. The more leads are used the better will be the results. I suspect that for the 12-standard leads (8 independent) there will be always an optimal transformation which will enhance the atypical beat and reduce typical beat amplitude to almost zero. The only requirement is the excitation of myocardium must be different for these two beats. This might open a road to 100% recognition and discrimination of atypical beats.

4.4 This technique can be applied to discriminate other spatial processes of different origin for example P-waves from the QRS complex.

5. REFERENCES

[1] Bakardjian, H. *Ventricular beat classifier using fractal number clustering***.** Med Biol Eng Comput. Sep, 30(5), pp. 495-502, 1992.

[2] Delgado, E., et all. *Recognition of Cardiac Arrhythmias by Means of Beat Clustering on ECG-Holter Records.* Computers in Cardiology 2007, Vol. 34, pp. 161-164, 2007.

[3] Krasteva, V., I Iliev. *Automatic Analysis and Visualization of Multilead Long-Term Recordings.* Proceedings of the Sixteenth International Scientific and Applied Conference ELECTRONICS - ET2007, Book 2, Sozopol, Bulgaria, pp. 67-72, 2007.

[4] Dower, G. E., H. B. Machado, J. A. Osborne. *On deriving the electrocardiogram from the vectorcardiographic leads*. Clin. Cardiol., 3, pp. 87-95, 1980.

[5] Levkov, Ch. *Orthogonal electrocardiogram derived from the limb and chest electrodes of the conventional 12-lead system.* Medical & Biol. Engineering & Computing MBEC, 25, pp. 155-164, 1987.

[6] Levkov Ch. *Derived 12 Channel Electrocardiogram from 4 Channel Holter Electrocardiogram*, Proceedings of XI International Scientific and Applied Conference , ELECTRONICS – ET2002, Book 1 pp.144-148, Sozopol, Bulgaria, 2002.

[7] Batchlor, C. D. et all. *Computer Search for Electrocardiographic Lead Directions to Optimize Diagnostic Differentiation: A Novel Concept in Electrocardiographic Lead Design***,** , Circulation v.36, pp. 320-330, 1967.

[8] Wang, J. Y. et all. *Detection of Acute Myocardial Ischemia by Vessel-Specific Leads, Derived from the 12-Lead Electrocardiogram*. Computers in Cardiology 2007, Vol. 34, pp. 301-304, 2007.