Derived 12 Channel Electrocardiogram from 4 Channel Holter Electrocardiogram

Chavdar Lev Levkov, Dr. Sc.
Signa Cor Laboratory, Sofia, Bulgaria, info@signacor.com

Summary: There is information redundancy in 12-channel standard electrocardiogram. The 24-hours ambulatory recording (Holter recording) is used for diagnosis of ishemic heart disease and more ECG channels must be used for precise diagnosis. 4 independent Holter ECG channels are used to derive standard 12-channel ECG. The transformation is a set of linear equations. ECG data base, lead vector approach and least square fit methods are used to obtain transformation coefficients. The results from clinical point of view are satisfactory and the final conclusion is that the method is helpful for everyday clinical applications.

1. INTRODUCTION

The conventional 12-Channel Electrocardiographic (12chECG) system is widely accepted and probably annually over 99% of the world ECG recordings are made with the conventional system. On the other hand the 24-hour Holter (continues recording of ECG) is a standard clinical procedure. Unfortunately from technical and historical reasons the leads which they used are different. There are not standards for Holter leads and variety of electrodes placing exists between different commercial products. The needs for more precise ST diagnostics leads some cardiologist and firms to use all 12 leads which is not very convenient from practical point of view.

1.1 Relation to previous work

There is information redundancy in 12chECG. The electrocardiogram genesis can be represented approximately by the action of a dipole current source located in the heart region of the human torso. Only 3 components X, Y and Z of the dipole can represent the total heart activity. The orthogonal ECG systems [1] are such an example. The possibility to synthesize 12chECG from orthogonal systems by the means of linear equations were shown before [2]. This derived 12chECG was successfully used in clinical practice with the same diagnostic criteria as the normal 12chECG.
To obtain a transformation between electrocardio-signals usually two methods are widely used: Lead vectors [1, 2, 3, 5, 6] and Least-square fit method [5, 6]

2. INSTRUMENTATION AND METHODS

Two recordings for every patient are stored - voltages from the conventional and from the Holter electrodes. Each standard recording consists of 8 signals.8 linearly independent conventional signals L, R, C1, ..., C6 between the corresponding electrodes and the left leg electrode make up the conventional (12-channel) system recording. Four linearly independent signals of the Holter system CS4, CX6, CS6, CS3 [4] are the other set. No special efforts are made to acquire a high degree of electrode placement accuracy since we have tried to simulate everyday clinical practice.

A program package is used for ECG processing. Various procedures as for example filtration, linear combinations, least square (LS) fit etc. can be implemented easily in dialogue with the computer. ECG waveforms can be edited visually and plotted on a plotter if necessary. ECG recordings of 76 individuals are conducted. There are 75% males and 25% females aged between 15 and 69 (mean value 42). In 58% of them there is no evidence of heart disease. The individuals with heart disease (44% cases) are patients of a cardiological clinic and various pathologies are encountered: hypertrophy, bundle branch blocks, myocardial infarction etc. Further on, the Standard and the Computed signals will be denoted with indices "S" and "C" respectively. Two methods are used to obtain transformation coefficients - the lead vector approach and the least-square fit.

2.1 Lead vector method (method 1)

The model widely accepted in clinical electrocardiography is that of a stationary heart dipole. The voltage V_c across two electrodes, according to this model, can be represented as follows:

$$V = \boldsymbol{L_x P_x} + \boldsymbol{L_y P_y} + \boldsymbol{L_z P_z} \qquad (1)$$

where $\boldsymbol{L_x}$, $\boldsymbol{L_y}$ and $\boldsymbol{L_z}$ are the components of the so called lead vector $\boldsymbol{L}$, and $\boldsymbol{P_x}$, $\boldsymbol{P_y}$ and $\boldsymbol{P_z}$ are the components of the so called heart vector $\boldsymbol{P}$. If X, Y and Z voltages proportional to corresponding components of $\boldsymbol{P}$ are used, then the components of $\boldsymbol{L}$ become non-dimensional and eq. (1) can be transformed into:

$$V = l_x X + l_y Y + l_z Z \qquad (2)$$

The lead vector components l_x, l_y, l_z are scaled according to Frank [1].
Theoretically, data from any three linearly independent lead vectors are sufficient to compute the three components of the heart vector.
Frank has published lead vector data for various leads including leads which are very near to suggested Holter leads. From these lead vectors each orthogonal component at least theoretically can be computed

$$X = a_1 CS3 + a_2 CX4 + a_3 CS6 \qquad (3)$$

The same equations can be written for Y and Z. Knowing the lead vectors of the standard 12-leads and X, Y and Z components then the standard lead voltages Vc can be computed easily.

$$Vc = b_x X + b_y Y + b_z Z \qquad (4)$$

where b_i is the scalar component of frank lead vector of the corresponding standard lead.
It is obvious that the problem does not have only one solution. The satisfactory solution can be found if averaging is performed of several equations.
This approach has two shortcomings:

- Lead vector values are experimentally obtained from a torso model and considerable discrepancies can be observed in the individuals.

- Lead vector values are very sensitive to heart dipole location even in the region of the heart silhouette.

A mathematical consideration can be pointed out which limits the possible values of coefficients in the linear equation summation. These coefficients must be as small as possible and preferably less than 1. Large values could make the corresponding components very sensitive to individual patient lead vectors and the result will be poor regardless of the theoretical compensation.

2.2 Least-square fit method (method 2)

The classical LS fit method was implemented in order to obtain the coefficients of transformation that will minimize the mean-square error between 12leads and derived signals. To derive standard 12chECG the solution is searched in the following form:

$$V_i = a_{i1}V_{cs4} + a_{i2}V_{cx6} + a_{i3}V_{cs6} + a_{i4}V_{cs3} \qquad for\ i[1,12] \qquad (5)$$

where V_i is corresponding 12 channel signal and V_{cxx} is corresponding 4-channel signal. The goal is to obtain satisfactory coefficients a_{ik}. The coefficients a_{ik} are obtained after solving this linear system and the best fit transformation has the same form as eq. (5). The average (or global) transformation coefficients for a group of individuals can be calculated in the following way: The LS fit is performed for multiple records simultaneously. All these records are assumed to be one large data set.

2.3 Signal comparison

In order to compare computed with real 12-lead signals, both represented in discrete form, three quantities are introduced: the distance d, the correlation coefficient r and the regression coefficient b, where for the X component:

$$d_x = \left[\frac{\Sigma (X_{Si} - X_{Ci})^2}{\Sigma X_{Si}^2} \right]^{1/2} \qquad (6)$$

$$r_x = \frac{\Sigma X_{Si} X_{Ci}}{(\Sigma X_{Si}^2 \, \Sigma X_{Ci}^2)^{1/2}} \qquad (7)$$

$$b_x = \frac{\Sigma X_{Si} X_{Ci}}{\Sigma X_{Si}^2} \qquad (8)$$

The same quantities are used for all 12-leads voltages. The distance d gives a normalized estimation for the differences between two signals and is a relative measure of the mean-square error. The correlation coefficient r estimates similarities between two wave patterns and is insensitive to their amplitude differences. The regression coefficient b is a suitable measure for amplitude differences when $r > 0.9$. For identical signals $d = 0$, $r = 1$, $b = 1$.

3. RESULTS

There was no evidence of any apparent correlation between the quality of the transformation and the type of disease, therefore the patients were not divided into nosological groups.

3.1 Coefficient values

Several transformations for each 12-lead component were tested. For lead vector method different possible values of lead vectors including those presented by Dower [2, 3], as well as different weights according to eq. (3) were used to calculate the transformation coefficients. If the mean regression coefficient b was significantly different from 1, the transformation was corrected by division of the transformation coefficients to b. Transformations obtained by the LS fit method give similar results.

3.2 Estimation of the transformation performance

Table 1 presents the mean estimation values for all 76 cases of d, r and b.

	I	II	III	aVR	aVL	aVF	V1	V2	V3	V4	V5	V6
d	.53	.32	.73	.33	.85	.48	.65	.58	.19	.20	.16	.17
b	1.18	.99	.98	1.00	1.64	.99	1.05	1.03	1.11	1.03	1.06	.96
r	.87	.94	.73	.92	.58	.89	.82	.79	.98	.98	.99	.98

Estimations of similarity between computed and standard leads for optimal transformation – all 74 individuals

Difference between signals important from a diagnostic point of view might not yield essential changes in d, r or b. For example, small Q waves are very informative about some cardiac disorders, but their weight in such an integral quantity as d is too small. For this reason the 12 conventional signals and derived 12-leads signals were plotted for every case under question for additional visual inspection.

4. DISCUSSION

4.1 Optimal transformation

Probably there is not an optimal (or unique) transformation. If the lead vector theory is assumed, numerous solutions to the problem exist theoretically at least. Transformations with significantly different coefficients lead to end results with comparable accuracy. The most important limitation factors for increasing the transformation accuracy are the individual anatomy and the electrode placement. These two factors are deliberately combined into one. The relatively constant spatial configuration between the ventricular mass center and the electrodes is the desired optimum that will reduce the ECG variability. At the moment any existing procedure aimed at solving this problem will be time consuming and totally impractical for clinical purposes. The non-dipolar heart activity components also limit the accuracy of reconstruction. Non-dipolar local signal components in any of the conventional ECG leads might not be present in reconstructed leads and vice versa.

4.2 Transformation accuracy

On the table are presented the estimation data. aVL, III, and V2 leads have the worst proximity. Obviously the lack of electrode in left arm position is the reason. L lead has extremely variable characteristics between different individuals and the precordial leads are very sensitive to electrode placement.

The Holter recorders have limited frequency response (upper limit is 40 Hz) and the standard electrocardiographs have 100 Hz upper frequency response. So the direct comparison is limited also from this side.

The estimation of the transformation is given in terms of correlation coefficients and mean-square distances. For a rough estimation one has to have in mind that beat-to-beat variability an ECG signal is of the order of $r \geq 0.990$ and $d \leq 0.1$.

5. CONCLUSION

It is unlikely that the conventional 12-lead system electrodes will be used in Holter recordings in the future. The difficulties in placement of so many electrodes and the availability of standard equipment should be considered.

On the other hand, the cardiologist is well trained to accept ECG information in 12-leads form. ST depression measurements and the location of the ishemic zone can be localized in 12-leads. The diagnostic accuracy will increase if both Holter and 12-leads systems are used simultaneously. Recent developments in computer technology give new possibilities, and different ways of displaying the ECG signals can be implemented in one device. Thus, the proposed possibility of obtaining the derived 12-leads from the Holter set of electrodes is important from a practical point of view.

REFERENCES:

[1].Frank, E. (1956) An accurate clinically practical system for spatial vectorcardiography. Circulation, 13, 737-749.

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

[3].Dower, G.E. (1984) The ECGD: A Derivation of the ECG from VCG leads. J. Electrocardiol., 17, 189-92.

[4].Exercise Standards.(1995) Circulation; 91, 580.

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

[6].Левков Ч. (1987) Инженерно осигуряване на автоматизирана електрокардиография. Дис. Труд ДТН.София

The paper has been reviewed by associate professor Ph.D. Georgy Mihov from department of Electronics, Technical University – Sofia.