Computer Analysis and Recognition of Cognitive Phase Space Electro-Cardio Graphic Image

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Abstract

A new approach to construction of cognitive phase space electro-cardio graphic image (PSG image) is described. Fulfilled observation has showed that values of some features of these images are typical for the concrete person and they stay constant in practice during rather prolonged time period. It allows to apply cognitive PSG image to person identification similar to known fingerprint method. The approach to construction of computer algorithm to person recognition process on basis of cognitive average phase space graphic image is considered.

1. Introduction

When problems of computer analysis and recognition of electrocardiograms (ECG) are solved the traditional representation of ECG as a time signal $u = u(t)$ leads to errors on recognition of it's relevant segments. First of all this situation is caused by complexity of analytic description of ECG generation process in its whole variety

As is known [1], the boundaries of such segments of real ECG usually are fuzzy. So, it is unlikely that the effective and simple computational algorithms of ECG interpretation would be constructed in future when this signal is represented traditionally. Moreover, some latest investigations [2] show that the cardiorhythm of healthy people has significant variation even when organism is in quiet state. This variation is caused not only by reaction on external disturbances but essentially by fractale nature of ECG itself. In other words, as distinct from existing theories, in particular U. Cannon's conception, the frequency of human pulse does not converge to steady-state value (homeostatic value): the pulse values are significantly fluctuated even when external disturbances are absent and this fact does not mean at all that any pathology of human organism is present.

In this connection now the alternative approaches to ECG analysis and interpretation problem based on using of cognitive graphic ideas were developed [3].

The cognitive representation of electrocardiosignal as compared with traditional one supposes it's transformation to space graphic image that would be more suitable and fruitful for the purpose of it's further interpretation. Apparently, idea of such representation is generated from vectorcardiogram systems, which visualize ECG from few orthogonal leads in a special way as a bounded graphic image [4].

In this paper we suggest a new approach to creation and computer analysis of cognitive graphic cardio image. This method in contrast to known vectorcardiogram one, allows to construct the space graphic image of ECG by using only one lead.

2. Cognitive APSG Image Construction

Let us briefly review the approach to construction of cognitive phase space electro-cardio graphic image, which we suggested in [5], Suppose we have the traditional electrocardiosignal, represented as a scalar time function $u(t)$. The basic idea is to transform this signal $u(t)$ by the convolution integral operators

$$y(t) = \int_{-\alpha}^{\alpha} \omega_y (t-\tau) u(t) d\tau , \tag{1}$$

$$z(t) = \int_{-\alpha}^{\alpha} \omega_z (t-\tau) u(t) d\tau , \tag{2}$$

where kernels ω_y and ω_z were chosen in a special manner. In this case the signal $u(t)$ in each time moment t is assigned to vector $x(t)=(y(t), z(t))$. The sequence $x[1], x[2],...,x[n]$ of such vectors, which were estimated in discrete time moments 1,2,... n , creates a locus in phase space Y-Z as a specific *2D* curve. This curve was named as the cognitive phase space electro-cardio graphic image (cognitive PSG image). Thus, electrocardiosignal which in general case is represented as infinite time sequence of repeated cardiocycles was folded by means of operators (1) and (2) to bounded cognitive PSG image having space cyclic repetition.

To study this cognitive PSG image we have constructed the special interactive computer system which was realized on basis of IBM PC. This system ensures: real time entry of cardiosignal into the computer from special sensor, the operator conversion of input signal in accordance with (1) and (2) using quick computational procedures, the representation both traditional ECG curve and space graphic image at the monitor screen. Source data and treatment results are stored in system data base jointly with patient's attributes.

Fig.1 shows the example of computer processing of real ECG, which was produced by I standard (according to Einthowen) lead (see Fig.1,a) and corresponding cognitive graphic image, which was generated from this ECG by using (1) and (2) operators (see Fig.1, b).Herewith every segment of cardiocycle of source signal $X(t)$, including informative segments *P, Q, R, S, T, V,* is corresponded to quite determined areas of cognitive graphic image and vice versa.

Let us introduce now the *2D* curve denoted by $X^{(N)}$ which approximates the points of cognitive phase space electro-cardio graphic image (see Fig.1,c). This *2D* curve was obtained with aid of original computational procedures by using the points of original sequence $x[1],x[2],...,x[n]$. Let us name $X^{(N)}$ as cognitive average phase space graphic image (cognitive APSG image) of testing person. It should be observed here that cognitive APSG image is similar to known analytic curve "cardioide". It is interesting that the almost similar curve was obtained by authors [6] in process of experimental investigations of cardio functions in phase coordinates.

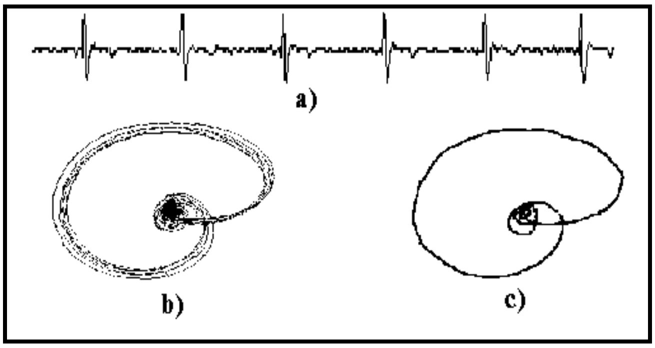

Fig. 1. The example of cognitive representation of ECG
a) Source ECG; b) PCG-image; c) APSG-image

3. Observation Results and Proposals

During prolonged period we have carried out numerous observances of cognitive phase space electro-cardio graphic images and corresponding APSG-images of different testing persons. Fulfilled observances have shown two following interesting properties of above space graphic structure:

Property 1. The values of some features of cognitive PSG images are typical for the concrete person and they stay constant in practice during rather prolonged time period. This fact is illustrated by Fig.2, that represents the cognitive PSG images of three testing persons, which were observed during two years.

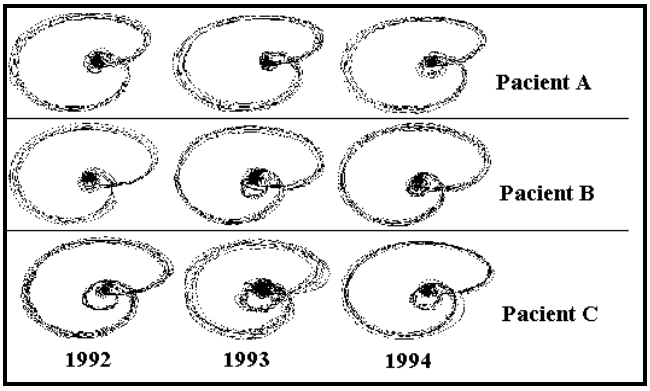

Fig. 2. The cognitive PCG images of three testing persons.

Property 2. Under the physical or emotion loads it was increased the "dispersion" of cognitive phase space electro-cardio image in respect to corresponding cognitive APSG image . Here at, the values of features, which are peculiar for the person, were not changed (see Fig.3). After a some time period the cognitive PSG image comes to initial state. This time period is peculiar for concrete testing person.

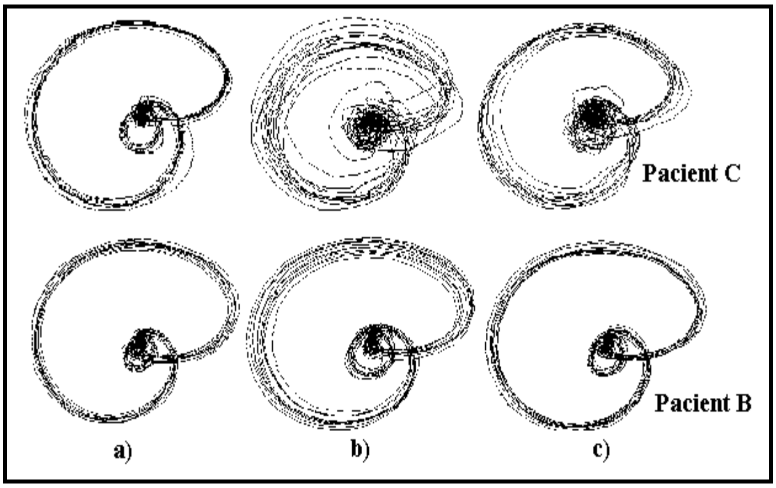

Fig.3. Changing of cognitive PSG image under loads
a) Before loads; b) Under loads; c) After 5 minutes.

Due to discovered properties of proposed cognitive PSG image we expect that it is possible to apply this approach to such branches as a person identification (like known fingerprint method) as well as to functional human state diagnostics.

4. Cognitive APSG Image Recognition

To solve the above actual application problem of person identification on basis of cognitive APSG images it is necessary to construct the effective algorithm of their recognition.

The person recognition process is further significantly simplified if we use two-stage recognition scheme.

At the first stage it is assumed that observing APSG image should be belonged to one of classes from finite set. In order to recognize these classes we should use some simple features of APSG images.

For example, one of such useful features may be the angle α of "symmetry" axis, shown on Fig.4.

As another feature it can be considered the curvature of APSG image relevant segments and may be used the new method of curvature computation, presented in [7]. In process of feature selection it should be remembered that according to our results [8] any feature ,which is not useful itself, may be useful in combination with other features.

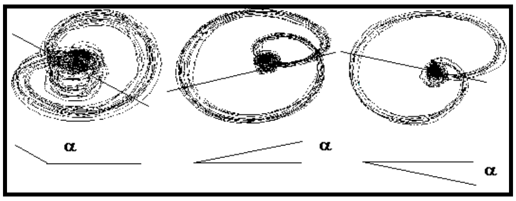

Fig. 4. Examples of PSG images with different values of angle α

The second stage provides with concrete person recognition. We consider this stage more detailed to show the process of construction the optimal decision rule.

Let us assume that definite class of APSG images, which was recognized at first stage, corresponds to the $K \geq 2$ different testing persons V_1 ,..., V_K **.** Let further $\{X_1^{(N)}$,..., $X_G^{(N)}$ $\}$ be a finite set of APSG images consisting of G ($G \geq 2K$) different N-dimensional extended vectors such that each i-th vector $X_i^{(N)} = (Y_{i\,1}, Z_{i\,1}, ..., Y_{i\,N}, Z_{i\,N})$ from this set presents N points of i-th APSG image and belongs to one of the K persons V_1 ,..., V_K.. Furthermore, there exist always such i =1,...,G and j = 1,...,G ($i \neq j$) that $X_i^{(N)}$ and $X_j^{(N)}$ belongs to V_k for every k=1,...,K.

It is assumed to be known a scalar function $l_i = l(X_i^{(N)})$ that depends on the number i only and is defined as

$$l_i = k, \quad \text{if } X_i^{(N)} \in V_k \ , \ 1 \leq i \leq G \ , \ 1 \leq k \leq K. \tag{3}$$

The set $\{X_1^{(N)},...,X_G^{(N)}\}$ together with $\{l_{1,...,}l_G\}$ gives the learning set.

To construct the optimal decision rule for recognition of testing persons suppose that we have $M \geq 2$ different so-called similarity measures $S_p^{(N)} = S_p(X_i^{(N)}, X_j^{(N)})$, p =1,...,M between any of two vectors $X_i^{(N)}$ and $X_j^{(N)}$ **.** Then an p-th decision rule corresponding to the p-th similarity measure can be derived of the follows form

$$X_i^{(N)} \in V_{l_{r(p)}},$$

if the number $r(p)$ satisfies the condition

$$S_p\,(X_i^{(N)}, X_{r(p)}^{(N)}) = \underset{1\le j\le G,\, j\ne i}{EXTR}\; S_p(X_i^{(N)}, X_j^{(N)})\,, \tag{4}$$

where symbol "*EXTR* " denotes minimum or maximum (depending on the choice of S_p (.)). Thus, it can be supposed the M different decision rules of the type (4).

Associated with any p-th decision rule (4) introduce now a p-th loss function, $L_p(i)$, which defines the loss for the erroneous recognition of the vector $x_i^{(N)}$ according to

$$L_p(i) = \begin{cases} 0 & \text{if} \quad l_{r(p)} = l_i \\ 1 & \text{otherwise} \end{cases} \tag{5}$$

in which (3) is used. This allows to evaluate the recognition quality by means of the p-th decision rule via

$$I_p = \sum_{i=1}^{G} L_p\,(i). \tag{6}$$

It follows from (6) together with (5) that decision rule (4) having the number $p = p^*$

$$p^* = \underset{1\le p\le M}{arg\,min} \sum_{i=1}^{G} L_p \tag{7}$$

is optimal in the above-mentioned sense.

Therefore expression (7) leads to the choice of the unique decision rule of person recognition based on the given learning set of G APSG images.

5.Conclusion

Thus the suggested approach allows to create the cognitive phase space electro-cardio image and corresponding cognitive average phase space graphic image, named as APSG image which are more expressive than traditional electrocardiograms. Two-stage computer algorithm of person recognition on basis of APSG image has been proposed. The optimal decision rule can be obtained by choosing from $M \geq 2$ different similarity measures between extended vectors, represented by APSG image points in finite learning set.

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