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Investigation of Human Interpretation Process Based on Eyetrack Features of Biosignal Visual Inspection

Piotr Augustyniak, *Member, IEEE*
Ryszard Tadeusiewicz, *Senior Member, IEEE*
AGH University of Science and Technology
30, Mickiewicza Ave.
30-059 Krakow Poland

Abstract— **Although well standardized, the human interpretation of biosignals highly depends on the observer experience and personal skills. In this paper, a new eyetrack-based approach is proposed for quantitative assessment of these important factors. The visual experiment carried out on cardiologists of various professional experience supplied the scanpaths data for the analysis in context of observed ECG traces. Selected parameters of the cardiologist eye trajectory were particularly correlating with the declared proficiency and the recording complexity, and thus may be interesting as an objective assessment tool for the professional staff survey. The paper proposes also a focus attention-based analysis of the human interpretation procedure and its evolution with the growth of experience. The proposed approach, without the verbalization necessity, allows the cardiologists know-how to be extracted, analyzed and implemented in the automatic interpretation algorithm for better emulate the human way of thinking.**

I. Introduction

One of the intrinsic features of the electrocardiogram and of other biosignals is the irregular temporal distribution of diagnostically important components. Nevertheless, rare are systematic investigations providing quantitative, signal content-related description of irregularities in a form applicable to an automated interpretation system. The general variability rules relating the medical content of the signal and its expected statistical parameters (e.g. instantaneous bandwidth and reliability) are very interesting in aspect of adaptive biosignals and data transmission in distributed interpretive monitoring networks. Searching for the signal meaning beyond its technical parameters and the involvement of medical knowledge implies the co-operation of experienced people. In this case, however results are very sensitive to human factors: prejudging, verbalization and others.

In this paper we follow the research on local vulnerability of the ECG record to the distortion [1] and investigate the local variations of the ECG trace conspicuity. Assuming the observer is properly engaged in the trace inspection, the gaze is controlled instinctively and the eyeglobe movements objectively represent the information gathering sequence. The analysis of experts' eyeglobe trajectories captured during the manual interpretation not only reveals regions of particular importance in the signal trace, but also reconstructs the human reasoning involved in the interpretation process. Therefore, the area of applications for eyetrack features captured during the visual inspection of biosignals include:

- objective assessment of cardiologist interpretation skills,
- prediction of required transmission channel parameters from the automatic rough estimation of medical contents,
- teaching of the visual interpretation using the guided repetition of expert's scanpath,
- application of human reasoning and non-verbalized rules in machine interpretation algorithms.

The research reported in this paper focus on the first two aspects listed above. Our aims were to select the eyetrack parameters discriminating the experienced observers and to estimate the quantitative relation between cardiac components automatically detected in the signal and its local diagnostic importance.

II. Material and Methods

Perceptual models have been recently recognized as valuable tool enriching the visual interaction of human with sophisticated devices [2] [3]. As a perceptual model of a biosignal record we understand a result of statistical processing of scanpaths, analyzed as polygonal curves in context of background visual information. The gaze order and fixation time correspond to the seeking sequence and to the amount of data gathered visually by the observer and thus represent the diagnostic importance of particular regions in the scene [4][5]. In the ECG, subsequent events in the cardiac cycle are represented by waves positions, therefore the wave start- and endpoints were selected as reference time points for the analysis of human foveation sequence aiming at estimating the local density of medical data.

A. Eye Tracking Method

In visual experiments we used the infrared reflection-based eyetracker OBER-2 [6] capturing two-dimensional trace of each eye at 750 Hz during the ECG presentation lasting for 8s. For the sidelight discrimination, the device

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uses time-differential method and provides the angular resolution of 0.02 deg. This value is equivalent to the ECG time interval of 30 ms if a standard chart plot (25mm/s) is viewed from a typical reading distance (40 cm). The position of both eyes was recorded simultaneously, however only the dominant eye was used to determine the electrocardiogram conspicuity. Fig 1 displays the physical background of the differential infrared reflection-based eyetrack acquisition.

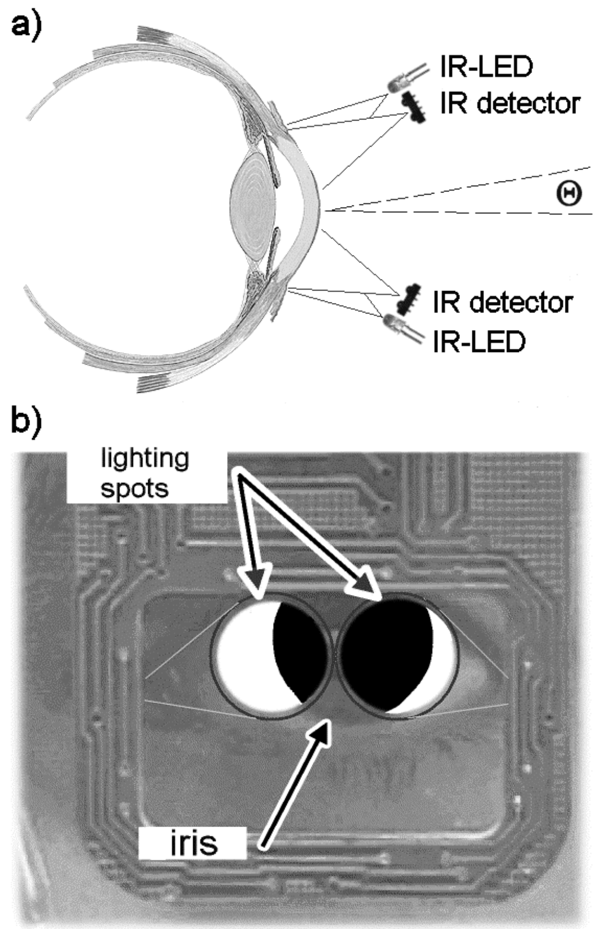

Fig. 1. a) Physical principle and b) technical details of the infrared reflection-based eyetracker OBER-2

B. Observers Population

The total of 38 volunteers were invited to the laboratory for the visual experiment. Among them there were 17 experts (12 ± 4 years of experience) and 21 students having only a basic knowledge about the ECG. All observers were asked to complete the statistical questionnaire on their ECG experience and possible eyesight defects before attempting to the visual task. Unfortunately, the optical glasses were very frequent in the experts group and particular conditions had to be observed in order to avoid side effects to the scanpaths. The glasses artifact is reduced if the relative position of glasses and eyetracker goggles remain unchanged during the calibration and the measurement phase.

C. Reference Traces

The ECG traces were randomly selected for interpretation from CSE recordings [7] and were presented as bitmaps on a 17 inch LCD. The display was simulating a conventional 12-leads paper recording. The reading distance was controlled with use of a chin support set in a distance of 40cm distance from the display center. Each ECG trace presentation was interlaced with the fixation point in the center of the display.

Each observer was asked for the interpretation of 8 traces. Each of 123 database traces appeared 2 to 4 times (2.43 on average). Pacemaker-stimulated recordings no. 67 and no. 70, were excluded for the lack of waveform reference points in the database. The reference wave borders, although not displayed, provided the cardio-physiological context for the scanpaths analysis. The horizontal axe of the scanpath is projected on the heart cycle temporal progress, represented by waves border positions, in order to estimate for each cardiac component the amount of information it contributes to the final diagnosis.

D. Scanpaths Signal Processing

Each visual experiment provides a four-column matrix representing raw eyeglobe coordinates at the evenly spaced time points [8]. Prior to the ECG traces investigation the observer is asked to gaze at the corners of displayed calibration rectangle. Identification of these gaze points in the eyetrack allows to calculate display-relative coordinates from the A/D converter output.

The further signal processing routines were developed in Matlab with regard to the aims of visual experiments. Main stages of this calculation include:

- the initial idle time and the interpretation task completion time were detected in the scanpath,
- using a set of reference wave borders provided in the CSE database, each foveation point in the scanpath was qualified as belonging to the particular ECG section,
- the number and duration of foveation points was averaged separately for each ECG section in all ECG displays,
- the contribution of each section's conspicuity was referred to the total observation time.

Since the foveation points are not directly referred to the ECG time, the intrinsic variability of waves' length does not influence the result.

Apart of the waves conspicuity statistics, the processing reveals the perceptual strategy related to main stages of the ECG interpretation process. The principle of strategy description is the identification of most attractive points coordinates and their gaze order aiming at relating foveation points to the ECG time and displayed ECG leads.

III. Experimental Results

The statistical parameters of all visual experiment results are summarized in table 1. Fig. 2 and 3 display examples of the eyeglobe trajectory over a 12-lead ECG plot and the corresponding bar graph of the attention density.

TABLE 1.
RESULTS OF ECG INSPECTION SCANPATHS ANALYSIS

Parameter	Unit	Observers	
		Experts	Students
idle time	ms	73 ± 55	88 ± 105
interpretation time	s	5.5 ± 1.5	6.2 ± 1.7
P wave foveation	%	23 ± 12	17 ± 12
PQ section foveation	%	7 ± 5	11 ± 10
QRS wave foveation	%	38 ± 15	26 ± 19
T wave foveation	%	18 ± 10	21 ± 10
TP section foveation	%	14 ± 5	25 ± 14
max. attention density	s/s	21.0	16.0
min. attention density	s/s	1.9	3.9

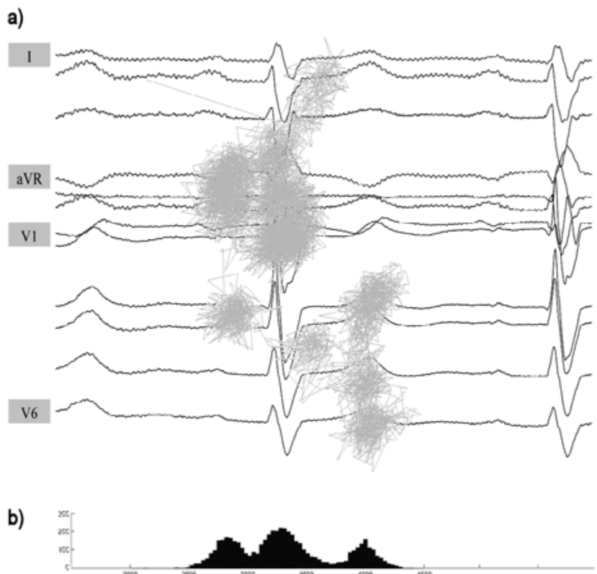

Fig. 2 a) The example of expert's eyeglobe trajectory over a 12-lead ECG plot (CSE-Mo-001) b) corresponding bar graph of the attention density

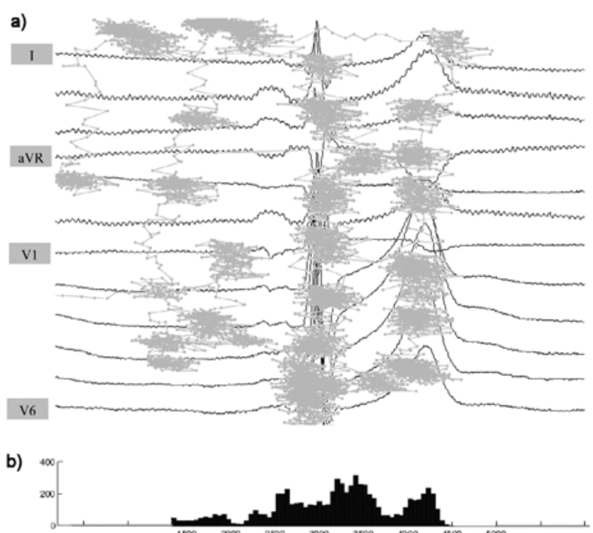

Fig. 3: a) The example of student's eyeglobe trajectory over a 12-lead ECG plot (CSE-Mo-021) b) corresponding bar graph of the attention density

Assuming students to behave as untrained observers, the only reason for difference are experts perceptual habits developed during the years of practice. These differences are particularly important within the QRS wave borders, foveated 50% longer by experts than by students. That indicates the information represented in the QRS shape as principal for the diagnostic decision.

The second group of result were derived by the analysis of perceptual strategy. Fig. 4 and 5 display examples of the strategy over a 12-lead ECG plot and table 2 summarizes the corresponding strategy description parameters.

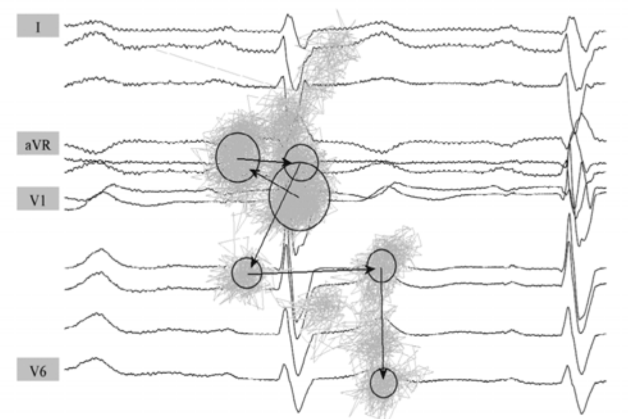

Fig. 4 The example of expert's perceptual strategy over a 12-lead ECG plot (CSE-Mo-001); the circle diameter represents foveation time.

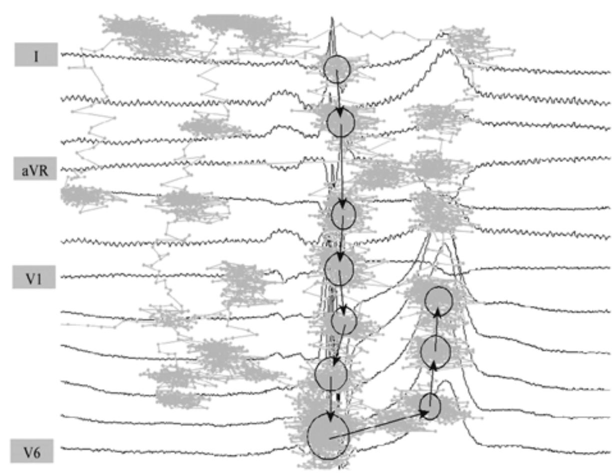

Fig. 5 The example of student's perceptual strategy over a 12-lead ECG plot (CSE-Mo-021); the circle diameter represents foveation time.

For the further studies on perceptual strategy repeatability we selected electrocardiogram images investigated by at least two observers from the same group. By comparing the positions and gaze order of five most important foveation points in the scanpaths we found that similarity between two experts is much more probable (37%) than between two students (17%). This result prove the proper representation of ECG interpretation process in the visual strategy.

TABLE 2.
QUANTITATIVE DESCRIPTION OF PERCEPTUAL STRATEGY

Parameter	Unit	Observers	
		Experts	Students
relative foveation time for the main focus point	%	31 ± 12	17 ± 10
number of foveation points[1]		6.1 ± 1.7	9.2 ± 3.9
foveation points distance	deg.	5.7 ± 2.4	3.1 ± 1.2
scanpath length to the last foveation point[2]	deg.	34.7 ± 5.1	28.5 ± 6.6
scanpath duration to the last foveation point[2]	s	3.6 ± 1.3	5.7 ± 1.5

The eye tracks gathered during the visual experiments need further exploration and contextual analysis with regard of CSE database records and the medical significance of the data. The example of unexplored area is the correctness of medical diagnoses made on a background of visually inspected traces.

IV. DISCUSSION

Visual experiments provide a quantitative description of the trace conspicuity in context of cardiac events represented in the signal. The scanpath advantages place it among most useful tools for investigation of human mental processes, surrounding perception and interaction as well as man-machine interfacing.

The scanpath, however, is very sensitive to the voluntary observer cooperation during visual tasks. Poor co-operation or misunderstanding of visual task rules was the main reason for exclusion of 18% of records from the scanpaths statistics. The result is also influenced by psycho-physiological factors difficult to control during the visual experiment:

- observer-dependent features varying from one person to another: eyesight defects influence, anatomy, perceptual and motoric skills, sex, race etc.
- observer status-dependent varying for each person from one day to another: psychophysiological status, drugs, climate influence etc.

The identification of basic phenomena only took three years of various visual experiments. Another challenge was development of the scanpaths pre-processing software towards standardizing and minimum operator assistance in recognition of desired trace features.

The scanpath statistics and perceptual strategies revealed many differences between cardiology experts and untrained observers concerning the ECG inspection methods. The most discriminative parameters of the scanpath are:

- attention density variations much higher in the expert group,
- number and distance of foveation points
- total scanpaths duration to the last significant foveation point.

All these parameters indicate a more precise and consistent way of information search in experts. Moreover, high variation of first foveation points focus time and distance suggest the hierarchical information gathering reflecting the parallel decisive process.

The reported research demonstrates that the common belief on irregular medical data distribution is fully justified for the electrocardiogram. Moreover, the local data distribution can be effectively measured through scanpaths analysis and expressed as attention density. The research address also the issue of objective assessment of cardiologist interpretation skills.

Future works in this very promising area should consider:

- extraction of heart disease-typical perceptual strategy, optimization and implementation in machine-interpretation algorithms;
- proposition of perception-based teaching and learning progress assessment rules;
- pursuit for the interpretation-related mental processes, which can not be controlled and reported knowingly without affecting the perception process.

An efficient method for the objective investigation of medical data distribution was applied to the electrocardiogram. The analysis of experts eyeglobe trajectories captured during the visual inspection of the record issues a reliable result indicating the level of medical importance for each signal section as well as observer's interpretation skills. Similar visual experiment-based methods may be applicable to other signals and images.

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[1] having at least 5% of relative foveation time
[2] to the last point having at least 5% of relative foveation time