How a Human Perceives the Electrocardiogram - the Pursuit of Information Distribution through Scanpath Analysis

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Abstract

This paper presents the scanpaths analysis technique in pursuit of the data distribution variability in the electrocardiogram.

Similar methods are already in use in many studies on active displays, man-machine interaction and human factors in interpretation of images. In all applications, the principle is a relationship between the local features of the scene and the parameters of eyeglobe trajectory captured in controlled circumstances. Experimental study of such relationship for the electrocardiogram was originally inspired by the research on adaptive discrete ECG representation using non-uniform sampling, but the area of possible application includes also physiological distortion assessment, perception-based interpretation learning and others.

Our experiment reveals important variability of signal conspicuity in context of cardiac events and significant differences between novices and experienced observers.

1. Introduction

The irregular distribution of diagnostically important features in electrocardiogram is commonly recognised. However, systematic investigations providing results in a form of quantitative description can hardly be found in the literature. Our previous works demonstrate temporal variability of ECG statistical parameters and the relation of diagnosis quality to the local signal distortion. The present paper reveals the local variations of the ECG trace conspicuity as a result of analysis of experts' eyeglobe trajectories captured during the manual interpretation. The regions of particular importance in the signal trace are detected and identified by the concentration of observer's gaze points [1].

1.1. Perceptual models

Perceptual models (PM) of various scenes have been recently recognised as valuable tool for improving interaction of a human with sophisticated devices [2] [3]. The PM of ECG is an outcome of statistical processing of scanpaths, analysed as polygonal curves in context of background visual information. The fixation time and gaze order correspond to the amount of data gathered visually by the observer and represent the diagnostic importance of particular regions in the scene [1]. In case of the ECG, the waves' positions represent subsequent events in the cardiac cycle and in this context the concentration of foveation time along the horizontal axis express the local density of medical data.

1.2. Quantitative assessment of perception

The quantitative measurement of data stream gathered from the visual scene is accurate only when considering the physiology of human perception and oculomotoric system represented in the scanpath [4]. Three groups of issues were identified as influencing the visual perception time:

- the detection of observation start and finishing moments,
- the dynamics of seeking new target and the accuracy of eyeglobe positioning
- the ambiguity of binocular perception

All these phenomena are detected in the scanpath, measured and used for correction of foveation time for each section of electrocardiogram. The heuristic-driven pre-processing algorithm provides also other observer-dependant features (e.g. the length of initial idle time or the degree of alertness) influencing the relationship of gaze time and localization of the observer's interest.

2. Materials and methods

The research on the perceptual model of the electrocardiogram was done through a series of visual experiments. Each of them consists of three stages:

1. the observer was given a certain standardised knowledge and was motivated to complete the information from the scene,
2. the observer scrutinised the scene in an unrestricted manner,
3. the observer announced the completion of the task.

At each stage, the scanpath may be influenced by unexpected observer's behaviour or other human factor, therefore high co-operation degree is essential. During the experiment the tasks were not evaluated mainly for the lack of methods available. This point, however, needs consideration in future research.

2.1. Eye tracking device

We used the infrared reflection-based eyetracker (OBER-2) [5] capturing 2D trace of each eye at 750 Hz during the 8s long presentation of the ECG. The device uses total illumination power of 5 mW/cm^2 and provides the angular resolution of 0.02 deg. This value corresponds to the time interval of 30 ms on a standard ECG chart plotted at 25mm/s, when viewed from a standard reading distance of 40 cm. Both eyes' positions were recorded simultaneously, however only the horizontal position of the dominant eye was used to determine the electrocardiogram conspicuity.

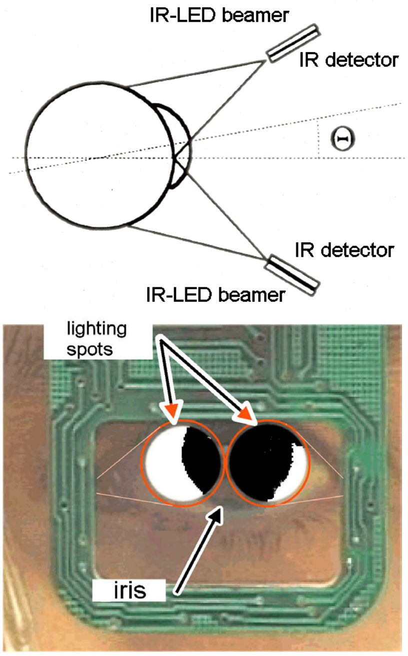

Figure 1. Physical principle and technical details of the infrared reflection-based eyetracker OBER-2.

2.2. Observers population

The recordings of scanpaths during manual interpretation of ECG traces were made in volunteers in similar laboratory conditions. For the visual experiment we invited 17 experts (12 +/- 4 years of experience) and 21 students having only basic knowledge about the ECG. Before attempting the visual task, all observers had to complete a questionnaire where they specified their professional specialisation, practise and skills in ECG interpretation as well as describe the eyesight defects they eventually have. As the experts in majority wear glasses, we had to check the side effect it has to the scanpaths. We found no significant difference in traces but only if the positions of the glasses and of the eyetracker goggles remain unchanged from the calibration to the measurement phase.

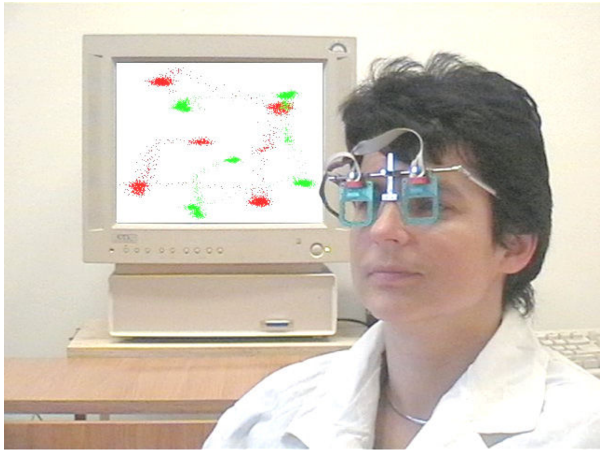

Figure 2. Cardiologist expert wearing eyetracker goggles, after completion of the calibration phase, now being ready to perform the visual task of ECG interpretation.

2.3. Reference traces

As visual targets we used randomly selected CSE recordings [6]. The reference wave borders were not displayed but provided the cardio-physiological background for the scanpaths analysis. Considering the waves' borders in the scanpath analysis was a key point of relationship between the cardiac event and the amount of information its representation contributes to the final diagnosis.

Each observer was asked for interpretation of 8 traces. Each trace from the database appeared 2 to 4 times (2.43 on average). Pacemaker-stimulated recordings no. 67 and no. 70, were excluded for the lack of waveform measurement points in the database.

Waveforms were presented on a computer display simulating a typical 12-leads paper recording. The reading distance was set to 40 cm and controlled with use of a chin support. Each presentation of the ECG trace was interlaced with the fixation point in the middle of the display.

3. Results

3.1. Scanpaths statistics

The results are summarized over all presented ECG traces in table 1. First, each foveation point in the scanpath was qualified as belonging to the particular ECG section in context of the corresponding set of reference wave borders. Next, the number of foveation points was averaged separately for each ECG section in all ECG displays. Finally, the contribution of each section's conspicuity was referred to the total observation time. Therefore, the foveation points are not directly referred to the time and the variability of waves' length does not influence the result.

Table 1. Statistical results of main scanpath parameters.

parameter	unit	observers	
		experts	students
idle time	ms	73 ± 55	88 ± 105
total 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
maximum attention density	s/s	21.0	16.0
minimum attention density	s/s	1.9	3.9

Figure 3 and 4 give two examples of the eyeglobe trajectory over a 12-lead ECG plot and the corresponding bar graphs of attention density for an expert and a student as observers. The leads sequence from the top to the bottom is: I-III, aVR, aVL, aVF, V1-V6.

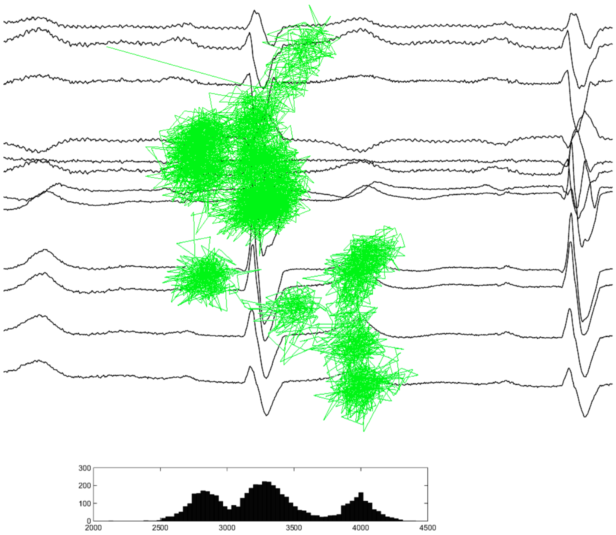

Figure 3. Example of the eyeglobe trajectory over a 12-lead ECG plot. The corresponding bar graph below displays the attention density. This is an expert scanpath (left eye) over the display of CSE-Mo001 file.

3.2. Observers categories

Two groups of observers were processed separately in order to reveal any difference of signal perception resulting from the skills in ECG interpretation. Further study of that difference is expected to explain the interpretation skills on a background of perception physiology as well as to give directions for perception-based learning methodology.

3.3. Attention density measure

Another issue was the measure of the attention density along the time axis of the ECG chart and its unit. The most natural seems the quotient of the corrected foveation time falling in the range of an ECG section and the interval length represented by this section. Since both values are expressed in seconds, the resulted attention density unit is expressed in s/s (cf. table 1).

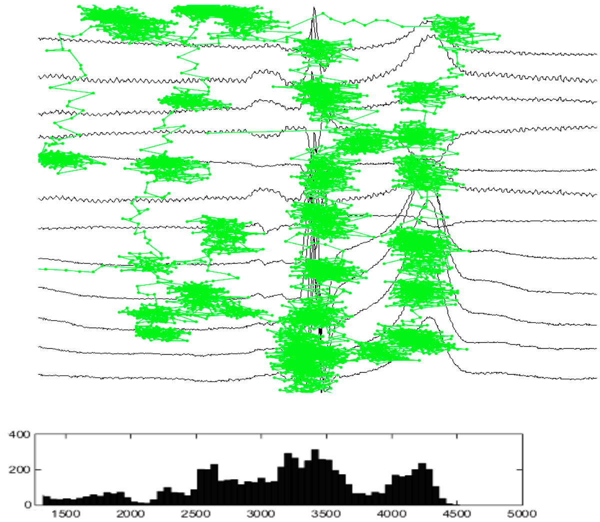

Figure 4. Example of the eyeglobe trajectory over a 12-lead ECG plot. The corresponding bar graph below displays the attention density. This is a student scanpath (right eye) over the display of CSE-Mo021 file.

4. Discussion

Particular difference in fixation time (expressed as percentage of the total observation time) was found at the QRS wave (38% - experts, 26% - students) and at the T-P section (14% - experts, 25% - students). Both groups showed irregularity in fixation time for ECG plot time unit - in experts from 21 s/s at the QRS to 1,9 s/s at the baseline and in students from 16 s/s to 3.9 s/s respectively.

4.1. Explanation of differences

In the typical image perception by an untrained observer some features in the scene are particularly conspicuous. The example given in [1] indicates the edges as attracting most foveation time. In the electrocardiogram, although the QRS complex having highest contribution of high frequency components is at the same the most important for both group of observers, the P wave, hardly distinguishable from the baseline and the very smooth T wave are lower, but not far from the QRS result. For these waves, the information is more difficult to extract and the visual pursuit needs more time.

For the group of students we can assume that they behave like untrained observers and try to find relationships of the scanpath and the local quantitative features of the scene (e. g. frequency). The difference of perception between students and experts can only be explained by perceptual and oculomotoric habits developed during the years of practice. These differences are particularly important in the QRS wave foveated 50% longer by experts than by students. That indicates the information represented in the QRS shape as principal for the diagnostic decision.

4.2. Co-operation with observers

The scanpath, although representative for the visual search, is highly influenced by the psycho-physiological factors that cannot be reliably controlled during the visual experiment. Some parameters show high variability from one observer to another. The identification of these phenomena and development of scanpaths pre-processing software took three years of various visual experiments. Currently, the software needs the operator assistance in recognition of observation start- and endpoint. Also the observer is assumed to willingly co-operate during the visual task. Poor co-operation was the main reason for exclusion of some records from the scanpaths statistics.

5. Conclusion

Initially we aimed at applying the PM in an effective non-destructive acquisition system with non-uniform sampling [7]. The resulted relation is suitable as an argument for the non-uniform sampling procedure. The presented work demonstrates that the common belief on irregular medical data distribution in the electrocardiogram is justified. Moreover, the local data distribution can be effectively measured through scanpaths analysis and expressed as attention density.

Additionally, the analysis of expert's scanpaths has some wider aspects:

- The perception is representative for mental processes, difficult to express knowingly.
- The perception-based learning is believed to overcome the problem of precise verbalisation of knowledge.
- The assessment of the ECG interpretation skills is expected to be more objective with consideration of the scanpath parameters

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References

[1] Boccignone G, Ferraro M, Caelli T. An Information-theoretic Approach to Active Vision. Proceedings of ICIAP. 2001

[2] Zangemeister WH, Stiehl HS, Freska C. Visual attention and cognition. Amsterdam: Elsevier Science, 1996.

[3] Pelz JB, Canosa R. Oculomotor behavior and perceptual strategies in complex tasks. Vision Research 2001; 41: 3587-96.

[4] Yarbus AL. Eye movements and vision. New York: Plenum Press 1967.

[5] Ober J, Hajda J, Loska J, Jamicki M. Application of eye movement measuring system Ober2 to medicine and technology. Proc. of SPIE 1997; 3061(1):327-32.

[6] Willems JL. Common Standards for Quantitative Electrocardiography. 10th CSE Progr. Report. ACCO 1990.

[7] Augustyniak P. Adaptive Discrete ECG Representation - Comparing Variable Depth Decimation and Continuous Non-Uniform Sampling. Computers in Cardiology 2002; 29:165-8.

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