CAPTURING LOCAL VARIATIONS OF ECG CONSPICUITY FOR ESTIMATION OF DIAGNOSTIC INFORMATION DISTRIBUTION

Piotr Augustyniak

Biocybernetics Lab. AGH Univ. of Science and Technology, Krakow, Poland

august@agh.edu.pl

Abstract: The paper presents a new approach to the issue of irregular distribution of diagnostic information in the electrocardiogram. The proposed method uses the analysis of eyeglobe trajectories captured from the expert during the interpretation of recordings. Main parameters of scanpaths: the eye fixation time and order are used for estimating the areas of particular doctor's interest, related to the events represented in the ECG. The correlation of fixation time and the amount of information gathered visually should consider the influence of all phenomena accompanying the visual pursuit. The automatic identification of these phenomena and the estimation of their influence are necessary for successful quantitative assessment of information distribution in the scene.

Introduction

The irregular distribution of diagnostically important features in medical images and signals is commonly recognised, however, no systematic investigations can be found in the literature. For the development of an effective ECG acquisition system with non-uniform sampling [1] the pursuit of diagnostic data distribution opens new possibility to maintain the signal diagnostability at a high level. The temporal variability of ECG statistical parameters (dynamics and spectrum) can not be directly related to the diagnostic features, therefore another quantitative description of local signal importance is necessary.

The present paper reveals the local variations of the ECG trace conspicuity as a result of analysis of experts' eyeglobe trajectories captured during the interpretation. Many studies have been done for the development of theories of visual perception and recognition [2], [3]. It has been proved that humans move their eyes over the most informative parts of the scene and that eye movements are strongly influenced by the visual content of the image and by the task being performed by the observer.

The direct relation of the eyeglobe positioning and the local scene importance is not easy to establish, since it requires the consideration of various phenomena in the human oculomotoric system accompanying the actual perception. The research described in this paper aimed at identification and estimation of influence of such phenomena. The identification is expected to be feasible in an automatic way and to avoid the inclusion of extra tasks into the visual experiment. In result, we worked out an algorithm for scanpaths pre-processing that computes a two dimensional mesh of attention density overlying the original scene. Therefore, the interpretation of the local conspicuity considers the visual context of the ECG diagnostic features.

Materials and Methods

Phenomena accompanying the actual perception: Three groups of issues were identified as influencing the visual perception time:

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

For the main visual experiment we used the infrared reflection-based eyetracker (OBER-2) [4] capturing 2D trace of each eye at 1000 Hz during the 8s-long presentation of the ECG. Before attempting to perform the visual task, the observer always calibrates the system sensitivity by a glance at the corners of steady white rectangular contour (fig. 1).

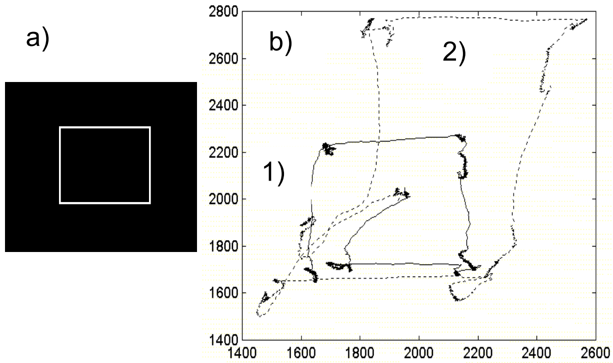

Figure 1: a) Calibration contour and b) Eyeball traces: 1) well-calibrated, 2) ill-calibrated

This work was funded by AGH Univ. of Science and Technology, grant No: 10.10.120.39

Thanks to the high sampling frequency, the processing of calibration trace yields basic parameters of observer's oculomotoric system:

- the idle time at the beginning of presentation as the interval between the presentation is displayed and the first voluntary target seeking represented by eye trajectory emerging from the noise in both dimensions.
- the dominant eye as those of lower variance of positioning during the fixation time.
- the fixation accuracy as standard deviation of eye position during the fixation time.
- the speed of new target seek as the eyeglobe velocity during the gaze shifting time
- the time for fine adjustment of eyeglobe position when the new target is captured, but not yet focussed.

All these parameters are computed in the heuristic-driven pre-processing algorithm and provide corrections to the attention density mesh for quantitative localisation of the observer's interest. The task end time is the most problematic, due to the variety of observer's behaviour after the active scene perception. For the lack of suitable universal method, the observer is asked to focus the gaze below the display once the task is done, what is detected automatically.

Perception time and the amount of information: The resolving power of the retina is limited outside the central few degrees of the fovea [3]. Therefore, all the information in the corresponding zone of the scene is captured in about 500 ms. Even if the gaze stays longer at one point no additional detail can be extracted. On the other hand, the very short presentations (0.01 - 60 ms) are "memorized" on the surface of fovea and later are analyzed by the human visual system. Thanks to this feature the sequence of images is perceived as continuous motion picture if only the presentation rate is high enough.

Due to the facts above, the correlation between foveation and attention can be expected in limited range fixation time. The pursuit of this correlation was the goal of visual experiment carried out in our laboratory. Thirty random sequences of characters (length 3 to 10) were presented to 13 observers (all male, age 18-35) in the limited time (100-800 ms). Immediately after each presentation, the observer was expected to speak out the sequence and the completeness of the information was scored. Apart from inter-personal differences, for each observer the score is better for short sequences and for longer presentation time. This result, evidenced also in everyday life, justifies the use of fixation points density as the estimate of local relevance of the image.

Quantitative measure of the ECG conspicuity: The aim of the last experiment was the identification of particularly conspicuous regions in the ECG plot that should be processed with care by the sampling adaptation algorithm in order to preserve full signal diagnosability. As visual targets we used randomly selected CSE recordings [5]. The reference wave borders, although not displayed, were used as marker points during the contextual scanpaths analysis. In this particular case, the mesh of attention density is significant in one dimension only and may be reduced to a time function. Its values represent the amount of average eye fixation time per chart time unit and the dimension is [s/s]. Another rough estimation of local ECG importance is the percentage of the whole observation time that the eyeglobe fixates at a specified region (e. g. QRS wave).

Results

For the visual experiment we invited 17 experts (12 +/- 4 years of experience) and 21 students having only basic knowledge about the ECG. 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 - 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. The results are summarized in table 1. Figure 2 and 3 give 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 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

The difference of perception between students and experts can only be explained by perceptual and oculomotoric habits developed during the years of practice. 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). 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.

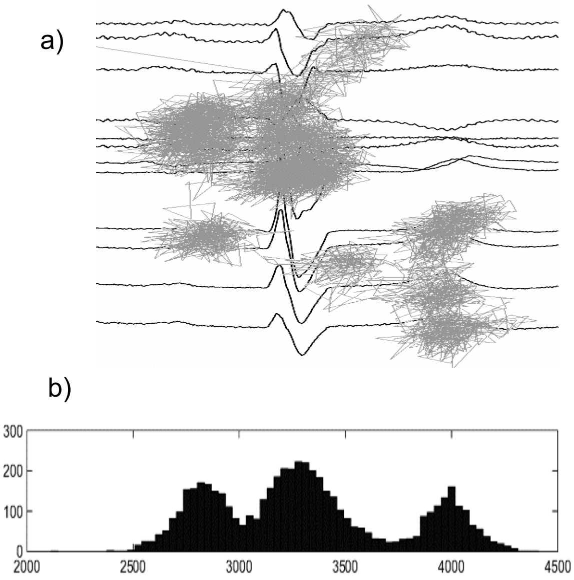

Figure 2: a) The example of expert's eyeglobe trajectory over a 12-lead ECG plot (CSE-Mo-001) b) corresponding bar graph of the attention density

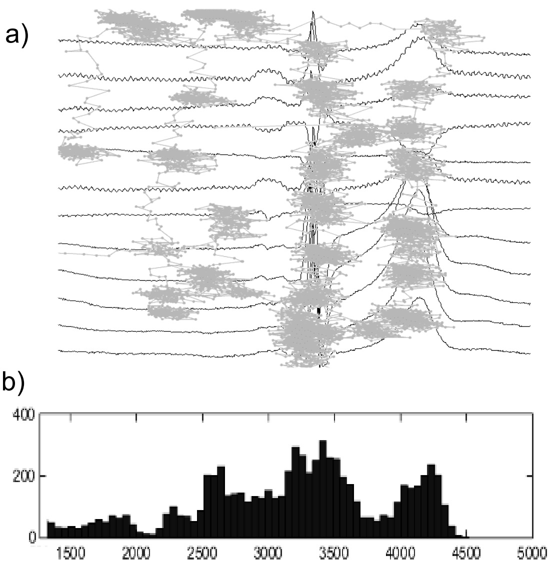

Figure 3: a) The example of student's eyeglobe trajectory over a 12-lead ECG plot (CSE-Mo-021) b) corresponding bar graph of the attention density

Discussion

Main result of the visual experiments is the perceptual model of electrocardiogram providing quantitative description of the trace conspicuity in context of cardiac events represented in the signal. The model precision is sufficient to drive the effective non-destructive acquisition system with non-uniform sampling.

The analysis of expert's scanpaths has some wider aspects:

- The perception is representative for the mental processes, difficult for a reliable modelling. The visual search can not be controlled and than reported knowingly without affecting the perception process.
- The perception-based learning is believed to overcome the problem of precise verbalization of knowledge by the speaker and imagination by the listener. Thanks to eliminate double translation misunderstandings it is considered as a valuable teaching tool and the scanpaths comparison may be used for an objective assessment of interpretation skills.
- A an objective and non-invasive method, scanpaths technique should be considered for investigation of perceptual models of various typical scenes in order to improve the human interaction with technical environment. Web pages, cockpit design, computer interfaces and advertisement displays are only first few examples.

The advantages of scanpath place it among the most useful tools for investigation of human mental processes, surrounding perception and interaction and man-machine interfacing. We believe, that our method is useful beyond the research of ECG properties and interpretation by a human.

On the other hand, the scanpath, is highly influenced by the psycho-physiological factors being out of control during the visual experiment. Some parameters show high variability from one observer to another. Some others highly depend on the psychophysiological status of the observer, drugs etc. 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 or misunderstanding of the visual task rules was the main reason for exclusion of some records from the scanpaths statistics.

Conclusions

A novel method for medical data distribution assessment was presented in an application to the electrocardiogram. The analysis of experts eyeglobe trajectories captured during the manual interpretation of the record gives an objective and reliable result indicating the level of medical importance for each signal section. The algorithm for automatic scanpath processing and identification of information-carrying sections should be improved in result of further research. The method can be extended to other signals and images. Another extension can be made towards the assessment of observer's interpretation skills.

References

[1] AUGUSTYNIAK P. (2002) 'Adaptive Discrete ECG Representation - Comparing Variable Depth Decimation and Continuous Non-Uniform Sampling' *Computers in Cardiology* **29**, pp. 165-168,

[2] YARBUS AL. (1967) 'Eye movements and vision' Plenum Press, New York

[3] PELZ JB., CANOSA R. (2001) 'Oculomotor behavior and perceptual strategies in complex tasks', *Vision Research*, vol. 41, pp. 3587-3596

[4] OBER J., HAJDA J., LOSKA J., JAMICKI M. (1997) 'Application of eye movement measuring system Ober2 to medicine and technology", *Proc. of SPIE*, vol. 3061 (1), pp. 327-332

[5] WILLEMS JL. (1990) 'Common Standards for Quantitative Electrocardiography' 10th CSE Progr. Report, ACCO Publ.

[6] BOCCIGNONE G. (2001) 'An Information-theoretic Approach to Active Vision' Proc. 11th International Conference on Image Analysis and Processing

[7] DICK A.O. (1980) 'Instrument scanning and controlling: using eye movement data to understand pilot behavior and strategies' NASA CR 3306,

[8] OBER J. K., OBER J. J., MALAWSKI M., SKIBNIEWSKI W., PRZEDPELSKA-OBER, E., HRYNIEWIECKI J., (2002) 'Monitoring Pilot's Eye Movements during the Combat Flight-The White Box', *Biocybernetics and Biomedical Engineering,* vol. 22, (2-3), pp. 241-264.

[9] TEIWES W. (1991) 'Videookulografie – Registrierung von Augenbewegungen in Drei Freiheittsgraden zur Erforscherung und Medizinischen Diagnostik des Gleichgewichts-systems' dissertation TU Berlin,

[10] WOLFE, J. M. (1996). Visual search. In H. Pashler (Ed.), Attention, . London, UK: University College London Press

[11] HASLWANTER T. (2002) 'Mechanics of Eye Movements: Implications of the Orbital Revolution' *Ann. N.Y. Acad. Sci*. 956, pp. 33–41.

[12] AUGUSTYNIAK P. (2003) 'How a Human Perceives the Electrocardiogram' *Computers in Cardiology*, vol. 30, pp. 601-604

[13] AUGUSTYNIAK P., MIKRUT Z (2002) 'Correlating the Degree of Observer's Preoccupation and the Observation Time: Visual Tasks with OBER2 Eyetracker' *JMIT* Vol. 3, pp. MT3-MT10.

[14] MIKRUT Z., AUGUSTYNIAK P (2002) 'Dominant Eye Recognition Based on Calibration of the OBER2 Eyetracker' – *IFMBE Proc.* Vol.3 2002, pp. 394-395.

[15] RAO R.P.N., ZELINSKY G.J., HAYHOE M.M., BALLARD D.H. (1997) 'Eye Movements in Visual Cognition: A Computational Study' *Technical Report 97.*1, National Resource Laboratory for the Study of Brain and Behavior, Department of Computer Science, University of Rochester, March 1997

[16] SALVUCCI D.D., ANDERSON J.R. (2000) 'Automated Eye-Movement Protocol Analysis' *Human-Computer Interaction* vol. 28