Automatic understanding of ECG signal

Piotr Augustyniak

AGH University of Science and Technology, Krakow, Poland

Abstract. The recently introduced methods of automatic understanding of digital content are very interesting alternative to the traditional scheme of signal processing in cardiology. Although the methodology of signal understanding was originally developped for medical images, significant improvements can be made also in principal areas of electrocardiogram applications: abnormality preselection, database searching and fingerprinting. This paper is devoted to introduction and discussion of advantages of this new approach.

1 Introduction

Traditional approach to the interpretation of electrocardiogram bases on enhancing and extracting selected signal features, most distinctive for the recognition of typical diseases [10]. The choice of features is optimized for representing most evident heart failures in an average patient that implies several negative consequences:

- limits the set of recognized heart diseases
- excludes the adaptivity of automatic diagnostic process to the patient-specific features and to the diagnostic goals
- requests unnecessary calculations for all the parameters and for all the recording time, regardless the uneven probabilities of particular diseases and the statistical prevalence of normal sinus rhythm.

An interesting alternative to that traditional approach was originally proposed for medical images and developed as 'image understanding' [6,8,12]. The authors suggest that the method shall also be useful for one-dimensional signals [14] and since medical measurements is a domain of particular manifestation of advantages of this new approach, serious considerations are worth to be made for automatic understanding of the electrocardiogram. The ECG signal is often reported as an example of medical record having severe abnormalities and life-critical nuances difficult to describe with a statistical signal features. That supports our belief that the semantic description of ECG contents [7,11,13], which is a background for automatic signal understanding, will be helpful in highlighting the medical information in a wide stream of extra-cardiac data. The issues of the appropriate representation of knowledge at each stage of understanding and of the optimal set of semantic rules used for description of electrocardiogram are left for future investigations.

2 Signal understanding in cardiology

The term of 'signal understanding' introduces several aspects of novelty having high importance from the viewpoint of diagnostic signal analysis:

- hypotheses-driven data search based on the a priori knowledge
- variable depth signal analysis depending on the local signal contents (usually symbolized by a T-letter)
- semantic description of the result containing a straightforward answer for a precise diagnostic question instead of a set of parameters and coefficients hardly interpretable in medical context.

These new aspects have various areas of application in the particular domains of electrocardiography. Three of them are discussed in next sections, but many others will certainly be found in the future. Leaving apart the medical impact, the bi-directional data flow in the automatic understanding scheme opens new area for optimization of diagnose-support algorithms in term of necessary calculations and event-to-result delay.

2.1 Diagnostics

The automated signal interpretation is currently a kernel of many modern diagnostic devices. However, in a common opinion the signal theory-based description of the ECG contents is not efficient in extracting diagnostic data, and the practical interpretation software is mostly based on heuristic statements. The signal interpretation is based on a traditional uni-directional data flow: processing-analysis-recognition and is therefore limited to the easy computable signal features representative for a closed set of cardiac diseases. Going further, the cardiologist is demanded to interpret a set of quantitative parameters derived mathematically from the signal (Fig. 1) but sometimes having not much in common with actual heart failure. Therefore, depending on experience, the diagnostics based on the raw signal may be more accurate than the result of parameters interpretation. The automatic understanding of electrocardiograms creates an original viewpoint and new areas of application of computers in cardiology. Instead of calculating a predefined set of statistical parameters, the method verifies several diagnostic hypotheses with use of the knowledge about the cardiac failures. The statistical parameters are calculated upon necessity with use of a method most appropriate for current hypothesis. Certainly, the advantage of automatic understanding consists in medical aspects considered throughout all the automatic process. Moreover, the result of automatic understanding is more comprehensible for human experts, since it contains alert marks illustrated by example signals and all exceptions not resolved by the software. Depending on user preferences, the alert marks may be sorted by disease severity, by hypothesis probability or simply by the occurrence time.

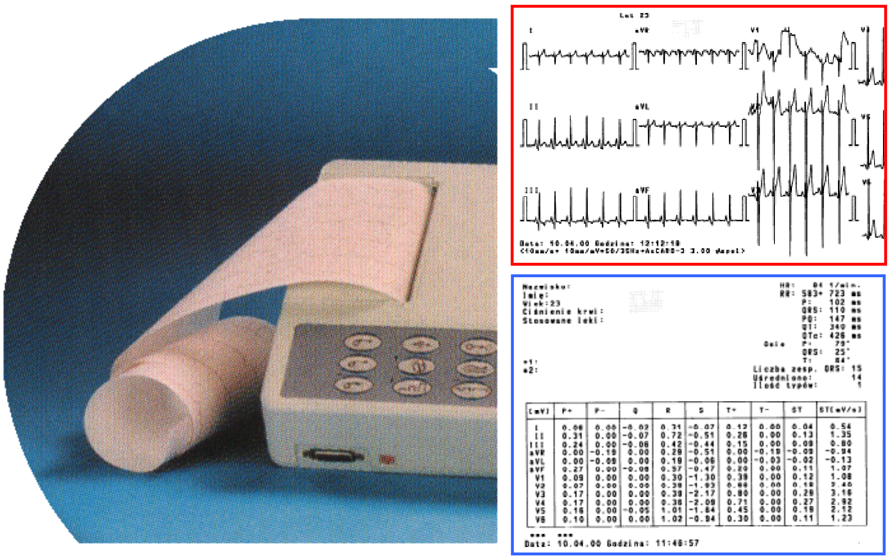

Fig. 1. Bedside ECG recorder with interpretation calculates a set of diagnostic parameters from the recorded signal

2.2 Pre-selection of abnormalities

In the remote monitoring of life-critical parameters, which is recently one of the most focused topic in the developed societies [1,2,4,5], the expert which can not be present close to his patient should be provided with the most accurate data. Recently, the majority of remote monitoring systems assumes a direct transfer of acquired vital signs to the interpretation center (Fig. 2). Leaving apart the costs of communication channel, the cardiologist is not supported in management of huge amount of data and in consequence more exposed to the risk of interpretation mistakes. A computer with an automatic understanding software provides new and efficient tool for preliminary classification of screening results. This pre-selection is based on the cognitive resonance and like a classical notion of resonance it favorites records well corresponding to a given set of diagnostic hypotheses. If a particular suspicion is confirmed as probable, additional features are extracted from the recorded signal and even a new detailed record may be requested if necessary. Those rare cases are represented by the relatively narrow column of T-letter. The advantages of such approach are twofold:

- the level of analysis depends on signal content: non relevant signals are processed at low costs and the revealed abnormalities cause a thorough investigation of the data,
- the pre-selection is based on medical findings rather than on statistical signal parameters - that corresponds well to the human investigation in electrocardiograms.

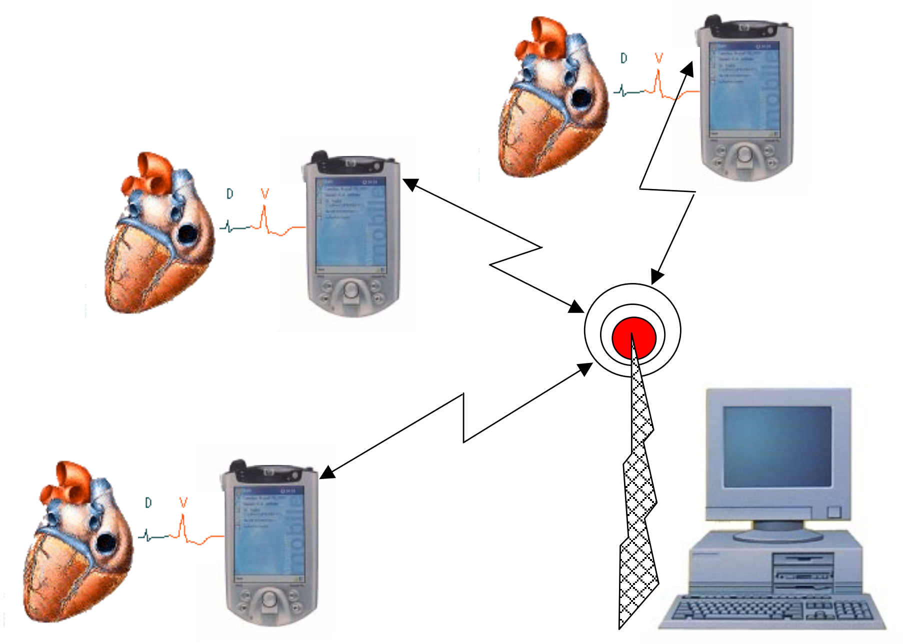

Fig. 2. Architecture of remote monitoring network for cardiology

The automatic understanding of the ECG closely follows the reasoning path of an expert without the principal disadvantage of human interpretation of signals: it does not depend on fatigue. This aspect is very important when considering the number of patients under monitoring and the responsibility of diagnostic decisions. Thanks to the use of automatic pre-selection of abnormalities, only the particular, unresolved cases need to be interpreted manually. In case of remote wearable cardiomonitor, automatic signal understanding may be implemented as adaptive diagnostic software. Since the pre-selection is made in a patient-side computer, the transmission channel is used only for alerts with representative signal sections and for the adaptation messages, therefore additional advantage is reduction of monitoring costs.

2.3 Intelligent database indexing

The multimedia database indexing (also called 'fingerprinting') is represented as a base of T-letter, and consists in extraction and description of most representative features sufficient for effective management of digital content (Fig. 3). In case of medical databases, the need of maximum diagnostic fidelity at a minimum data rate is very similar to those of signal compression, expect for no necessity to accurate data reconstruction. In this field the use of semantic description of the signal contents resulting from automatic understanding process is very promising. Its main advantage is to focus on medical aspects rather than on technical description of the ECG. Similar approach is already commercialized for management of digital media as MPEG-7 standard. In case of medical record the diagnostic meaning of the signal have to be preserved with maximum care. The unchanged content is completed by a preceding data fingerprint containing the description of most representative features from the user's viewpoint. In case of electrocardiograms these features includes intermediate data for the diagnostic parameters. The area of

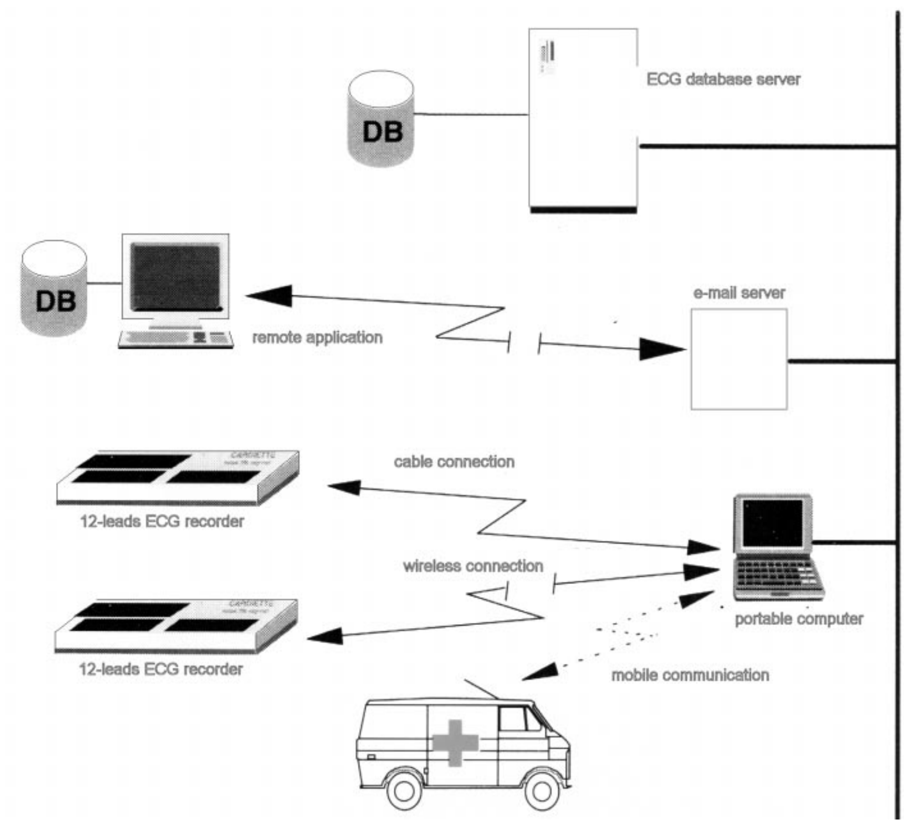

Fig. 3. Example of a wide area network for management of data and knowledge in cardiology

application of record indexing in cardiology extends beyond the traditional meaning of similarity search and includes:

- comparative diagnostics with other cases in world wide resources
- prospective therapy optimization and risk stratification, provided the database contains indexed information on the therapy history,

- remote diagnostics and surgery preparation while the patient is underway, that may significantly reduce the total intervention time in emergency cases.

Technically speaking, the novelty of this approach comes from the fact that automatic understanding uses the knowledge about signal merit content and consists of verification of some diagnostic hypotheses. During this process some hypotheses gain over the others being more probable that highlights the medical problem. The prejudgement information in a form of a series of symbols denoting the semantic context of the signal is computed for each record and put in a fingerprint area. Having a record from the particular patient, the database client has to compute the fingerprint and to send it as a database querry. The server engine compares fingerprints and selects only records matching in medical sense to the pattern. Similarity of medical sense is here understood as a similar degree of correspondence with a set of diagnostic hypotheses. We have a motivated belief that this kind of comparing is much more suitable for medical records than a direct comparison of electrocardiograms.

3 Conclusion

The automatic understanding of the ECG signal is expected to have a considerable impact on the automated diagnosis procedures. Two principal advantages over traditional interpretation methods were marked in preceding sections, but should be repeated here:

- medical context is considered at every stages of automated process, statistical parameters are calculated upon request from diagnostic hypotheses,
- the result is presented in a form much more suitable for human understanding and more appropriate from the viewpoint of further therapy.

In the future, efforts should be made towards finding the appropriate representation of knowledge at each stage of understanding and the optimal set of semantic rules used for description of ECG contents.

References

1. Chiarugi F. et al. (2002) Real-time Cardiac Monitoring over a Regional Health Network: Preliminary Results from Initial Field Testing. Computers in Cardiology **29**, 347–350
2. Gouaux F., et al. (2002) Ambient Intelligence and Pervasive Systems for the Monitoring of Citizens at Cardiac Risk: New Solutions from the EPI-MEDICS Project. Computers in Cardiology **29**, 289–292
3. Les Z., Tadeusiewicz R. (2000) Shape Understanding System - Generating Exemplars Of The Polygon Class. Hamza M.H., Sarfraz E. (eds.): Computer Graphics and Imaging.IASTED/ACTA Press.Anaheim.Calgary,Zurich,139–144

4. Maglaveras N., Gogou G., Chouvarda I., Koutkias V., Lekka I., Adamidis D., Karvounis C., Louridas G., Balas EA (2002) Using Contact Centers in Tele-Management and Home Care of Congestive Heart Failure Patients: The CHS Experience. Computers in Cardiology **29**, 281–284
5. Nelwan SP., van Dam TB., Klootwijk P., Meil SH. (2002) Ubiquitous Mobile Access to Real-time Patient Monitoring Data. Computers in Cardiology **29**, 557–560
6. Ogiela M. R., Tadeusiewicz R. (2001) Advances in syntactic imaging tech- niques for perception of medical images. The Imaging Science Journal, **49**, Issue: 2, 113–120
7. Ogiela M. R., Tadeusiewicz R. (2001) New Aspects of Using the Structural Graph-Grammar Based Techniques for Recognition of Selected Medical Images. Journal of Digital Imaging, **14(2)**, Suppl 1, 231–232
8. Ogiela M. R., Tadeusiewicz R., Ogiela L. (2002) Development of Intelligent Medical Pattern Perception Systems. Proceedings D of the 5th International Multi-Conference, Information Society - IS2002, Development and Reengineering of Information Systems, 251-254
9. Papakonstantinou G., Skordolakis E., Gritzali F. (1986) An attribute grammar for QRS detection. Pattern Recognition. vol. **19**, 297–303
10. Pietka E. (1991) Feature Extraction in Computerized Approach to the ECG Analysis. Pattern Recognition **24** 139–146
11. Tadeusiewicz R., Ogiela M. (2001) Examples of the Application of New Approach to Structural Analysis of Medical Images. Archive of Theoretical and Applied Computer Science, **13(4)**, 311–327
12. Tadeusiewicz R., Ogiela M. R. (2002) Automatic Understanding Of Medical Images - New Achievements in Syntactic Analysis Of Selected Medical Images. Biocybernetics and Biomedical Engineering, **22(4)**, 17–29
13. Tadeusiewicz R., Ogiela M.R. (2003) Artificial Intelligence Techniques in Retrieval of Visual Data Semantic Information. Menasalvas E., Segovia J., Szczepaniak P.S. (eds.): Advances in Web Intelligence. Lecture Notes in Artificial Intelligence, nr 2663, Springer Verlag, 18–27
14. Wszolek, W., Tadeusiewicz, R., Izworski, A., Wszolek, T. (2002) Recognition and Understanding of The Pathological Speech Using Artificial Intelligence Methods. Hamza M.H. (ed.): Artificial Intelligence and Applications, IASTED, ACTA Press Anaheim-Calgary-Zurich, 504–508.