IMPLEMENTING THE ECG INTERPRETATION PROCEDURE IN A DISTRIBUTED WEARABLE COMPUTER SYSTEM

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Abstract: This paper introduces a new adaptive approach to the cardiologic home-care telemetry. The key idea of the proposed software architecture is the intelligent task splitting between the patient-side wearable computer and the stationary server in a health care center. The predominant part of typical easy records is interpreted by the remote device without reaching his computational limits and providing a fairly condensed diagnostic result over a wireless communication channel. Only few rare cases, computationally too difficult for a wearable recorder, have to be transmitted as raw signal to the central computer. The wearable computer software was re-designed and supports the automatic upload and linking of complementary interpretation procedures on request.

INTRODUCTION:

Wearable computers became currently spread as a valuable tool for remote heart diagnostic and surveillance of elderly people [1] [2]. Home-care ECG recorders are found extremely useful when a long-term acquisition is necessary from a remote or sparsely populated area. However, two most common architectures of interpretation networks [3] [4] are often complained about:

- the direct signal transmission involves high cost of telecommunication service,
- the performance of remote interpretation quality is often affected in result of the compromise of computational power to energy consumption.

An alternative approach is currently developed in AGH-UST Biocybernetic Laboratory [5] and assumes that the interpretation process is performed not at a particular network end but as a distributed computing task. From the user viewpoint, main advantage consists in flexible adaptability of recording device software to the patient status, current diagnostic goals and transmission channel availability. The star-shaped network is managed by a stationary server node receiving medical data at diverse processing stages (from raw signals to a full diagnostic outcome) and includes several remote wearable recording devices communicating over the worldwide range bi-directional GPRS link (fig 1).

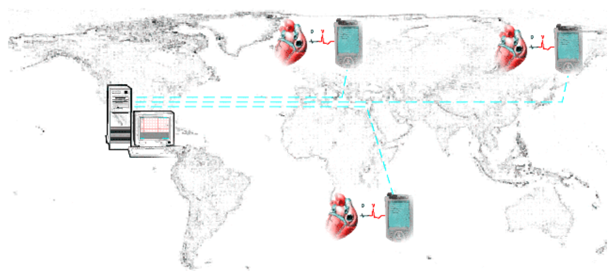

Figure 1. Global architecture of the worldwide home-care service.

Main novelty of our approach is the automatic completion of the remote device interpretation procedure, with subroutines uploaded from the supervising node [6]. The remote modification of wearable recorder functionality is achieved in three independent aspects:

- modification of calculation parameters,
- upload of specific diagnostic procedures as dynamically linked libraries,
- adaptation of reported information content and priority.

The modification is initiated from the server side as a result of fuzzy logic decision considering:

- available computational power of a specific remote device,
- patient status and diagnostic goals variability
- frequency and probability of unresolved ECG strips occurrence

Modification of calculation parameters is also used for the adjustment of interpretation procedure to the patient-specific signal features.

METHOD:

Technically writing, the remote recording adaptability was reached with use of two layers of dedicated software. The basic layer contains unalterable modules: data acquisition and wireless communication services as well as fundamental user interface procedures. The flexible overlay includes all interpretation and report formatting procedures programmed as diagnosis-oriented dynamic libraries, which may be charged and released upon request. This approach not only personalizes the remote recorder to the patient-specific signal features, but also gives an unprecedented flexibility required for a pertinent real-time reaction for unexpected events. Most common and frequent episodes are interpreted by the wearable device software and issue only a tiny and cost-acceptable data stream. The occurrence of any difficult or unresolved event is reported as a short strip of raw signal for the interpretation by the node software automatically, or in very rare cases with the assistance of expert cardiologist (fig 2).

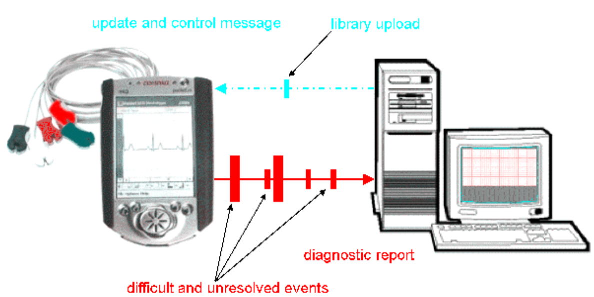

Figure 2. Elements of co-operation between the remote recording device and the node server.

The re-programmable overlay contains also report formatting procedures [7], therefore the report content, data priority and reporting interval can be adjusted remotely. Here again, the decision is justified by the patient status determined from the past diagnostic results, but occasionally the patient can also trigger a report regardless the current reporting interval. The use of circular memory buffer provides a short strip of signal directly preceding the event button press for the analysis and reporting. The data communication format contains mandatory data description fields and optional data containers of variable size. This approach creates space for future extensions of diagnostic signals, data, patient communications, patient positioning coordinates, jpeg pictures etc.

Other crucial issue is data priority in the report. Normal case reporting may include supplementary data and no diagnosis consistency is lost if it is delayed in the network. Abnormal case report is a potential emergency message carrier and must not be appended by additional data. In this case the overall network transmission delay is expected not to excess the value of 2s typical for the bedside digital electrocardiographs.

Additional supervisory process is necessary for optimal information management and task sharing. Such procedure consists a part of each interpretive function running on the remote recorder aiming at diagnosis quality assessment. At this point the software decides what was reliably interpreted by the recorder and what is too difficult and needs further processing by the server. Another supervisory procedure is running on the server within each processing thread and manages the interpretive libraries for each co-operating remote recorder (fig. 3). At this point the software analyses remote recorder errors, estimates the probability of events repetition and the available remote computational power in order to decide about uploading a complementary interpretive library to the wearable device.

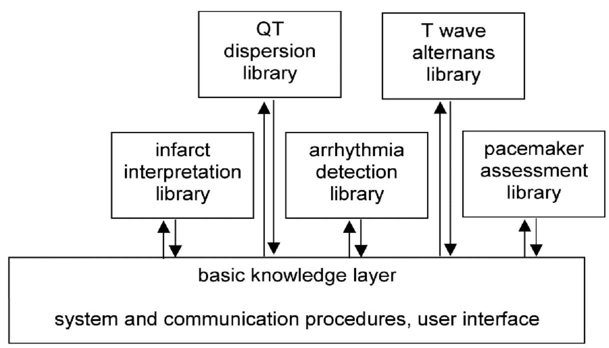

Figure 3. Scheme of dependencies between the remote recorder basic knowledge layer and examples of optional dynamically linked libraries.

The co-operation of the network elements is conceptually based on a model of human relations often observed in cardiology: numerous general practitioners interpret most of cases on they own reporting only most difficult problems to the expert and getting from him hints increasing their diagnostic skills.

RESULTS:

At present, the prototype of the remote recorder is made on a basis of a PDA computer with a wireless modem and 3-channels micro-voltage acquisition card. The electronic circuitry was subject to tests performed in accordance to the appropriate IEC standards for ECG recording devices [8] [9] [10].
The electrical tests were performed on a single prototype device in a specialized laboratory complying with national measurements standards. Main results of these measurements are displayed in table 1.

Table 1: Selected results of recorders electrical tests

parameter	value	conditions
1 LSB linearity range	-1.87 ÷ 1.83 mV	2mV range
CMRR	92 dB	DC ÷ 100 Hz worst case
bandwidth	0.03 ÷ 100 Hz	-3 dB
voltage noise (ref. to input)	8,3 μV	0,1 ÷ 10 Hz
channel crosstalk	-77 dB	DC ÷ 100 Hz worst case

As the transmission channel is digital and bit-accurate, the electrical tests of wireless communication were limited to the electromagnetic compatibility and interference immunity issues. The interference immunity test was performed on five health volunteers in various life conditions (at rest, during physical exercise, during sleep) and the distant software reconfiguration was validated with use of an ECG simulator. The results confirm the overall conformance of the network cooperation to the initial assumptions.
As the main issue for the further investigation was indicated the compatibility of recorder interpretation software and its complementary part in the node workstation. The server procedure, although designed for different platform, should be able to continue the ECG interpretation from the point where it was abandoned by the remote recorder as too complicated.

DISCUSSION AND CONCLUSION:
For the remote recorder software prototype the assessment of correct interpretation probability was made on context of the server software outcome. With respect of the true disease representation, this comparison is sufficient for the decision on whether the processing is reliably done by the recorder or the signal have to be entirely transmitted to the server.
The technology of distributed ECG interpretation is mastered in its key points: wearable device re-programmability, communication issues and network management. Now, many new challenges open to the cardiologists thanks to the flexible interactive diagnostic link not constrained by the time or distance. The future of our proposal lies in the doctor's hands. What will they find useful?
During the tests some issues were postpone for further investigations and some other were solved approximately. Main questions to answer by the experts are:
- how should the diagnostic result influence the reporting frequency?
- which additional data should be requested and how it should be processed as a consequence of detected heart abnormality?
- how to justify the decision on the remote update of interpretation library on a medical background of disease severity and probability of re-occurrence.

As it was mentioned before, the area of possible applications of a remote interpretive recorder network extends far beyond the diagnostic standards of today's cardiology.
The ideas include, but are not limited to:
- acquisition and processing of other vital signs as necessary for the diagnosis: (e.g. breathing, pulsoxymetry, noninvasive blood pressure, electromyography),
- cooperation between interpretation centers and specialized diagnostic services,
- bi-directional messaging with the remote patient, automated or man-operated guidance on physical load, drugs intake or control the emergency (pre-medical aid).

From the technical viewpoint the research is accomplished with success. Certainly, practical validation of the usability of remote monitoring networks and new features they offer is now expected from medical world. Any suggestions are welcome!

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References:

1. Chiarugi F., et al. Continuous ECG Monitoring in the Management of Pre-Hospital Health Emergencies Computers in Cardiology 2003;30:205-208
2. Khoór S., et al. Internet-Based, GPRS, Long-Term ECG Monitoring and Non-Linear Heart-Rate Analysis for Cardiovascular Telemedicine Management Computers in Cardiology 2003;30:209-212
3. Gouaux F., et al. Ambient Intelligence and Pervasive Systems for the Monitoring of Citizens at Cardiac Risk: New Solutions from the EPI-MEDICS Project Computers in Cardiology 2002;29:289-292
4. Pinna GD., et al. Home Telemonitoring of Chronic Heart Failure Patients: Novel System Architecture of the Home or Hospital in Heart Failure Study Computers in Cardiology 2003;30:105-108
5. Augustyniak P. PDA-Based System for Cardiology Home Care and Pregnancy Monitoring. International Congress on Electrocardiology, 2004
6. Augustyniak P. Automatic understanding of ECG signal. [In:] Kłopotek MA., Wierzchoń ST., Trojanowski K. (eds) Intelligent Information Processing and Web Mining. Springer 2004;591-594
7. Augustyniak P. Optimizing the machine description of electrocardiogram. Journal of Medical Informatics and Technology 2004;8:MM-41-MM48
8. IEC 60601-2-25 Medical electrical equipment: Particular requirements for the safety of electrocardiographs. 1999.
9. IEC 60601-2-27 Medical electrical equipment: Particular requirements for the safety electrocardiographic monitoring equipments. 1994
10. IEC 60601-2-47 Medical electrical equipment: Particular requirements for the safety, including essential performance, of ambulatory electrocardiographic systems. 2001