WACBE World Congress on Bioengineering 2007
Bangkok, THAILAND

TASK-DEPENDENT ADAPTABILITY OF REMOTE RECORDER IN A CARDIAC SURVEILLANCE NETWORK

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The paper discusses a reconfigurable software for automated ECG interpretation and reporting. The target application is a star-shaped wireless surveillance network for out-hospital patients and elderly people. The interpretation process is distributed between the remote recorder and the central server in order to provide maximum adaptability to the patient status at optimal diagnostic reliability and use of resources. Such approach implied significant communication cost and suffers from cumulative interpretation errors. Studying various existing applications we usually encountered a very similar architecture based on the upgradeable modules concept. The presented alternative approach considers medical data at various processing stage in context of their volume, priority, reliability and interdependence with a goal of optimal performance and adequacy of medical report to the expectations implied by the patient status. The aim of the newly proposed architecture is twofold: cut the error propagation chains and reduce the data volume at early stages of processing. Verification of the proposed prototype was based on the comparison of diagnoses made by distributed and static software, frequency and correctness of software reconfiguration attempts and on the analysis of dynamic response to a sudden event. As demonstrated in the tests, 768 (89,6%) of adaptation attempts were technically appropriate, among of them 643 (99,4%) software upgrades and 97 (80,2%) software replacements yielded diagnostic results similar to the reference observed from the experts' survey. The software adaptation during the seamless ECG monitoring made on a background of automated diagnosis verification and resources assessment yields the unprecedented advantages of the surveillance system.

INTRODUCTION

With support of the progress in wireless communication technology, seamless out-hospital surveillance of physiological parameters matured recently very fast. Two principal types of electronic devices are in use in today marketed systems: patient-side recorders and central servers fulfilling in a surveillance network strictly defined tasks. *Per analogiam* to the human world it is expected however, that these devices could cooperate adaptively. The uniformity, sometimes mistaken with 'standardization' is a significant drawback and often leads to unnecessary computing and transmission channel overload caused by irrelevant or unreliable data [1-2]
Personalization and high responsiveness to the patient status variability aim at simulating the continuous presence of medical staff. Our approach assumes the use of software reconfiguration tools or in future version even hardware reprogrammability to achieve this aim. Since the automatic software reconfiguration is a very sensitive task, it has to be investigated in details and carefully implemented with regard of multiple technically originated and medically justified criteria. The medical principles were based on the hidden survey about diagnostic parameters preferences made automatically in cardiologists [3]. This paper presents the concept of the adaptive system, but focuses more on technical description of medical data attributes relevant for optimal automated task sharing in a surveillance network.

MATERIAL AND METHODS

Data relevance and priority

The key point of our concept is multidimensional optimization of the interpreting software architecture realized by dynamically linking of applicable libraries uploaded from the server via bi-directional wireless channel. The optimization is limited by two constraints: by resources availability, including wireless channel throughput and by the mutual interdependencies of procedures implying their precedence and role in the processing chain. We abandoned the commonly used rigid architecture and took an opportunity of re-designing the interpretive software to put in front procedures highly effective in data stream reduction [4].

Effective management of the ECG interpretation process rises up a necessity of complementary statistical description of elementary interpretation procedures and the issued data. These attributes are used by the automatic management software to optimize the processing chain by giving priority to the relevant and accurate data and reducing unnecessary computation and data flow. Both the relevance and the expected accuracy depend on patient status, thus the automatic management of interpretation process leads to personalization and task adaptation of the remote recorder. Four principal attributes (fig. 1a) are:

- input quality (quality of the input signal, reliability of preceding procedures),
- data dependence (dependence on input datastream, previously computed parameters, preceding interpretation stages),
- result reliability (input quality, procedure accuracy which implies complexity)
- result priority (considering diagnostic goal and patient status).

Gradual repository of interpretation procedures

Gradual increase of computation complexity with the improvement of result accuracy is commonly observed in software engineering. Although the rule is not precise, we assume this relation to be linear. The repository consisting of finite number of different algorithms (i.e. originating from various manufacturers) performing a particular elementary ECG interpretation step was sorted by expected result accuracy. Similarly, the interpretation procedures sequence still exhibits the complexity rising for the improving accuracy. The management of interpretation process considers the external conditions and requirements and continuously seeks for best available accuracy to complexity ratio yielding the expected accuracy of diagnostic result (fig. 1b). Each time the accuracy expectations are not met, the procedure or procedures chain are un-linked and replaced by upgraded or downgraded alternative version.

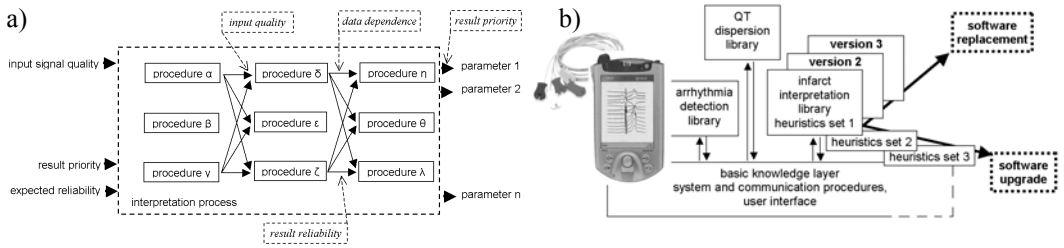

Figure 1. (a) Labelling of ECG interpretation procedures (b) Two dimensional space of modification for remote recorder interpretation software.

Reporting and processing intervals

All solutions of interpretive software available for our study perform full calculation processes and yield a complete set of diagnostic results for each input data epoch. However human experts usually perform hypothesis-driven interpretation sequence and limit the diagnostic set to the most relevant results. A natural consequence of proposed signal interpretation adaptability is the flexible format of diagnostic report supporting adjustable data content and priority. Because data priority is adapted to diagnostic goals, it has a considerable impact to the processing economy, releasing the hardware resources for most relevant procedures in their accurate versions.

Although the correct settings of data priority attribute can be easily derived from the hidden survey, the appropriate selection of the individual update interval or data validity period is more problematic. Depending on the data variability and patient status, each component of the diagnostic result has to be calculated and transmitted as rarely as its validity period expires. Even among basic diagnostic parameters in cardiology, a significant difference in variability was observed in the study. In physiological norm, the heart rate (HR) should be reported to a beat-to-beat rate (i.e. up to 4 Hz), while the QT dispersion (QTD) need a single update per a 5-minute interval (0.0033 Hz).

RESULT AND DISCUSSION

The behavior of automatically adjustable software was investigated in a limited-scale network prototype. The database contained 2751 one-hour 12-leads ECG records reproduced by a multi-channel programmable generator. In case of 857 signals, the first half contained a physiological record and the second half represented sudden occurrence of one of 14 most common pathologies. The adaptation processes were roughly classified to two categories: software upgrade consisting in modifying of control coefficients vector and software replacement consisting in relinking dynamic libraries containing interpretive procedures (fig. 2).

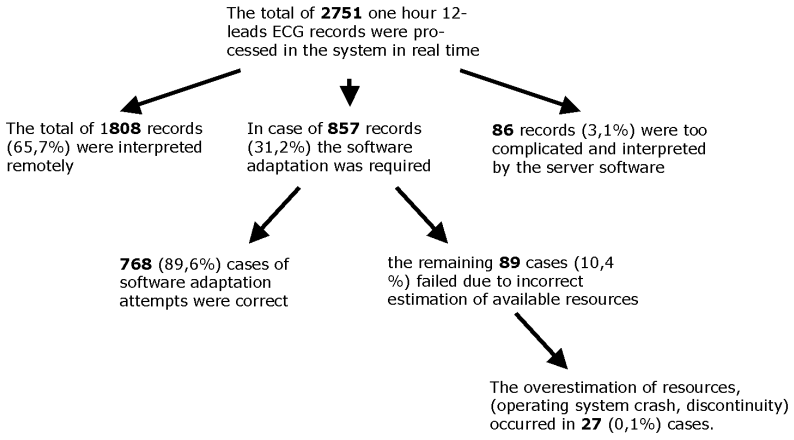

Figure 2. Diagram of adaptation correctness for the whole experiment

Main goal of the test was the assessment of the software adaptation correctness, thus the software provided selective disabling of the principal adaptivity features.

In technical aspect, the correctness of software upgrade and replacement is expressed by the percentage of incorrect adaptation attempts. As such were considered resources overestimation leading to allocation violation and underestimation resulting in suspension of the software upgrade when the upgrade was feasible (tab. 1). In medical aspect, the correctness of interpretive software upgrade and replacement is expressed by the percentage of adaptation attempts leading to diagnostic parameters converging to the reference values (tab. 2). The overall distance in the diagnostic parameters hyperspace is expressed by the diagnostic parameters error weighted by diagnosis priority.

Table 1. Technical correctness of software upgrade and replacement

action	upgrade possible	upgrade impossible
upgrade performed	647 (75,5%)	27 (3,1%) resources overestimation
upgrade suspended or library replacement	62 (7,3%) resources underestimation	121 (14,1%)

Table 2. Medical correctness of software adaptation

action	diagnosis improvement	diagnosis degradation
software upgrade	643 (99,4%)	4 (0,6%)
software replacement	97 (80,2%)	24 (19,8%)

Our tests shows that 768 (89,6%) of adaptation attempts were technically appropriate, among of them 643 (99,4%) software upgrades and 97 (80,2%) software replacements yielded diagnostic results converging to the reference observed from the experts' survey. Among the 857 adaptation attempts, 89 (10,4 %) failed in result of incorrect estimation of resources availability. Resources overestimation resulting in the remote OS crash and thus monitoring discontinuity occurred in 27 (3,1%) cases.

Acknowledgment
Scientific work supported by the Polish State Committee for Scientific Research resources in years 2004-2007 as a research project No. 3 T11E 00127.

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