Autoadaptivity and Optimization in Distributed ECG Interpretation

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***Abstract*—This paper addresses principal issues of the ECG interpretation adaptivity in a distributed surveillance network. In the age of pervasive access to wireless digital communication, distributed biosignal interpretation networks may not only optimally solve difficult medical cases, but also adapt the data acquisition, interpretation, and transmission to the variable patient's status and availability of technical resources. The background of such adaptivity is the innovative use of results from the automatic ECG analysis to the seamless remote modification of the interpreting software. Since the medical relevance of issued diagnostic data depends on the patient's status, the interpretation adaptivity implies the flexibility of report content and frequency. Proposed solutions are based on the research on human experts behavior, procedures reliability, and usage statistics. Despite the limited scale of our prototype client–server application, the tests yielded very promising results: the transmission channel occupation was reduced by 2.6 to 5.6 times comparing to the rigid reporting mode and the improvement of the remotely computed diagnostic outcome was achieved in case of over 80% of software adaptation attempts.**

***Index Terms*—Distributed systems, e-health, home care, pervasive ECG monitoring, ubiquitous computing.**

I. INTRODUCTION

IN THE contemporary information society, remote surveillance, and heart diagnostic are widely spread benefiting from wearable computers and wireless digital communication [1], [2]. This technique, often put forward in context of cardiovascular off-hospital patients [3]–[5], has actually a much larger impact on the quality of live [6], [7]. It concerns also seamless monitoring of vital signs from sportsmen, elderly people living on their own, or members of military or civil services exposed to danger. Wearable recorders do not limit the everyday subject activity while the embedded intelligence simulates well the continuous assistance of medical experts. Surveillance networks use a conventional star-shaped topology. They are managed by the central server and include several remote wearable recording devices communicating over a digital data link of worldwide range. Two approaches to the automatic signal interpretation represented in systems marketed today, assume either the transmission of the raw signal to the interpretation center (e.g., CardioNet [8], Spacelabs [9], and Cardiobeat CT2014 [10]) or the signal processing fully embedded in the remote device (e.g., Welch Allyn Micropaq [11], GE Healthcare SEER Light [12], and QRS Diagnostic Biolog [13]). Focusing on their drawbacks, first method involves high cost of telecommunication service, while the reliability of the second is limited as a result of the compromise between computing power and energy savings.

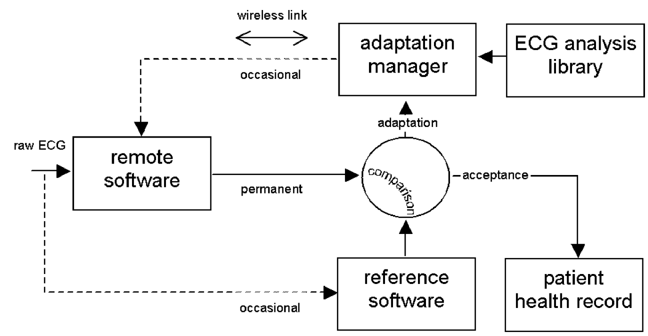

Fig. 1. General scheme of the autoadaptive system for ubiquitous cardiology.

Our approach postulates that the interpretation process is performed as a distributed computing task. Particular subtasks of the interpretation process are flexibly shared between the remote recorder and the central server and automatically controlled via bidirectional digital wireless transmission channel (see Fig. 1). The adaptivity of data interpretation and transmission is based on the quality of diagnostic parameters, continuously estimated in context of the patient's status by a procedure mimicking the human performance. The adaptation is modulated by the availability of the remote RAM, CPU workload, the battery status, and the wireless link quality.

The distributed ECG interpretation process is initiated in the remote device immediately after the signal acquisition, and continued as far as necessary and possible. In case of a typical ECG, the system first tries to modify the remote interpretive software and than if necessary, allots the interpretation to the server. Real-time adaptation of the remote interpretation procedure is achieved by the modification of settings or by the replacement of specialized subroutine libraries, which are loaded from the supervising central server [14] and dynamically linked to the running software. The adaptation is supervised by the server software with optional human assistance in critical cases.

Proposed solution implements three innovative concepts.

1) Application of medical outcomes and statistical description of the human experts behavior to the modification of automatic ECG interpretation.
2) Diagnostic quality-based feedback and dynamically linked libraries (dlls) to agile modification of the running software. The server-to-remote link carries software control data, library codes, and patient's messages.

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TABLE I
EXCERPT FROM DISEASE-SPECIFIC RELEVANCE OF ECG DIAGNOSTIC PARAMETERS (FULL MATRIX CONTAINS 22 COLUMNS WITH PARAMETERS) [22]

disease	heart rate	dominant trigger src	PQ duration	QRS axis
normal sinus rhythm	0.15	0.25	0.12	0.15
sinus tachycardia	0.55	0.25	0.10	0.13
sinus bradycardia	0.57	0.23	0.10	0.13
probable AV block	0.23	0.17	0.27	0.18
ventricular escape beats	0.27	0.61	0.07	0.05
atrial fibrillation	0.35	0.08	n. a.	0.06
AV conduction defect	0.19	0.13	0.39	0.21
myocardial infarction	0.15	0.12	0.14	0.28
atrial enlargements	0.12	0.02	0.15	0.02
ventricular hypertrophies	0.03	0.07	0.05	0.31
left bundle branch block	0.11	0.18	0.21	0.34
right bundle branch block	0.08	0.17	0.21	0.28

3) Seamless optimization of the processing implying the use of a flexible prioritized data transmission format.

Studies carried out within the framework of presented research included the analysis of human experts behavior and their mutual relations, the scanpath-based identification of interpretation strategies in human [15], [16] and others. This paper limits its scope to interpretive software adaptation and seamless diagnostic quality control.

II. MATERIALS AND METHODS

A. Backgrounds for Adaptation of ECG Interpretation

Studying different approaches found in the literature [17]–[21], we generalized the diagnostic information flow chart and rearranged it as a binary decision tree. The tree nodes define the particular quantitative conditions for the optimal selection of further interpretation steps.

Modification of the user interface in the precommercial ECG interpretation software was made for the hidden poll-based studies concerning disease-specific doctors' choice of the final report contents [22]. The randomly ordered and preselected items have replaced the default proposal displayed once the interpretation is completed. The doctor was prompted to willingly select or unselect the results he or she wishes to include in the report. The order of selections and the chosen items are captured with the diagnostic outcome. Finally, the statistical processing of the doctors action records revealed their preferences for 14 most common diseases.

These studies, described in details in [22] confirmed the common, but poorly justified belief that—depending on the disease—for a human expert some diagnostic results are more important than others. Normalizing the usage statistics scores resulted in attributing each disease with a relevance-based list of most expected diagnostic parameters (see Table I).

The agile software of the remote recorder faces several technical constraints while the corresponding server-side application may use virtually unlimited resources. Therefore, the diagnostic result occasionally issued by the server is accurate enough to play the role of the reference in the assessment of remote interpretation quality. The resulting similarity-based estimate of recorder-side interpretation quality is issued automatically by the server (see Section II-B) and used to adapt the remote ECG interpretation. The disease-dependent dissimilarity measure (DSm) (1) uses differences Δv_i between respective values of measurement parameters i weighted by corresponding relevance value w_i given in Table I.

$$\mathrm{DSm} = \sum_{i=1}^{I} \Delta v_i w_i, \qquad \text{where } \sum_{i=1}^{I} w_i = 1. \tag{1}$$

Relative difference ratios Δv_i between the measured and the reference values were calculated accordingly to (2)

$$\Delta v_i = \frac{v_i^{\mathrm{meas}} - v_i^{\mathrm{ref}}}{v_i^{\mathrm{ref}}} \tag{2}$$

for $I = 12$ common quantitative diagnostic parameters (HR, P-, QRS-, T wave lengths, PQ and QT intervals, P-, QRS axes, the largest values of ST elevation and depression in all leads and two corresponding values of ST slope).

A new quality estimator needs to be defined for the assessment of dynamic properties of the autoadaptive system. Since the measurement result is expected to converge to the reference value in theoretically unlimited number of subsequent software adaptation trials, the asymptotic accuracy (AAc) for each parameter i is expressed as (3) follows:

$$\mathrm{AAc}_i = \lim_{t\to\infty} \left| v_i^{\mathrm{meas}}(t) - v_i^{\mathrm{ref}} \right| \tag{3}$$

where $v_i^{\mathrm{meas}}(t)$ is the subsequent measurement outcome and v_i^{ref} is the server-calculated reference value. This general definition of the linear AAc is valid also in the particular case of discrete nonuniform adaptation and with constraints on the number of modification attempts applied in our system.

B. Quality Control Routines for ECG Interpretive Software

In majority of cases, the software of the remote recorder performs the complete ECG interpretation, and only diagnostic results are transmitted to the center over the wireless link. To maintain the quality of interpretation results, two procedures validate the received data on the server side.

Redundant reinterpretation compares the results from the remote interpretation with the reference values yielded from occasional server-side calculations for the same signal strip. The verification begins with sending a raw signal request from the server. The remote recorder responds with a short strip (8 s) of raw ECG from the buffer, sent along with the results of interpretation performed independently. This signal is next reinterpreted by the server and the values received from the remote recorder are individually compared to this reference. Studies of the International Electrotechnical Commission (IEC) 60601 guidelines for required calculation accuracy [23] and consultations with cardiologists led us to propose specific values of tolerance thresholds (see Table II) and apply them to the evaluation of differences Δv_i (2). Excessive dissimilarity values trigger the decision on the automatic modification of the remote recorder interpretation software. Therefore, increasing the threshold values leads to limiting the pursuit for a better software architecture, while decreasing them triggers the

TABLE II
EXPERT-DERIVED INDIVIDUAL THRESHOLDS OF MEASUREMENTS AND DIAGNOSTIC RESULT TOLERANCE

parameters group	procedure example	relative accuracy threshold [%]
1	QRS detection, heart rate;	2
2	wave limits detection, ST-segment assessment;	5
3	morphology classification, arrhythmia detection;	10
4	QRS electrical axis reconstruction;	20

modification attempts even for small error values, and thus, makes the adaptation inefficient. In rare cases, when the server software alerts about poor reliability of the result, the reference values are verified by a human expert.

The volume of the 8 s signal strip is 48 kB, thus the upload time is 24 s (16 kbps). Provided the redundant reinterpretation is performed once per four minutes (in average), additional occupation of the wireless channel is of the order of 1 kbps.

Knowledge base similarity test verifies the consistency of each incoming diagnostic report by comparing the results to the closest respective values from past records stored for the same patient in the server database. If the global value of DSm does not exceed 15%, the record is considered similar to the current. In the collection of ten past similar records the mean values are calculated for all diagnostic parameters. These values determine centers of expectancy ranges (whose sizes are given in Table II), for corresponding parameters from the current record. The remote result is considered reliable if the incoming packet contains all the data in their expected ranges. Otherwise, the server assumes the remote interpretation failed and issues the raw signal request.

The database search uses the data priority attribute depending on fundamental patient's status-dependent findings (e.g., heart rate (HR) or rhythm type) in order to reduce the workload. The similarity check is performed perpetually, since it does not additionally load the transmission channel.

C. Adaptation Mechanisms

In a distributed system, the automatic management of interpretation task sharing directly influences the monitoring costs and diagnostic reliability. An implementation-specific design specifies procedures running on the remote recorder (e.g., signal acquisition and buffering, and patient interfacing), on the central server (e.g., ventricular late potentials detection and frequency-domain HR variability analysis) or on either of these devices (e.g., beat detection and classification, and wave delineation). For the last category, task-sharing rules derived from the studies of human interpretation of the ECG [15], [16], [22], define medically justified conditions for processing, adaptation, and results verification algorithms.

Several procedures in the ECG interpretation algorithm contain heuristically determined factors and thresholds. These values are usually tuned by the developer [23] with the use of reference databases (e.g., CSE [24] in case of wavelength). In

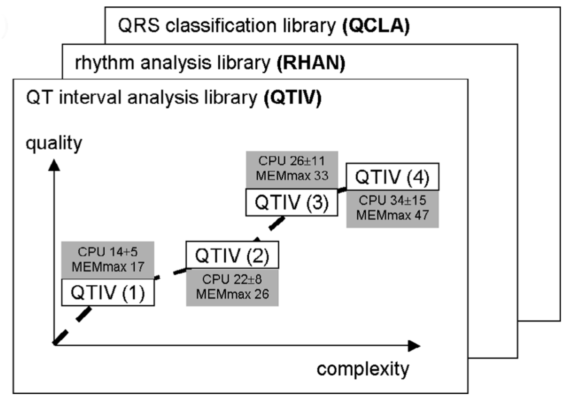

Fig. 2. Task-oriented libraries of the interpretation subroutines.

general-purpose software, these coefficients are not modified in course of processing [25], and thus, often referred to as "*constants*". Typical examples are the normal-abnormal limits depending on sex, race, or drugs usage. Making the factory tuning for each specific group of patients or selected diseases yields patient class-specific sets of values. With regard to the classified patient, the dedicated set of "*constants*" is expected to be (and usually is) more appropriate than the general set.

The *coefficients update* (CU) is the most direct method of the remote interpretive software modification. It consists in setting specific values of the "*constants*" for each particular procedure, based on the patient's category and status verified perpetually by the server. The CU requires very few data to be sent to the remote recorder, but also has limited influence on the signal interpretation.

The *software upgrade* (SU) or *replacement* (SR) both provide deep modification of the interpretive software features and require the server-side expert system for the management of remote interpretation subroutines. It works with a knowledge base containing executable codes and machine descriptions of all the task-oriented libraries corresponding to the commutable blocks of the interpretive software (see Fig. 2).

Subroutines within the libraries are commutable, thus designed for the same computational purpose, but with different prerequisites for the resources requirements and result quality. They also have standardized *data gateways* enabling the replacement required by the remote optimization, while the interpretation is running. Each subroutine is described by the attributes of *quality*, *resources requirements*, and *external dependency* specifying its relations with the other components in the signal interpretation tree. Commutable subroutines also have unified *modification interfaces* used in CU mode to provide the external access to few parameters.

With regard to the reliability and consistency of the remote diagnostic outcome in the context of current diagnostic goal and available resources, the ECG interpretation may be adapted with use of one of the following modes (see Table III).

1) Calculation coefficients update (CU).
2) Linking of a supplementary interpretive library (SU) with possible unlinking of a working interpretive library issuing the low-priority (see Table I) results if necessary (SR).

TABLE III
SIMPLIFIED DECISION MATRIX FOR THE REMOTE INTERPRETATION SOFTWARE ADAPTATION MODES

interpretation error severity	resources available memory + processing / transmission			
	yes / yes	yes / no	no / yes	no / no
low	CU	CU	CU	CU
intermediate	SU	SU	ST	SR
high	ST	SU	ST	SR

Remark: *Remote reinterpretation* of the buffered ECG and one step of *redundant central reinterpretation* are performed for the automatic assessment of result reliability after each CU, SU and SR attempt.

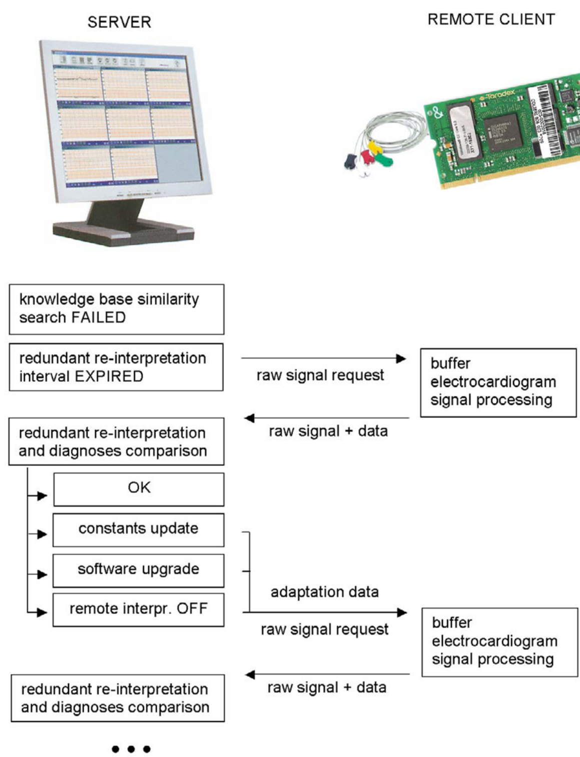

Fig. 3. Flow diagram of the *knowledge base similarity check* and the *redundant reinterpretation* for the automatic assessment of result reliability.

3) Server-side task allotment (ST), the remote interpretation is overridden by the results issued by the server.

The decision about the adaptation of the remote interpretive software is taken by the software management expert system. The command message and the modifying data (new "*constants*" or executable code) are sent to the remote recorder over the bidirectional wireless transmission channel (see Fig. 3). The continuity of monitoring is maintained due to the remote ECG signal buffering up to 60 s, although clinical tests should estimate how far the monitoring system response time (several seconds) is critical in case of sudden cardiac events.

If the count of adaptation steps reaches the limit of four, the interpretive software architecture in the recorder returns to its last valid settings. If the unsuccessful adaptation repeats, the raw signal of one or two preselected ECG leads is continuously transmitted to the server (ST) and the central interpretation results override the remote outcome.

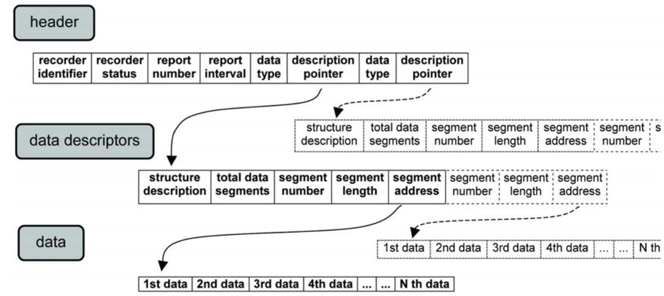

Fig. 4. Data communication format; the mandatory fields are bordered by the solid line, and the optional fields are bordered by the dashed line.

D. Adaptive Transmission Format

The medical information is represented inside the ECG interpretation process in various data forms, including signals, metadata, ECG descriptors, and final diagnostic statements. The adaptivity of remote interpretation cannot be considered without a flexible format of the transmitted data. In particular, besides the signals and the parameters specified by the international standards [26], the adaptive task sharing requires a support for the transmission of "*internal*" data at various processing stages [27]. The system uses the custom-designed communication format containing mandatory data description fields and optional data containers of variable size (see Fig. 4). Nevertheless, the output regularized by the central server may follow any specification of patient health record.

The flexibility of report format allows for the transmission of each diagnostic parameter with its appropriate sampling interval. The temporal variability differs up to three orders between particular diagnostic parameters [28]. The report frequency, corresponding to the Nyquist rate for the respective cardiac series, ranges from 3 Hz (once per heart beat) for the HR to 0.0033 Hz (once per 5 min strip) for the ST-segment depression. The short-term statistics show that the occurrence of critical values usually increases the probability of further variations. The patient's status sampling frequency is thus determined individually for each parameter considering the past and present values with respect to the Shannon rule.

Irregularly sampled data streams from the remote adaptive interpretation are nonuniform time series and require the recipient-side interpolation to estimate the midpoint values. The use of cubic splines [29] reproduces all the diagnostic parameters within the respective accuracy limits (see Table II).

E. Prototype Details

The prototype remote recorder was based on a development kit of the PXA-270CPU [30] running GNU/Linux operating system with the Aspect-500 (Aspel) ECG acquisition module (8 channels, 12 bits, 500 sps) and bidirectional GPRS connection [31], [32]. The prototype server was based on a PC with Linux OS and the 100 Mbps static IP Internet connection.

The largest partition of the remote system memory (512 kB) is allocated for the raw ECG circular buffer of the capacity of 64 s. The second largest memory block is allocated for the variables

TABLE IV
INVENTORY OF INTERPRETING PROCEDURES WITH RESPECTIVE CPU/MEMORY REQUIREMENTS [%]/[KILOBYTES]

procedure name	version number				
	1	2	3	4	5
heartbeat detector	7/25	8/32	10/38	15/42	16/48
heartbeat classifier	15/18	17/26	20/35		
wave delimitation procedure	35/22	65/26			
ST-segment assessment	10/10	12/17	13/25		
arrhythmia detector	5/7	8/10	13/12	19/15	
heart rate variability analyzer	30/25	51/38	68/44		
electrical axes calculator	7/8	27/21			
rhythm identification procedure	5/12	6/18	8/26		
QT-segment assessment	13/20	17/31	33/35		

and the executable code of the interpretive software. Since several interpreting modules are implemented as dlls, the remote resources are primarily dependent on the available program and temporary data memory and require a constant monitoring.

The agile software of the remote recorder consists of nine facultative interpretive components. For each of them the working code can be selected by the management expert system from specialized library containing 2 to 5 mutually commutable subroutines precompiled for the remote platform. Table IV presents the applied versions of subroutines along with the computation and maximum memory requirements specified jointly for the executable code and variables.

The selected code is downloaded from the server each time before linking [33]. Although the adaptation using SU needs a considerable time, the range of alternative procedures is not limited at the recorder manufacturing stage. The volume of the largest single procedure is 17 kB, thus the download time is 3.4 s, assuming full bandwidth of the GPRS link (40 kbps).

The concise resources report (18 bytes) is a mandatory part of the remote recorder status area in every data packet or may be independently pooled by the server. The report consists of a few variables representing the battery status, the ambient temperature, the quality of the GPRS channel, the processor usage, the memory allocation, and identifiers of linked software libraries.

F. Test Signals and Experimental Setup

The tests were focused on the correctness and benefits of the processing and transmission adaptivity, and the sharing of interpretation task. The prototype software provided options for selective disabling the adaptation. In all the experiments, we used 2751 artificially combined signals originating from 58 records of Common Standards for quantitative Electrocardiography (CSE) Multilead Database [24]. Cardiologists annotated the CSE records, since the database does not directly disclose the pathology information. In each test signal, the appearance of a single pathology was simulated by the concatenation of several repetitions of a record annotated as normal followed by several repetitions of a pathology-specific record. In the vicinity of the concatenation point, the count of samples was adjusted accordingly to the precedent RR interval and the baseline level of the subsequent record was corrected for each lead independently. Such test records simulate the abrupt cardiac changes and facilitate the technical analysis of the adaptive system behavior.

TABLE V
QUANTITATIVE ASSESSMENT OF THE ADAPTIVE COMMUNICATION FORMAT BENEFITS AND THEIR PROBABILITY

optimization aspect	occurrence probability [%]	data rate [bps]* for the adaptation disabled	data rate [bps]* for the adaptation enabled	data reduction ratio
non-uniform reporting	100	3580	639	**5.6**
irregular reporting	31.2	3580	1380	2.6

* Not including 1066 bps for reinterpretation of 8 s signal strip every 360 s

A multichannel arbitrary generator reproduced the analog signals of the total duration of 1–1.5 h. Reference values of wave borders for the assessment of interpretation in the distributed system were calculated as the mean of CSE results.

III. RESULTS

The evaluation strategy focuses on algorithmic aspects of the prototype system and includes measurements of benefits and threats implied by the adaptive approach.

A. Quantitative Benefit Results

The aims of first tests were comparing of the agile and rigid procedures implemented on the same hardware platform and quantifying advantages of the adaptable interpretive software over methods being in use today. Two principal benefits are as follows.

1) Reduction of digital communication costs achieved with content-adaptive signal and data representation.
2) Extended autonomy being a result of avoiding the unnecessary computation and data transmission.

Comparing to the reporting of all measurement results in regular time intervals (i.e., adaptation disabled), a significant data reduction (see Table V) was a consequence of the adaptation of report content and frequency. The irregular reporting concerns only measurement parameters, which time variability may be predicted from actual values (31.2% of cases).

The life of the remote recorder battery was extended in average by 65% comparing to the same remote recorder running the software with all optimization options disabled.

The delay of messages varied from 1.3 s (abnormal finding message of high priority) to 6 s (regular report). The diagnostic data quality and the transmission delay were measured with respect to the procedures recommended by IEC [23].

Estimation of the longest adaptation delay was performed with use of the real wireless general packet radio service connection (see Table VI).

B. Correctness of the Adaptation Process

A second group of tests was carried out in order to assess the correctness of the implemented task sharing rules. The test procedure was focused on the following aspects.

1) Efficiency of the iterative software adaptation expressed by the required number of iterations.

TABLE VI
DELAY TO THE REMOTE RECORDER ADAPTATION [SECOND]

action	longest delay	average delay	standard deviation
coefficients update (CU)	17.1[a)]	4.3	1.3
software upgrade (SU)	6.0	4.4	1.5
software replacement (SR)	5.9	4.5	1.5
server-side allotment (ST) [b)]	2.4	0.8	0.3

[a]Four steps of calculation coefficients update.
[b]To the remote device software modification.

TABLE VII
EFFICIENCY OF THE ITERATIVE SOFTWARE ADAPTATION (CALCULATION CONSTANTS UPDATE)

calculation constants update steps	cumulative percentage	
	converging	non-converging
first	63.1	36.9
second	74.5	25.5
third	79.1	20.9
fourth	80.7	19.3

TABLE VIII
MEDICAL CORRECTNESS OF THE SOFTWARE UPGRADE AND REPLACEMENT

action	diagnosis improvement	diagnosis degradation
software upgrade	643 (99.4%)	4 (0.6%)
software replacement	97 (80.2%)	24 (19.8%)

2) Convergence of the remotely computed diagnostic parameters to the server-computed reference values.

In case the remote software is modified in result of the data inconsistency, the iterative interpretation of the buffered ECG is repeated until the values of the remotely calculated diagnostic results are within the tolerance margins (see Table II) around their respective reference values (3) (see Table VII).

In the medical aspect, the correctness of the single SU or SR was measured by the percentage of cases for which in result of the software adaptation new diagnostic parameters approach to the reference values (1) (see Table VIII) and reduce the DSm value. The calculation of DSm (1) uses the relevance of diagnostic data (see Table I). and thus favorites certain procedures over others.

The medical correctness of SR decisions summarized in the last row of Table VIII is the quality estimator of the software management expert system. For over 80% of cases, the SR improved the diagnostic result.

C. Dynamic Behavior

This complementary test revealed the correctness of the SR decisions in the aspects of expert-derived diagnosis priority and availability of resources. As it is presented in Table IX, the estimation of the remote resources availability is not fully reliable. If the resources availability is overestimated the remote operating system may crash. In the opposite case, the underestimation of available resources leads to desisting from the necessary upgrade or to the replacement of the linked libraries (SR) despite their possible coexistence.

TABLE IX
TECHNICAL CORRECTNESS OF THE SOFTWARE UPGRADE AND REPLACEMENT

action	upgrade possible	upgrade impossible
upgrade performed	647 (75.5%)	27 (3.1%) resources overestimation
upgrade desisted or software replacement instead of upgrade	62 (7.3%) resources underestimation	121 (14.1%)

IV. DISCUSSION AND CONCLUSION

A. Idea

The results of the research on the human strategy for the ECG perception, interpretation, and information interchange were applied as foundations of the automatic system with distributed interpretation for continuous cardiac surveillance.

The easy-to-use technical surrounding of a human, created mainly with the software, is in today's information society an often-referenced quality-of-life estimator.

An interesting issue is the discrete and nonuniform nature of the adaptation. In regular control systems, the control signal is linearly proportional to the error value accordingly to the feedback transmittance. In discrete systems, this proportion is modulated by discrete steps, usually having the uniform size. In the proposed system, the available procedures are attributed by their inherent performance and requirements factors, and a linear response to the diagnostic error cannot be expected.

B. Experimental Results

The implementation of the adaptive interpretation is based on the disease-specific relevance of diagnostic parameters and on the definition of task sharing rules. Test results show the improvement on the diagnosis quality against the rigid software, however, further analysis of outliers is required.

The adaptive processing and transmission combine the advantages of two solutions being in use today [34], [35].

1) Load of the transmission channel (ca. 2 kbps) is nearly as low as when the remote interpretation was used.
2) Interpretation reliability is almost as high as in the centralized interpretation architectures with an occasional assistance from human expert.

The content-dependent format of the reported data provides further impact to the diagnostics quality.

1) Monitoring and alerting parameters are adjustable to the patient-specific features during the recording.
2) Specification of the report contents and frequency follows any unexpected event and the interpretation is flexible enough to cover a variety of diagnostic goals changed or updated remotely.

C. Further Considerations

Most problematic is now the compatibility of the interpretive software designed for two different platforms. Multiplying the interchange points, where the ECG interpretation could be taken over from the remote recorder and continued by the server, affects the optimization of server interpretation thread. Consequently, the processing chain of the server thread tends to mimic the design of its remote counterpart, losing the benefits of efficient hardware platform.

In our prototype, the resources underestimation (see Table IX) is considered as a minor issue but this is worth to be examined in the future versions. If the replacing procedure sufficiently ameliorates the diagnostic result, further adaptation is not performed even if the availability of resources reported after the replacement allows for a higher grade procedure.

The behavior in presence of outliers and the raw signal noise needs more testing in clinical conditions (in parallel to currently approved systems). The influences of the noise and propagated processing errors on the subsequent interpretation stages highly depend on the quality of interpretive procedures. In the experimental part, we relied on specific software resources (from Aspel, SA), and finer software collection will improve the noise immunity of the system.

The use of diagnostic results as arguments for the interpretation management looks interesting, but it should be more thoroughly investigated to reveal any unexpected system behavior and to predict the possible medical risk.

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