ADVANCED ECG INTERPRETATION ROUTINES AS WORLD-DISTRIBUTED WEB SERVICES

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ABSTRACT

The manufacturers of ECG equipment usually face the advanced interpretation routines implementation problem. The development of these routines entails great financial expenditures, however for their specificity, the customers rarely demand them. This paper proposes a distributed computing approach to the advanced interpretation routines. Our proposal assumes each cardiologic issue to be interpreted by an unique specialized center automatically or with a human expert assistance if necessary. The interpretation service is accessible through the web for distant clients meeting the selection criteria. These may include customers of a particular enterprise, members of a given society or subscribed individual cardiologists. Among numerous advantages of this proposal, the most important is world wide unification of methods since most complicated software have to be developed only once and remain undisclosed to the others.

1 INTRODUCTION

The ECG interpretation process, currently fully automated, consists of various signal processing, pattern recognition and decisive procedures. The representative patterns and their physiological meaning are usually defined by well established world wide standards, but the mathematical tools differ from one software manufacturer to the other. Additionally, newly introduced diagnostic methods are fully or partially patented forcing the other manufacturers to develop their custom solutions. Consequently, new constraints are created for interoperability and for standardization of the interpretation procedure from the input to output points.

Unfortunately for the manufacturers, the customers rarely demand the most sophisticated algorithms, because the corresponding medical cases are relatively infrequent. In result, the research expenditures are hardly returned, and the specialized functions increasing the price of advanced equipment are rarely justified by the everyday diagnostic practice.

The alternative approach developed in our laboratory bases on designing all the advanced ECG interpretation routines as world-distributed web services. The electro-cardiographs could be marketed as low-cost general-purpose interpretive units whose autonomy is limited to resolving the most frequent heart diseases. Such devices are today equipped with an internet connection support but use it only as an interface to the electronic patient record. The key idea is to extend this connectivity by co-operating with multiple method-specialized remote interpretation services. The service could be organized and managed by the inventor of each particular diagnostic method or other high-quality computation provider. Our approach is an example of distributed computing [1] and the principal advantage of such services is the issue of reliable results without disclosure of algorithm details. Throughout this paper we present principal technical problems encountered during the design and development of the example QT-dispersion service and discuss the alternative solutions.

QT-dispersion, derived from inter-lead comparison of QT interval duration in several leads of standard ECG is one of the most significant predictive factors of repolarization abnormalities (fig. 1). The extensive research originated from early 80-ties [2] [3] shown that the heterogeneity of refractoriness in myocardial tissue contributes to increased vulnerability to ventricular tachyarrhythmias. Increased QT-dispersion is associated with cardiac death in nonischemic patients, with ventricular fibrillation and sustained tachycardia and other severe heart failures. This parameter is also used to identify high-risk patients awaiting heart transplantation.

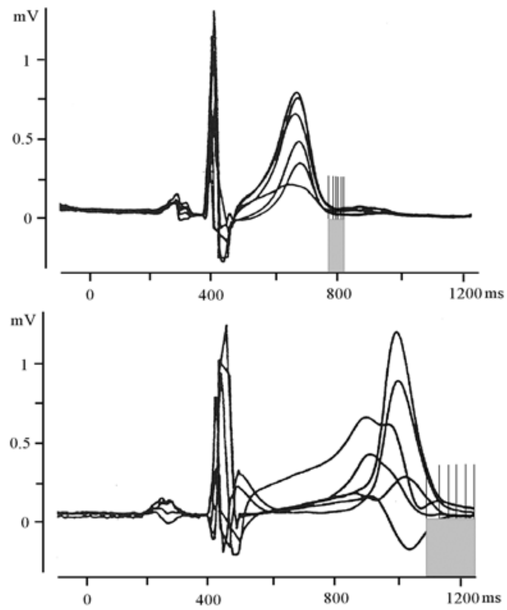

Figure 1. Precordial leads representation of an example heartbeat a) normal, b) high QT-dispersion (Long QT Syndrome)

2 MATERIALS AND METHODS

This chapter presents main technical issues concerned during the design and development of QT-Dispersion service. Except for the signal processing algorithm all other issues are common for any ECG interpretation routine designed as a web service.

2.1 The computation algorithm

Although not patented, the QT-dispersion algorithm is implemented by various manufacturers [4] [5] [6] in different way and returns with significantly diverse results for the same test signal. The most problematic issue is the correct delimitation of T-end point for each ECG lead independently. Not having the opportunity for the source code inspection, we suspect various approximation techniques to be responsible for the differences. The other source of differences is the statistics used for outliers suppression, that excludes leads differing too much from the mean value as too difficult to be analysed. Consequently, the results are not reproducible from one machine to another and the serial comparison or follow-up are manufacturer-dependent. Our algorithm uses the parabola approximation of T-wave maximum and a maximum slope approximation of T-wave end, as recommended in the literature (fig 2) [7]. The additional advantage of approximation techniques is the tolerance to the wide range of signal sampling frequencies.

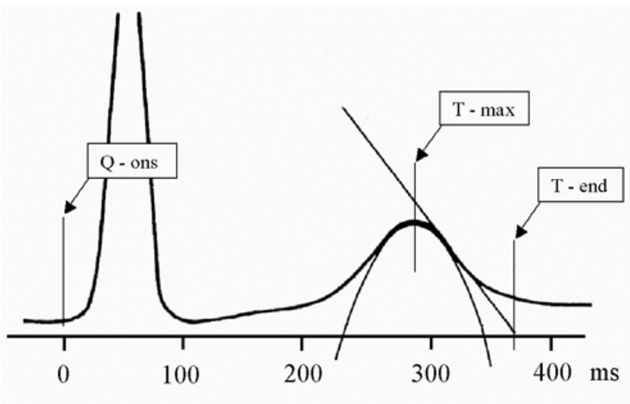

Figure 2. Details on T-wave maximum and T-end point measurement.

2.2 Remote client identification

The service in its experimental stage is accessed by a closed group of remote clients, recognized by their IP addresses. For the future expansion the remote client identification procedure was implemented. The purpose of this procedure is twofold:

- assigning the diagnostic outcome to the proper client request,
- identifying the service subscriber status and prevent from unauthorized or multiple task request.

Client identification procedure is expandable for the future client management in case of subscription would be made payable. This proposal may be considered at a first approach to the service's financial support. The subscribers have to pay for the number of interpretation tasks requested over a given period and not for the potential ability of the analysis embedded in their recorders.

2.3 Machine and human access

Our initial approach was designed for machine access only, as presented in the introduction. The general-purpose ECG recorder provides the acquired signal over the network, requests the interpretation service and collects the diagnostic outcome. At the testing stage we had to consider the human access as well and as we found it useful in some circumstances, the human clients are accepted in the final version of the service. The service is accessible for medical researchers over the Internet. The server interface is able to perform the requested computation on the uploaded user data and to return the result without the disclosure of software code. The service can be manually launched and controlled by the user via limited set of parameters. Any modern graphic-based web browser is suitable as user interface if it supports the transfer of user files, the selection of options and the results presentation. The transfer of computation results as a file is also under consideration, making support for text interface-based terminals.

As the service will exit from its experimental stage, the user will be also provided with a HTML manual and the knowledge guide containing links to the original papers. Although the medical library is not the main function of the service, the collection of publications provides the medical researcher with the most appropriate knowledge facilitating the preparation of the experiment and the right choice of data processing methods and options.

2.4 Signal quality verification

Signal quality verification is necessary for correct estimation of diagnostic outcome reliability. The service is probably not fully protected against the upload of a non-ECG signal, but in case of noisy signals or spikes in the T-end area, the analysis may finish with an incorrect result. Distorted input signals are identified and an appropriate three-level warning message is issued together with the diagnostic outcome.

The signal quality is estimated by computation of several parameters:

- the slope of power spectrum decay,
- the percentage of monotonic sections,
- the number of isolated signal accelerations and decelerations etc.

The signal is not altered in any way before the diagnostic processing starts. In case the result is not satisfactory for the recipient, he may submit a filtered version or simply other, distortion-free signal section.

2.5 Multithreading and human assistance

Diagnostic subroutines of the service software were designed to be launched as multiple remotely controlled asynchronous threads (fig. 3). The clients have regular user privileges with access limited to their thread and their parent directory. Two way of supervision are designed for the service: server administration and medical expert assistance. The help from a qualified cardiologist is crucial at this point, because not only resolves current conflicts or misinterpretation cases, but also gathers and qualifies information on errors. Consequently, medical remarks are considered as the background for future versions of interpretive software.

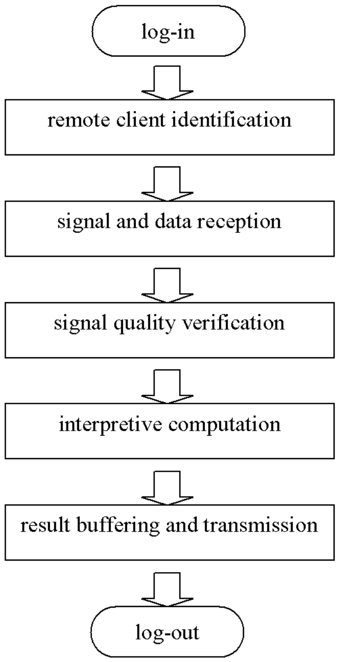

Figure 3. Interpretation request processing chain

3 RESULTS

The prototype of the service was build on a Linux-based web server (Apache). For the human access, a standard website is developed in order to upload the signal, launch the processing thread and present the diagnostic outcome. For the machine access an automatic login and identification procedure is provided, and the returning message contains the diagnostic oucome in binary format. The service test was initially made using human access, because we had problems to modify of an existing ECG machine by adding communication interface, proper data upload and task request format support. Except for two real ECG machines, the remaining clients were emulated during the test with use of independent PC machines. The other advantage of client simulation was the alternative local implementation of the diagnostic subroutines made on the PCs, allowing easy measurement of the delay caused by remote operation.

3.1 Experimental devices setup

The tests were performed on the prototype QT-dispersion service with static IP address and 100Mbps direct Internet connection. A maximum of 10 clients were simultaneously performed their computation tasks. This number was limited only by the available IP reserve. The remote computation was nearly as fast as its local counterpart, the systematic delay measured for the remote processing was 130ms ± 53ms and was found not significant for the diagnostic performance.

Similar test was repeated for the node server connected to the web out of the institution area and domain. The packet routing procedure and consecutive mediation of internet nodes influences the processing delay, in particular for the first connection (1639ms ± 280 ms). Subsequent connections from the same machine is performed much faster (170ms ± 67ms).

The other challenge was the test of wireless client-server connection. These experiments were performed within the institution address domain for one wireless-connected client while the others use a regular cable connection. The separated client used a 802.11g LAN PC Card set for the maximum data transfer of 11Mbps. Here again, the time necessary to establish the connection was very significant (up to 5s), and the subsequent tasks were processed faster (210ms ± 97ms).

3.2 Results and observations

Table 1 summarizes all the mean values and standard deviations of delay caused by the remote operation of QT-dispersion interpretation. The delay was measured by the client computer as a difference of completion time between the remote and local task performed on the same signal section.

Table 1. Statistics of the QT-dispersion interpretation delay (remote processing vs. local processing).

connection method	average delay [ms]	standard deviation [ms]
100Mbps ethernet connection within the same address domain	130	53
100Mbps ethernet connection different address domains (first look-up)	1639	280
100Mbps ethernet connection different address domains (subsequent connection)	170	67
802.11g LAN PC Card 11Mbps infrastructure mode (first look-up)	4105	880
802.11g LAN PC Card 11Mbps infrastructure mode (subsequent connection)	210	97

Three sources of the delay may be identified:

- remote service connection and file transfer,
- client recognition, data verification and result buffering,
- interpretive computation in a multitasking environment, particularly for computationally heavy requests.

The contribution of particular components depends on the service scale, internet connection, computation power etc. Because of high specialization, the service scale may be accurately adjusted to the medical demand.

4 DISCUSSION AND FINAL REMARKS

The authors are not inventing a new diagnostic procedure for the ECG analysis. Instead, the authors propose new technical solution for the implementation of existing highly specialized procedures as web-accessible services. The example service has been designed and developed for QT-dispersion interpretation, and the principle of this experiment was rather to face and solve all the range of technical issues, than to open a 'virtual clinic'. Other medical signal processing-based services, not limited to the cardiology, may follow our path. The advantages we found important and unprecedented are:

- worldwide standardization of procedures and interoperability implied by the implementation of common diagnostic algorithms in the servers,
- justified low cost at high scales of service (the subscriber pays for the really performed analyses),
- high reliability of the interpretation based on spare server matrices and alternative path connections,
- protection of inventor's intellectual property rights.

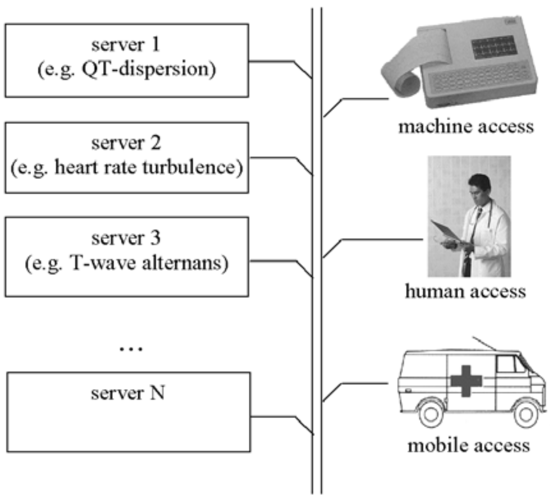

Figure 4. Worldwide accessibility of ECG specialized interpretive services.

The experimental part confirmed the hope for the practical usefulness of the service. Except for the first request, the tasks were performed by the remote service not noticeably longer than by the corresponding local subroutine. In case of multiple interpretation tasks requested from different specialized services in parallel (fig. 4), the processing may be completed even faster than a sequential local analysis performed by an interpretive electrocardiograph with limited computation power.

For the further experiment we plan the use of the GPRS client connection that simulates better the conditions in a busy network of worldwide range. The 3G global telecommunication should definitely solve the problem of clients in motion (e.g. ambulance) or remote areas inhabitants with no wired access to the Internet.

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