A Web Access to Data in a Mobile ECG Monitoring System[1]

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Abstract. The cardiovascular diseases and, in particular, diseases related to arrhythmias are a problem that affects a big percentage of the population, being one of the major cause of death in Europe. The new advances in the fields of PDAs, intelligent mobile phones, wireless communications and vital parameter sensors have permitted the development of revolutionary medical monitoring systems, which strikingly improve the lifestyle of patients. However, not all those monitoring systems provide patients with a real anywhere and any time assistance. We have developed a system that goes a step further than the previous approaches, being designed to capture, record and, as a distinctive feature, to locally analyze the ECG signals in a PDA carried by the patient. In that sense, the system has a decision support module based on decision tree methods that can detect, with high precision, risk arrhythmias that the user is suffering. Then alarms are sent in time to an alarm center in order to receive the proper medical assistance through GPRS. Hence, the users are provided with anywhere and any time assistance. One of the aims when building the system has been to optimize limited and expensive resources like PDA memory size and wireless communication costs. Moreover, the accessibility is also an important feature of the system that has been achieved by the development of web services that query the data computed in the PDA. In this way, authorized people (physicians and relatives) can have an easy access to that data.

Introduction

Traditionally Holter recording has been used during normal patient activity to record the cardiological signal called electrocardiogram (ECG). A Holter is a small, mobile and light device that records, during a period of 24 or 48 hours, ECG signals which are later analyzed in the hospital. This solution presents the advantage that patients could continue living a normal life in their homes but, it also presents a serious drawback: if the patient suffers from a serious rhythm irregularity the Holter only records it making possible to establish later a diagnostic but it does not react to it in real time.

Innovations in the fields of PDAs, intelligent mobile, wireless communications and vital parameter sensors permitted the development of revolutionary medical monitoring systems, that strikingly improve the lifestyle of patients, offering them security even outside the hospital. In that sense it could be mentioned, for example, the

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modern cellular phones e.g Vitaphone [2] that, in case of an emergency, can record the signals through the metal electrodes situated on its back and transmit them to the cardiac monitor center situated in the hospital. There are other commercial monitoring systems that use PDAs to store the ECG signals, e.g. Ventracor [3], Cardio Control [4]. For these systems additional features like GSM/GPRS transmission to an analyzing unit are also being developed. These systems continuously send ECGs to a health center through a wireless communication network, where the signals are analyzed.

In the research monitoring area, stand out several research projects like: @Home [5], TeleMediCare [6], or PhMon [7], whose aims are to build platforms for real time remote monitoring. Those computers perform some local real-time monitoring in order to detect some anomalies and send alarms to a control center or a hospital. However, we have not been able to find precise descriptions of what kind of ECG analysis is performed exactly in any of these systems.

In spite of the advantages these kinds of systems provide in relation to holters, they still present main problems related to the fact that a complete ECG analysis is not performed in the place where the signal is acquired. Therefore, there is a loss of efficiency in the use of the wireless network because normal ECGs are also sent (and wireless communications imply a high cost); and, in the case of the wireless network is not available (e.g. in a tunnel, in an elevator, etc.) at some moment, there might be a loss of ECG signal with the corresponding risk of not detecting some anomalies.

Our proposal, the MOLEC system, is a solution that allows the continue ECG monitoring of patients outside the hospital, in their normal live. It has a quick notification of possible emergency cases to an alarm center and provides physicians with all the necessary information for a fast and correct diagnostic, and authorized relatives with information about the current health state of the patient.

The main goal of this paper has been to investigate that last part of the system: the possibilities of accessing PDA data through the web. In order to do that we have defined a set of interesting web services, implemented them in different components of the MOLEC system and obtained some performance measures with the aim of chosing the best architectural alternative.

In the rest of the paper we explain the global architecture of MOLEC (section 2) detail the MOLEC Monitor (section 3) and MOLEC Center (section 4) with the different web services that provide. Further, performance and communication costs considerations are discussed (section 5) and finally the conclusions are presented.

2. Global Architecture of MOLEC

The main components of the architecture appear in Figure 1. The *MOLEC Monitor* is a standard PDA (handheld computer) that acquires signals sent by ECG sensors carried by the users. The *MOLEC Monitor* is capable not only of storing the ECG signal like Holter does, but also it is an embedded real-time system that captures, processes, detects, analyzes and notifies possible dangerous abnormalities to an alarm center through the network from anywhere and at any time. It also maintains a small, database (referred as local database) with references to the compressed signals files and details of abnormal ECG events so the physicians could find out valuable information of the last cardiac activity of the patient.

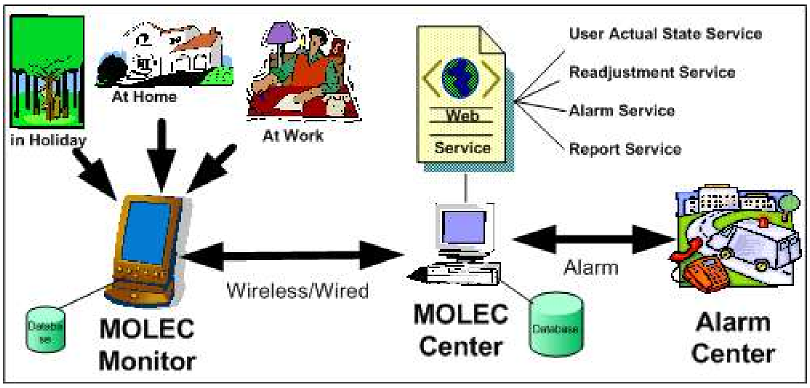


Figure 1. Architecture of MOLEC

The *MOLEC Center* is the system part that manages the communication with all the PDA monitors and updates the MOLEC Center's database (referred as global database) with the new information that receives from each of them. Moreover it acts like an intermediary between a PDA and the alarm center (when alarms events are detected) and provides different type of information about the monitored users through specialized web services. The *Alarm Center* receives all the risk alarms detected into the PDA, in order to react and immediately provide proper medical assistance.

3. MOLEC Monitor

The MOLEC Monitor has a modular implementation, each module corresponding to a distinct task that the PDA perform. A brief description for each module is provided below (for more details refer to [8] and [9]).

The *ECG Signal Acquisition Module* manages the communication between the PDA and the ECG sensors in order to receive the ECG signal and convert it into a signal understandable by the entire system. Thus it acts like a mediator between PDA and the ECG sensors so that the system could adapt with any type of ECG sensors.

The *Data Preprocessing Module* analyzes the ECG signal in order to detect the beats and the typical parts that characterize it. For the arrhythmia detection it is significant the identification of the presence or absence of some wave events: the points where P, QRS and T waves start, end and their peaks. For the implementation of this module we have used the ECGPUWAVE tool [?] that extracts the wave events of an ECG signal, and built an automata that divides the signal into a sequence of beats.

The *Decision Support Module* is the module in charge of the arrhythmia detection. Two main steps take place during this analysis: identification of the beat types and classification of the arrhythmias. In order to classify the beat we have used a method based on decision trees. The learned functions are represented by a set of if-then rules to improve human readability. Those rules have been extracted, codified in a programming language and tested. The validation of the rules previously generated took place using the hold-out validation. In order to classify the rhythms, we used a combination of rules: Cardiologic and Inferring rules. The Cardiologic rules were obtained through the translation of the arrhythmia descriptions found in the specialized cardiologic literature and in parallel, we obtained the Inferring rules by using techniques based on decision trees. Finally we combined them and chose the best rules to detect each rhythm. Complete details of the ECG analysis process can be found in

[8].

The *Interface Module* is responsible for data visualization and measurements display. The figure 2 shows a picture of the MOLEC Monitor. It provides a friendly interface that draws the ECG signal as soon as the current beat and rhythm types are obtained on-line by the Decision Support Module.

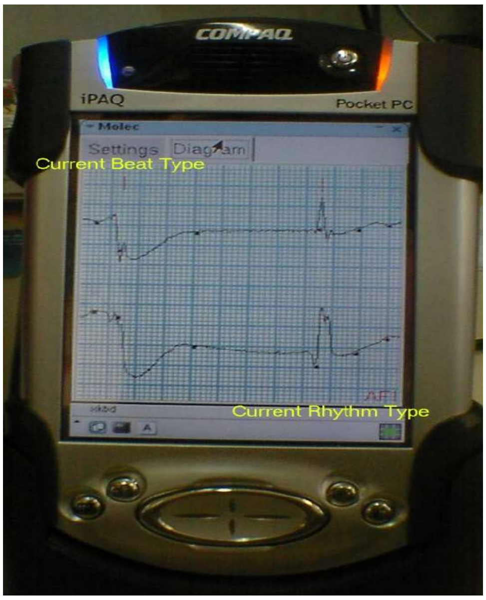


Figure 2. ECG visualization in MOLEC Monitor

The *Alarm Manager Module* receives the current heart rhythm detected by the decision support module and decides whether to generate an alarm. Not all the arrhythmias should be sent in real time to cardiologists so that they can confirm them and/or make their decisions: only those considered very dangerous by them. With the help of some cardiologists, we have considered two groups, one for high-risk arrhythmias, that is, arrhythmias that should be notified to the alarm center when they were detected by the system and the other one for the moderate-risk arrhythmias and normal rhythms that are stored but not immediately notified.

The *Communication Module* manages all the communication between the MOLEC Monitor and the MOLEC Center. It constructs the different type of messages that the PDA decides to send to the MOLEC Center and also receives the acknowledge, request or setting messages that the other one could send.

The goal of the *Data Manager Module* is to efficiently manage the restricted memory resources available in the PDA, at least when compared to the great capacity of ECG sensors to generate data.

We have chosen compressed XML file format to locally store the ECG signals. The XML files offer an appropriate method to store the ECG signals together with the determined annotations, easy exchange of the data and besides very good ratio when compressed. In this way it is saved not only important memory of the PDA, but also communication costs if the signal segment contained has to be sent. These files are managed through a local database that contains the references of all of them having in this way a quickly availability of the signal. An example of an XML file that contains the information of an ECG signal appears in Figure 3.

```xml
<?xml version="1.0"?>
<signal>
    <header>
        <patient>207</ patient>
        <frequency>360</ frequency >
        <no_samples>1054</no_samples>
        <gain>200</gain>
        <channels>2</ channels >
        <baseline>1024</baseline>
    </ header >
    <samples>
        <sample>
            <channel0>1092</ channel0>
            < channel1>1082</ channel1>
        </sample>
        <sample>
            < channel0>1091</ channel0>
            < channel1>1083</ channel1>
        </sample>
        <sample>
            < channel0>1091</ channel0>
            < channel1>1083</ channel1>
            <annotation>(</annotation>
        </sample>
    </samples>
</signal>
```

Figure 3. XML Signal

In case of anomalous beat and rhythm types detection, information about them are also stored in the local database. Thus the physician could query it and obtain relevant information about the evolution of the monitored user. At this point, we assume that physicians only make queries about abnormal beats and rhythms.

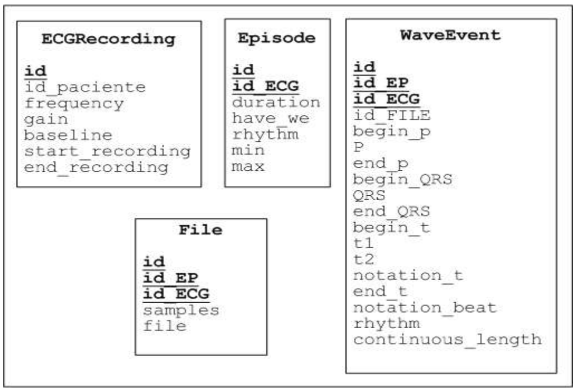


Figure 4. Database of the MOLEC Monitor

In figure 4 it can be observed the structure of the database used. The ECGRecording table identifies the continue monitoring intervals. The Episode tabla keeps information of the different rhythm changes that the monitored user suffered during each monitoring interval. The WaveEvent table register information about the anomalous beats and that ones that occurred during an anomalous episode. Finally, the File table is the one that keeps the reference of all the signal files presented in the PDA.

The possibility to query the database is offered by the system through a set of web services as explained in next section.

4. MOLEC Center

The MOLEC Center's tasks are: 1) to manage the communication with all the PDA Monitors, to forward the alarm messages that a PDA Monitor could send and 2) to offer various information about the monitored users through the *web services*. The web services allow the agents that query the system to obtain quickly actualized reports from information processed into the PDA through a simple web page. These reports vary depending on the one hand of the detail level that they need and on the other hand of the access level that they have in the system. We have chosen web services to expose the functionality of MOLEC because they make use of standard technologies that reduce the heterogeneity and facilitate application integration [REF WS]. These web services supplied by the system are described further.

4.1. Reports Web Service

Specialized literature [11] associates the functionality of holters with a set of reports, which enables physicians to analyze the data easily and quickly. Commercial products offer also various kind of reports. MOLEC system supplies a set of reports that include the information that the other reports provide. The reports are offered through the Reports Web Service in order to answer queries usually asked by physicians. Moreover, they have the possibility to obtain *updated* information about the cardiac activity of the monitored user in *real time* through a simple web page.

There are three kind of reports offered by MOLEC:

1) The *Arrhythmia Identification* report that shows the different rhythm types that the user suffered during a monitoring period, the number of episodes involved for each rhythm with the corresponding duration, minimum and maximum frequency.

2) The *ST Segments Evolution* report that informs about the behavior of the T wave, relevant when detecting the isquemic episodes. We identify six different morphologies for the T wave and inform about the amount of the occurrence of each of them.

3) The *Abnormal Beats Detail* report that informs about the abnormal beats discovered in the ECG signal, being the most complex and costly type of query. The queries are made depending on the origin of the beats that can be ventricular (corresponding to beat types V, !, E and e) or supraventricular (corresponding to beat types S, F, a and J) and offers details about the beat types involved, if they are isolated or not, and if not, the number of consecutive beats. An example of this type of query is presented below for a ventricular origin (V, !, E or e) of the beat and performed for a particular user (207).

Table 1. Detail of abnormal ventricular beats

```
SELECT  w.rhythm, w.notation_beat,  count(*) , w.continuous_length
FROM    ECGRecording e, Episode p, WaveEvent w
WHERE   e.id_patient = 207  and e.id = p.id_ECG and
        p.id = w.id_EP and   (w.notation_beat = “V”  OR
        w.notation_beat = “E”  OR w.notation_beat = “!”  OR
        w.notation_beat = “e” ) and end_recording is null
GROUP BY w.id_EP, w.continuous_ length
```

The resulting columns show the rhythm and beat type and the length of a continuous sequence and the number of its occurrence. Note that this query is realized on the actual monitoring sequence as the end_recording was set null.

4.2. User Current State Web Service

This web service is intended to inform about the current state of the monitored user at that moment (wherever this one is placed). It offers information about the user's current rhythm, cardiac frequency and the time since when he maintains this rhythm. This kind of service is aimed more at the relatives. One possible extension of this could consist of sending the latest changes in the monitored user state to the family using the SMS messages.

4.3. Notified Alarms Web Service

This web service supplies information about the problems that may have occurred during a certain monitoring period. More exactly, it informs about the alarms that the system notified to the Alarm Center, the type, duration of the episodes and the moment when they took place.

4.4. ECG Signal Consulting Web Service

The ECG Signal Consulting Web Service permits authorized agents to obtain parts of the ECG signal registered from a certain patient for printing and extra analyzes. The response latency for this service depends on if the signal in question has already been transferred from the PDA to the MOLEC Center (e.g. with an alarm message) or not. This type of request could increase the wireless communication costs with the MOLEC Monitor if the signal part requested is still in the PDA. Nevertheless it is supposed that the physician would opt to ask for a signal segment still placed into the PDA only if he is considering it relevant for a fast diagnosis and after analyzing the previous reports that MOLEC offers to it.

4.5. Setting Web Service

This service offers to the physicians the possibility of setting, during the monitoring, a set of parameters for a monitored user. In this way, the service responds to several needs like: setting of diagnosis, medicine dosage adjustment or alarm notification policy setting.

For example, in case of the alarm notification policy setting, the physicians could customize the standard alarm cases set for a monitored user. They could increase this set by adding new alarm cases to be notified or, on the contrary, to consider that some alarms cases are fairly often for that user and to set them to be notified only when are longer than a certain duration.

5. Web Services in MOLEC System: Access Performance and Availability

The web services mentioned previously are provided by the MOLEC System in order to allow authorized agents to obtain information processed into the MOLEC Monitor independently of its location. Issues like response latency and communication costs are taken into account in order to define a proper communication policy and optimal architecture able of supplying, promptly and at anytime, the widest information possible to the formulated query.

In this section we have performed some tests in order to decide a proper architecture for the web services. The test consisted on performing some web services (the reports web services) over a database with data related to a recording of a half an hour ECG signal. Hence, we compared two approaches to query the database in order to find the fastest and the most economical way to supply this type of service.

In the *first approach* the web service report is invoked in the PDA (see figure 5) where an XML-RPC Server is located. The request is processed in this way: 1) The Server Consumer invokes the Report service offered by the PDA; 2) the PDA processes the SQL query in the local database and sends the answer back to the Server Consumer where it is displayed.

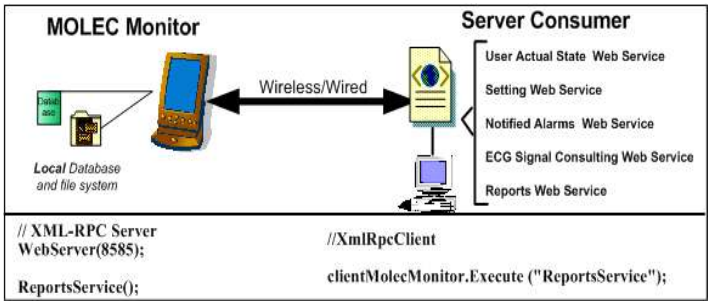


Figure 5. Web Service Report is invoked in the PDA

In the *second approach* the web service report is invoked in the MOLEC Center (see figure 6) where an XML-RPC server is located. The request is processed in this way: 1) The server consumer invokes the report service offered by the MOLEC Center; 2) MOLEC Center processes the SQL query in the global database but previously the remaining part of the PDA database is transferred to the MOLEC Center, in this way the MOLEC Center invokes the transfer service offered by the PDA and updates the global database; 3) MOLEC Center sends the answer back to the server consumer. In this sense the interesting question is: what is the volume of data to be transferred from the PDA to the MOLEC Center? In this case, we have considered several possibilities of distribution of data at the moment of the request sending: 1) all the database is placed in the PDA; 2) 90% of the database has already been transferred to the MOLEC Center; 3) half of the database is already in the MOLEC Center.

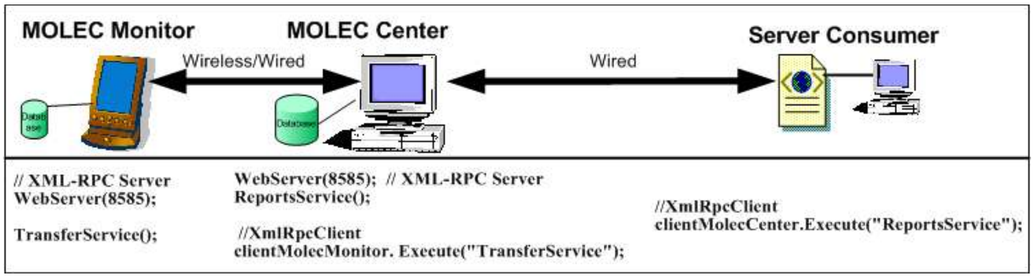
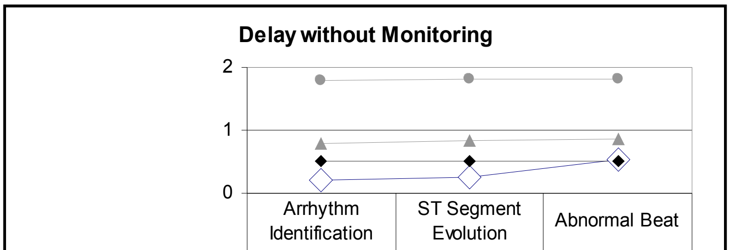


Figure 6. Web Service Report is invoked in the MOLEC Center

In the previous figure it can be seen that the service offered by both approaches uses the XML-RPC. It is the lite version if we compared by WSDK that allows the monitoring and the remote invoking in the same time on the PDA. The PDA used for this tests was an IPAQ 3970 with Linux OS and SQlite, an embeddable SQL database engine. With respect to the wireless communication method, we have used Bluetooth which offers a bandwidth of up to 1M. The latency of the responses for the different types of queries in the case that the monitoring process in the PDA was stopped are reflected in the figure 7.

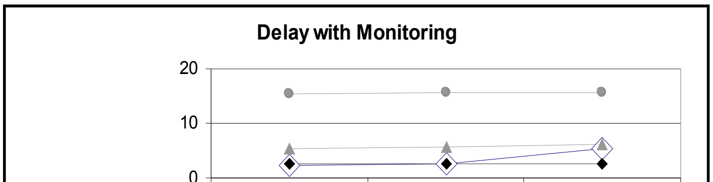


	Arrhythm Identification	ST Segment Evolution	Abnormal Beat
PDA	0.22	0.26	0.54
PC with 0% DB	1.802	1.804	1.806
PC with 50% DB	0.802	0.84	0.86
PC with 90% DB	0.502	0.504	0.506

Figure 7. Query response delay using a database that contains ½ hour monitoring data and with no monitoring at the PDA.

It can be seen that the delay of the query response when the SQL query is performed in the PDA and the case of PC with 90% of the database are similar. In the other two cases the delay obtained increase proportionally with the amount of information that has to be transferred, being evident that the bandwidth used have a big influence on all the results.

This latency can drastically increase when the monitoring is performed in the PDA at the same time or the database size increases. Moreover, the way that each method affects the monitoring process has also to be considered. The results for the same set of tests but when the PDA performs the monitoring process can be observed in the figure 8.



	Arrhythm Identification	ST Segment Evolution	Abnormal Beat
PDA	2.2	2.6	5.4
PC with 0% DB	15.502	15.54	15.56
PC with 50% DB	5.502	5.54	6.1
PC with 90% DB	2.502	2.54	2.56

Figure 8. Query response delay for ½ hour monitoring database.

In this case it is more evident how the monitoring process affects each query response, the delays obtained being appreciably greater than for the previous situation and the case of the PC with 90% of the database gets better results. Moreover, in case of further consecutive requests no additional information would be necessary to be transferred from the PDA, the response time would decrease until values in the order of milliseconds.

On the other hand, in the case of locally queries in the PDA, although the example considered before gives acceptable results, the response delay by abnormal beat increases up to 30 seconds for databases that contain information of eight hours of monitoring, meanwhile the monitoring process is considerable affected.

Therefore, at this moment, although it would be technically possible to answer SQL queries required by the web service from the PDA, the involved delays and the impact on the monitoring process performance at the PDA makes impractical that option. Our proposal consists on locating the web services at the Monitor Center. The execution of those web services would send SQL queries to the global database located there. But, first, the remaining part of the database in the corresponding PDA should be sent to the Monitor Center and inserted in the global database, producing a delay in the query answering. With the goal of not delaying too much those answers, then, under some conditions, the global database is updated with the local databases. At this moment the conditions[2] are the following ones: when the PDA database reaches a predetermined volume, when an alarm takes place, and when a web service is invoked.

5. Conclusions

Monitoring systems that provide anywhere and anytime assistance are of great interest nowadays, and in particular, monitoring systems for people that suffer from arrhythmias. The use of small but powerful enough computers (like PDAs) with wireless interfaces in those systems permits us to define architectures where local real-time monitoring is performed. In those kind of monitoring systems, it is required to offer the possibility of obtaining interesting information for physicians (and relatives) by accessing data generated at the PDA that performs the local real-time monitoring.

2More intelligent conditions could be added here. For example, when the PDA is connected to a fixed network, or to a non-expensive wireless network like WLAN or Bluetooth.

In this paper, we present an approach where that kind of information can be obtained by using web service technology. Moreover, a set of web services has been defined, implemented and several tests have been performed in order to decide which is the best option to locate the web services in our architecture. Although, at this moment, it would be technically possible to deploy the web services at the PDA, it is better to deploy them in an intermediary element (like our MOLEC Center) in order to get better performance and not to degrade the monitoring process at the PDA.

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