An Interactive Wireless-based Telemedicine System for Back Care Applications

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Abstract

According to recent reports, millions of workers suffer from dorso-lumbar pain due to their occupation. This problem affects people, who work seated in front of a screen; who have to stand up for long periods of time; who have to handle heavy weights; or who have to endure forced and awkward postures. In this paper, a system is proposed to allow the assessment of the muscular condition in any environment (at work, at school, in the house...), in a comfortable and simple way for the patient and using the advances in wireless communications. Only a wireless electromyograph and a handheld device (Personal Digital Assistant (PDA) or mobile phone) with wireless interface are needed. By the PDA or mobile phone, the user can configure the medical device and transmit online the electromyographic signals to a remote server. In this way, the specialist can consult the results and assess the function of the muscle during the activity in order to establish healthy behaviours for the patient. Again, the PDA or mobile phone is used to show the report.

Keywords: Wireless telemedicine, handheld devices, multimedia, health monitoring, electromyography, back lumbar pain, usability.

1. Introduction

It is estimated that 58-84% of the population suffer back pain at some point of their lives [1]. That is the reason why these disorders have an enormous socioeconomic impact in industrialized countries and these disorders continue to be a significant public health problem.

In order to deal with this issue providing flexibility to patients and specialists, we can profit from the recent growth in mobile computing technologies that enables telemedicine applications to operate on mobile devices. Nowadays, telemedicine systems are broadened to using telecommunication technology to provide medical information and services for a multitude of purposes, such as diagnosis of illness, transfer of medical data and records, monitoring rehabilitation or treatment processes, and even conducting surgical operations. Most recently, another notion has emerged: the evolution from traditional desktop telemedicine platforms (for simply the practice of medicine) to wireless and mobile configurations for delivering medical and healthcare services [2].

Wireless networking is becoming more popular as telemedicine applications arise to accommodate the aforementioned flexibility to patients and specialists [3-8]. Wi-Fi is the most common wireless technology. It uses the 2.4GHz globally license free Industrial, Scientific and Medical (ISM) band. Wi-Fi requires a setup process and it is the suitable technology to Local-Area Network (LAN); it is recommended for transferences that need a great bandwidth or for constant connections to the net or Internet.

This paper tries to take advantage of this kind of technology in benefit of the health care and especially in the use of electromyography techniques. Electromyography is the study of muscle function through the recording of the electrical activity associated with functioning muscle [9]. It describes and evaluates the neuromuscular response of the muscular contraction in subjects with and without pathologies of the musculoskeletal system from the bioelectrical information registered during specific activities. Specifically, surface electromyography (sEMG) is a non-invasive kinesiological technique used to study movement [10], during which pairs of surface electrodes are mounted directly on the skin. In most cases patients have to obtain signals

data at regular intervals or several times a day. In these situations, they have to visit the health care centre or take the signals at home using complex and expensive devices. The aim of the system proposed in this paper is to avoid such displacement using wireless technologies, to widen the usability of the telemedicine applications and to generate automatic feedback reports. With this objective, the data captured by the electromyograph are sent online and using wireless technology to a handheld device (PDA or mobile phone). Later, the data are relayed to a server placed in the sanitary centre accessible by Internet. A background application processes the information in real-time and it generates a feedback report which can be consulted and modified by the specialist and downloaded by the client using the PDA or mobile phone to visualize it.

The rest of this paper is organized as follows. In section 2 the background of this work is shown. Section 3 describes the handheld device-based telemedicine system. In Section 4, the system implementation is explained; this one is divided in three big phases. In Section 5, an example of the application is presented, and finally, in Section 6, the different conclusions which can be extracted are established.

2. Background

There have been important advances in wireless communications and network technologies in the last decades. These advances have had a significant impact on m-Health (Mobile Health) systems, defined as "mobile computing, medical sensor and communications technologies for health care" [2]. This impact is mainly due to an important growth in the use of handheld devices (*PDAs* and *mobile phones*). On the other hand, the use of wireless technologies represents a natural evolution of traditional telemedical systems.

Among wireless medical applications, those related to home monitoring [11]-[13] and computer-assisted rehabilitation and therapy [14] should be highlighted. Both involve the monitoring of different parameters like heart rate, blood pressure or movement (for example, fall detection) [15].

There are several previous works which use PDAs for different aims: to have access to the patient's information; data acquisition, processing and communication [3]-[5], [16], [17]; a proxy for medical devices [6]; data integration from multiple sources [18]; and a useful tool in high mobility environments [7], [19].

The use of handheld devices entails important benefits such as the possibility of having access to information from anywhere, sending immediate clinical orders to patients, or the opportunity to consult medical experts at any moment.

Part of this paper is focused on the aspects related to problems in the integration and implementation of mobile and medical devices and also mobile networks. In our opinion, the most interesting and motivating point of the paper is, in fact, demonstrating that the objective of m-Health can be achieved: *"To utilize health care application written on mobile devices that are connected through the wireless networking and communication technology to improve healthcare safety and outcomes, whereas reducing costs".* Most of the studies related to m-Health consider the following challenges:

- *Healthcare professionals:* Most of healthcare professionals haven't experienced the new technologies and are even reluctant to their use if that usage entails a hard and long learning process. In this context, aspects such as user-friendliness are essential, as well as lightness and functionality in application design, even at the cost of realizing less attractive user interfaces.
- *Integration into clinician's workflow and work methodology:* The success of the applications based on new technologies depends on their integration in the processes and methodology used by health professionals.
- *Technology:* The evolution of communication networks reveals the need of developing applications that allow the use of different technologies: Internet, Wi-Fi, Bluetooth and cellular networks (2.5G, 3G and future 4G) and evaluating their performance to support the m-Health services. The development of the applications should also allow the user to select among the different available connection alternatives.
- *Mobile devices:* Nowadays, there is a great variety of mobile devices available in the market (PDAs, smart phones, tablet PCs, laptops, etc.). Several studies consider PDAs and mobile phones as medical specialists' favourite mobile devices. As computing standards and data format standards for m-Health do not exist, the interoperability between systems is even more complicated.

Our previous works [20], [21], [22] were focused on using local area networks and the Internet as communication network. The present work also represents an evolution towards using wireless technologies to improve the quality of health care. However, there are some differences between our work and other authors' works mentioned before:

- *Handheld devices:* The developed software can be used both in PDAs and mobile phones. The possibility of using it in a mobile phone has greatly increased its usability. The system has been developed taking into account aspects as usability, reliability and feasibility.

The evolution from traditional desktop telemedicine platforms to wireless and mobile configurations is taking place

The platform allows therapists to retrieve health records from patients and send medical reports avoiding unnecessary trips

- *Open interface:* Most health care systems have their own medical devices. Most previous works have not taken into account the fact that these devices use their own proprietary configuration protocols. Our system has been developed to use commercially available hardware and software components. We have designed a scalable and modular software which allows us to include new technologies as they appear in the market.

- *Configuration:* In the proposed system, the handheld device is not only used as a data acquisition and communication platform but also as a configuration interface of the medical device.

- *Gateway:* In our system, the handheld device can act as a gateway between multiple devices (electromyography (EMG), electrocardiogram (ECG), video, audio, etc.…) and the Internet. The fact that medical devices do not need to have a direct access to the Internet has some advantages. For example, medical devices just need to implement wireless technologies with short ranges, saving power and costs. In addition, medical devices are manufactured by different vendors and use incompatible configuration protocols, but our system can translate proprietary protocols and integrate data from heterogeneous sources.

- *OffLine and OnLine mode:* The system can be configured in either offline or online way. If the online mode is chosen, the measurements are transmitted in real time. Therefore a permanent Internet connection is necessary for the whole exercise length. However the offline mode allows the movement assessment regardless of whether the user has or not a permanent connectivity. With the aim of checking that 3G network is suitable to support our m-Health service we analyse the impact of the wireless network in the communication between the mobile device and the server.

3. Handheld-based telemedicine system

The system platform allows therapists to obtain health records from patients at their homes, avoiding visits from patients to a medical center or visits from therapists to patients' homes. Moreover, the medical reports, diagnosis and subsequent treatment steps are available on patients' interactive PDA or mobile phones. Figure 1 shows a diagram of the system under development with three differentiated domains: the smart home domain, the service provider domain and the therapist domain. The following list summarizes the steps involved in the operation of the application:

1. The therapist draws the therapy work plan, which will be stored in the server database. Each work plan consists of questionnaires and multimedia content describing medical advices and therapy exercises. The questionnaires are used to create and update user profiles.

2. The patient receives the work plan on his handled device as an interactive service. It is necessary that users login to the service and fill in the initial questionnaire in order to access their personalized work plan.

3. When needed, the sensor equipment undergoes a remote configuration to prepare for the activities. Also, users receive (video) configuration instructions for the positioning of sensors or the execution of exercises.

4. Once the patients are ready, they perform the exercises and the data (biometric signals, weight, blood pressure) capture starts. The application sends the data back to the server, which implements the Electronic Health Record (EHR). The data can be captured and sent to the server in real time.

5. The server processes the raw EHR data to detect anomalies and assess a preliminary diagnosis. Together with the questionnaire, the EHR data is used to create user profiles that describe the state of patients and their health habits.

6. Therapists access the data in the server to follow up the progress of each patient. The server user interface presents therapists a comprehensive summary of the results of the tests and questionnaires, the preliminary diagnosis and a list of media items related to the patient profile. Then, the therapists generate the pertinent medical reports.

7. Again, patients receive the results of the tests, together with the medical reports, the updated work plan and the media recommendations on their handheld device.

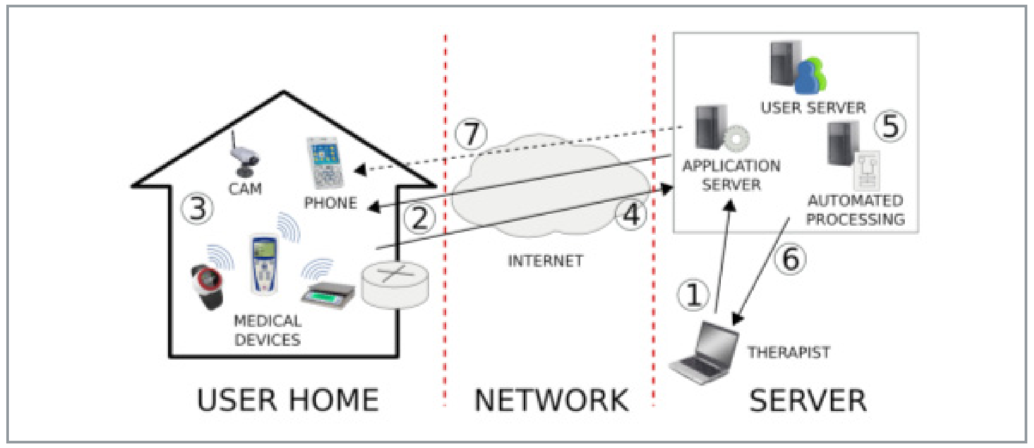

Figure 1. *Handheld device-based telemedicine system.*

ISSN 1889-8297 / Waves · 2010 · year 2

3.1. Medical and Handheld Devices

The medical device used for the work is the *ME6000 Biomonitor System* (Figure 2). It is an 8 or 16 channels electromyograph, which carries out surface measurements of electrical potential of 8 or 16 muscles simultaneously. This device can be used in laboratory or in field tests, because it is a small, light and portable surface electromyograph. Besides sEMG, it allows using other types of sensors, both physical and environmental (goniometers, meters of cardiac frequency, etc). It has trigger in/out connections which facilitate a simple synchronization with other medical equipments.

It allows on-line records using Universal Serial Bus (USB) cable or telemetry to Personal Computer (PC) (optional) and off-line without computer, using a compact flash memory card (256MB extendable). The electromyograph uses a PCMCIA (Personal Computer Memory Card International Association) adapter Cardbus D-Link AirPlus to 2.4GHz, which establishes one WLAN (Wireless Local Area Nerwork) interface using IEEE 802.11b technology.

We have worked with a *PDA Hewlett Packard IPAQ HX4700 Pocket PC* and with a mobile phone Nokia E61. It requires two necessary features: WLAN Wi-Fi 802.11b wireless standard and JAVA MIDP 2.0 (Mobile Information Device Profile) profile with CLDC 1.1 (Connected Limited Device Configuration) configuration.

Wi-Fi technology will be used for the communication between the ME6000 Biomonitor System and the mobile unit, but also for sending data to the server. The ME6000 network configuration must be established previously. The wireless mode is a connection in *ad-hoc*, the authentication is *open* and an extended *128-bit WEP* protocol with a *104-bit key* size is used.

The aforementioned profile and configuration have been installed, and the *.jar* and *.jad files* created have been downloaded in order to run the application in the mobile device. A *Java Application Descriptor (JAD)* file contains a predefined set of attributes, which allows application management software to identify, retrieve, and install the *MIDlets*. A MIDlet is an application written for a Mobile Information Device (MID) Profile. All attributes appearing in the JAD file are made available to the MIDlets. A Java Archive (JAR) file contains: Java classes for each MIDlet in the suite (a suite is a group of MIDlets that can share resources at runtime), Java classes shared between MIDlets, resource files used by the MIDlets (for example, image files) and a manifest file describing the JAR contents and specifying attributes used by application management software to identify and install the MIDlet suite.

As a server, a computer waits for service requests from other devices on the network (in this case an application running in a PDA or mobile phone). It receives the medical data and stores it. The server is used to locate the web page, too. It allows the user to know how to use the Biomonitor System and to locate the electrodes, among other information.

4. Development of the system

The Figure 3 describes the sequence of actions to be followed by both participant actors (specialist and user) in the telemedicine system proposed for the back care.

The mobile device gathers health measurements from the medical device and sends them to the server for later processing

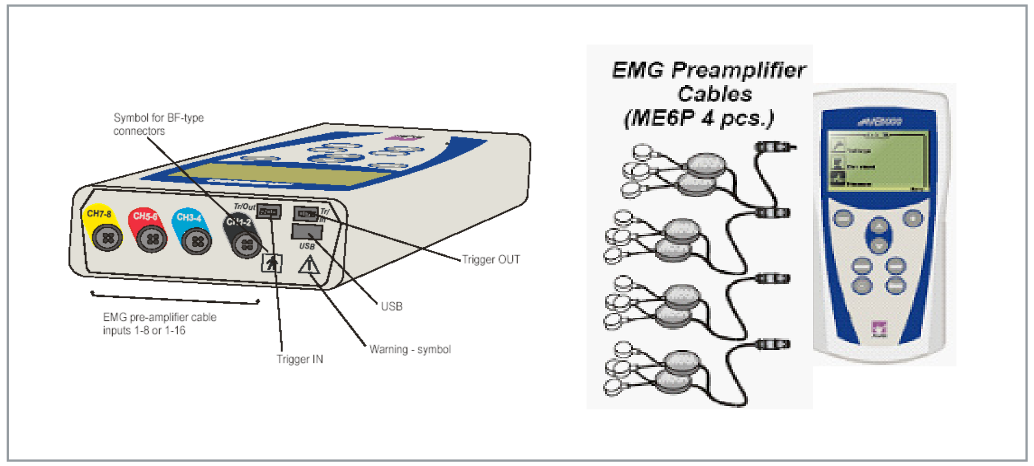

Figure 2. *Medical device (ME6000 Biomonitor).*

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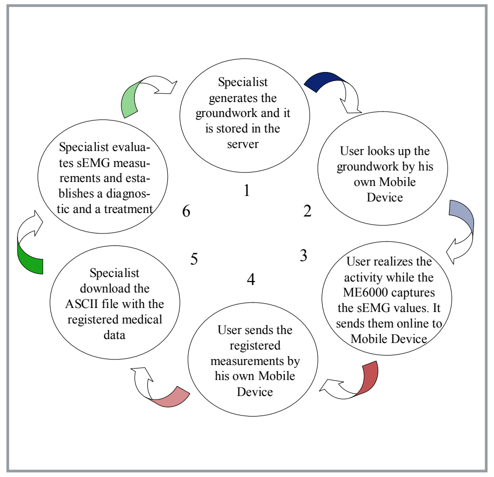
The application has been tested comparing subjects with and without low back disorders

Two applications have been developed using Java in order to materialize the presented system: one to be running in the server and another to be executed in the handheld device.

Step 1: A web page has been developed to include the information that the professional considers necessary about the correct execution of a specific movement to evaluate. The kind of information included can be *text* describing the sequence of steps of the activity, *images* showing the right placing of the electrodes on the



■ **Figure 3.** *Cycle of life of the telemedicine system.*

skin or *videos* explaining the complete exercise. Figure 4 shows an example of this kind of information. This kind of data is displayed clearly in a PC screen or in screens with graphical limitations, such as a PDA or mobile phone screens, given that the web site has been designed to be accessed by pocket PCs, too.

Step 2: The application running in the handheld device provides the user with three possible actions. The first action (Start, in Figure 5) is the collection of sEMG measurements while the user is executing the proposed movement. This information is sent online by the electromyograph to the mobile device, which stores the raw data using the *Record Management System (RMS)* [23].

■ **Figure 4.** *Telemedicine web site and PDA screenshot.*

The application allows selecting between three different protocols whose parameters of configuration have been defined and stored previously. The most important parameters are the *duration of the exercise* and the *sampling frequency.* With both parameters, the number of measurements is calculated. In this way, when all values have been received, the mobile device sends a message of end of connection. Then, the electromyograph stops the measuring and sends its last message.

■ **Figure 5.** *Screenshot of the mobile device.*

So, the communication between medical device and mobile device sets five specific phases: *Connection,* to establish the wireless connection; *Medical Device Configuration,* to define the kind of signal, number of active channels, etc; *Registered Measurements,* to send the packets with the EMG values; End, to define the end of the registration; and *Disconnection,* to finish the wireless connection.

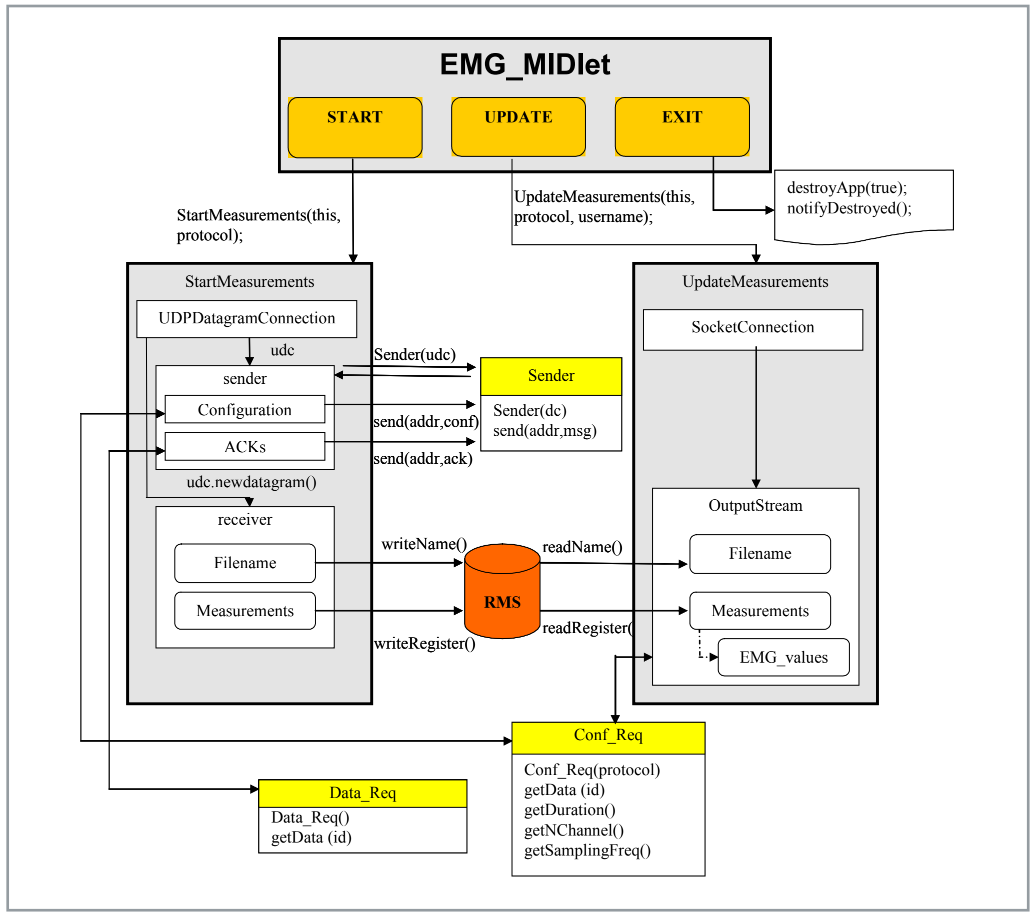
The wireless connection established between medical and mobile device works through an ad-hoc network [24]. It can be identified as a network without infrastructure where all the nodes are connected through wireless links, and where there is no central or dominant node.

The second action (*Update,* in Figure 5) is the transmission of the information stored in the *record stores* using a simple wireless connection by Internet. Among the information sent are the *username* of the patient and the *protocol name.*

Finally, the third action (*Exit,* in Figure 5) allows exiting the application when the measurement is finished, or aborting it. Therefore, the MIDlet which is being executed in the mobile device is destroyed.

Figure 6 describes the main processes of the application developed for the mobile device and the relationship between the different objects which have been programmed.

Step 3: An application developed in Java is running at the server. It is waiting to receive information across a socket and it creates an ASCII file with a specific format compatible with Electromiograph software from the received information.



■ **Figure 6.** *Process diagram of the EMG_MIDlet.*

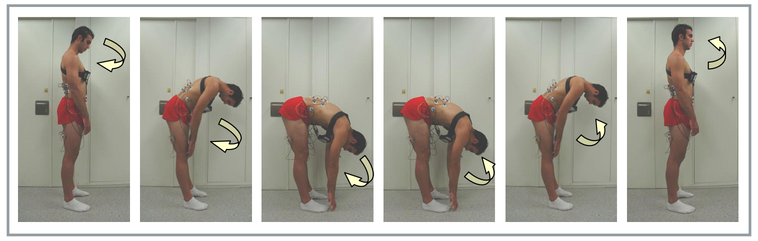
5. Application example and results

One way to assess the behaviour of the spine in pain-free and low back pain subjects is through the test of trunk forward bending. During trunk flexion from the erect position, there is a sudden *myolectrical silence,* or relaxation of the *erector spinae (ES)* muscles, at the end of flexion. This is the *flexion-relaxation phenomenon* [25]. This phenomenon is produced with accentuation in healthy subjects and lightly in pathological subjects. This test carried out with the architecture presented in this paper is useful in order to diagnose the existence of backache without the need of medical visits.

Two young male adults participated in the test. Both were physically fit, with similar weight, height and age. The first subject (control) had never suffered from low back pain or any other kind of low back disorders. The second subject (patient) showed repeated episodes of pain on the lumbar region during the last month, with time off work due to low back pain, and a diagnosis of L4-L5 lumbar disc herniation given by a medical specialist (clinical history, magnetic resonance evidence and radiculopathy symptoms confirmed by physical exploration). The subjects looked up in the web page with their PDA, the instructions for the correct execution of the exercise (a demonstrative video is included) and how to place the electrodes. They were attached bilaterally on the upper and lower *rectus abdominis, erector spinae,* and *biceps femoris* muscles.

Five repetitions of the trunk flexion-extension cycle were performed. Both trunk flexion and extension took 4 seconds each, resting for a second at maximum flexion. Each cycle was distributed as follows: seconds 1-2, neck and trunk flexion, until the hands reach the knees; seconds 3-4: further trunk flexion, until second 5, when the subject kept a position of maximum non-forced flexion. Extension was performed inversely during seconds 6 to 9 (see Figure 7).

After the exercise, the medical data were sent to the server using the developed application. The specialist downloaded the ASCII file created and represented the EMG signals. The results of the pain-free patient are showed in Figure 8. It represents the raw signal in the 8 channels used



■ **Figure 7.** *Example of a session.*

and with the five periods of flexion and extension marked. The results show that the muscles stimulation of both sides is coordinated in time and amplitude.

But in order to assess the behaviour of the spine in both subjects, a processing of the signal is necessary. The raw EMG data were full-wave rectified, averaged over 500 samples (Root Mean Square) and normalized as a percentage of their maximum value to make easier the interpretation and evaluation of the results. The duration of each cycle of movement was divided into 18 equal time intervals. Then, the mean of the five repetitions was calculated, getting only one EMG pattern of trunk flexion-extension movement (Figure 9).

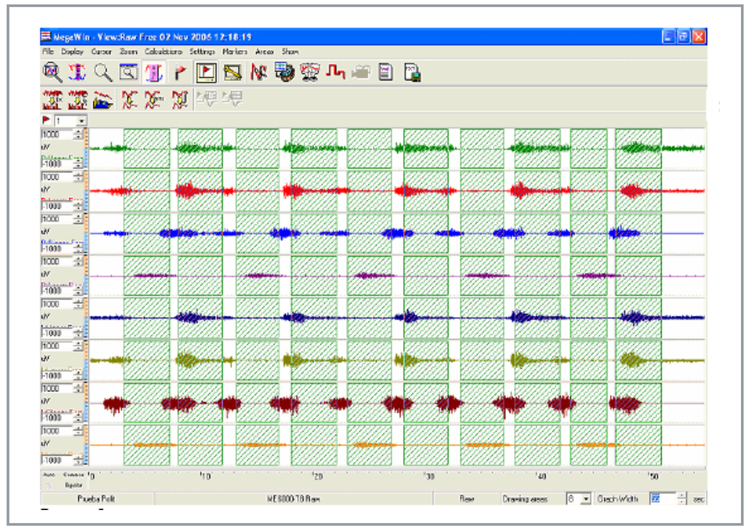


Figure 8. *Raw signal registered in the 8 channels.*

The Figure 9 shows that the first activation peak of the erector spinae in the pain-free subject starts with the beginning of the flexion movement and lasts until the second half of flexion time, when an abrupt decrease of the electrical activity takes place. Muscle activity shows values below the initial baseline (myolectrical silence) until the beginning of extension time, when the second activation peak starts, and lasts until the end of extension. This is the normal ES activation pattern in pain-free subjects [26]. However, the other patient kept a high level of activation during the whole flexion–extension cycle: in the subject with low back pain myolectrical silence of the ES was absent. This is a well-known sign of low back pain [26], which is clearly shown using this application.

6. Conclusions

The telemedicine system offers telediagnosis and televigilance services using efficiently wireless communications and technologies of storage and transfer of information. Also, it helps out with the use of electromyographs in different environments and applications without disrupting the normal daily lives of the patients. These devices are usually difficult to use, but this complexity disappears with the developed application: the user only has to turn the electromyograph on and run the application in his/her PDA or mobile phone. This system could be useful in several fields, such as rehabilitation, work ergonomics, sports medicine or physical education. The possibility of extending the telemedicine system to other medical applications is very attractive. And it is possible with *ME6000 Biomonitor* because it adds options and accessories as a neurophysiological option, sensor of cardiac frequency or respiratory volume, accelerometer, inclinometer, goniometer, etc., even the one called *ME4 Isolation Unit,* which allows the acquisition of signals obtained by other external medical equipments, synchronized to sEMG records, providing the treatment of the different signals together.

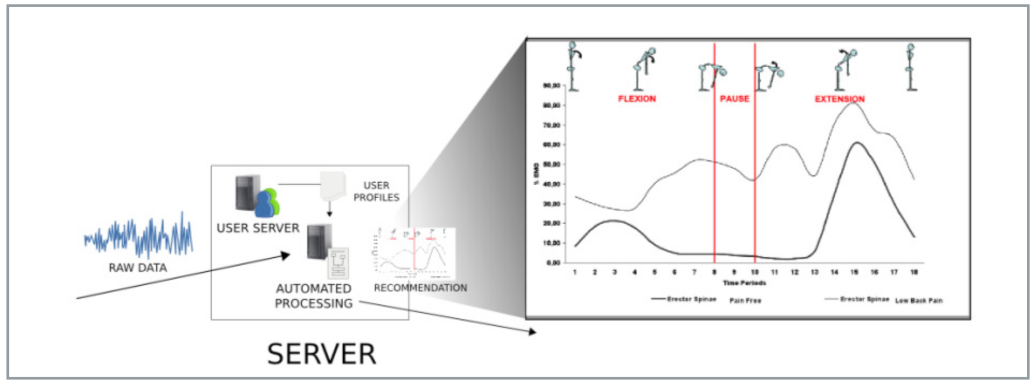


Figure 9. *Results in a pain-free subject and a low back patient.*

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Biographies

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