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Changing communications within hospital and home health care

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***Abstract*— Over the last decade, new hospitals are integrating Information and Communication Technologies (ICTs) in their facilities. Although e-health is a relatively recent term for healthcare practice supported by electronic processes, ubiquitous healthcare monitoring, also known as m-health, is already an emerging research area. Patient monitoring in diverse environments, such as nursing homes or assisted living, are gaining importance. Traditional methods present some problems, as they don't allow enough patient mobility. In this situation, real time transmission of multiple medical data, wearable computing, wireless access in ubiquitous systems and wearable devices for pervasive healthcare can meet the needs of these environments. However, the software and infrastructure deployed in hospitals is not easy to migrate to wireless systems. In some cases, the migration to new technologies can be costly. This paper focuses on the design of a modular, scalable and economical framework to improve the monitoring and checking of patients in different contexts. The challenge is to produce a system to transmit the patient's biomedical data directly to a hospital for monitoring or diagnosis using new communication modules. The modular designed adopted is intended to provide a future-proofed system, whose functionality may be upgraded by modifying the hardware or software. The modules have been validated in different contexts to prove their versatility.**

I. INTRODUCTION

M-Health was first introduced as "Unwired e-med" in the IEEE Transactions on Information Technology in Biomedicine journal [1]. Recent years, this term has included the use of mobile devices (such as PDAs, Smartphones and mobile sensors) in collecting aggregate and patient level health data, providing healthcare information to physicians. Nowadays, patient history, laboratory results, pharmaceutical data, insurance information, and medical resources can be accessed remotely, enhanced by mobile technology, thereby improving the quality of patient care.

The development and improvement of Wireless Communications and Mobile Networks has impacted m-Health directly. Advances in mobile technologies have made wireless telemedicine more practical, both within hospitals [2] and in home care. In this case, patient records can be accessed by health-care professionals from any given location by connecting to the Hospital Information System (HIS) due to wireless technologies (Wi-Fi, GPRS, 3G, etc.).

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On the other side, given the rapidly growing aging population, the increased burden of chronic diseases, and the increasing healthcare costs, there is a need for the development, implementation, and deployment, of new models of healthcare services. Although face-to-face consultations between a clinician and a patient will never be replaced, there are cases that can be managed more efficiently by adopting m-Health solutions. Today, handheld devices are being used in home health care to fight eldering and chronic diseases, allowing real-time monitoring of patient vitals and direct provision of care. In this scenario, Information and Communications Technologies (ICTs), interoperability and specially home monitoring, play an important role.

Wireless Personal Area Networks (WPANs) are defined by IEEE standard 802.15 [3]. The most relevant enabling technologies for m-Health systems are Bluetooth [4] and ZigBee [5]. A recent report predicts the initial market volume of new Bluetooth Low Energy technology to be in the billions [6]. Besides, IEEE standard 802.11 [7] is increasing his presence in these scenarios due to the spread of Wi-Fi. These technologies allow devices such as mobile and smartphones, personal digital assistants (PDAs) or portable computers to communicate and send data to each other without the need for wires or cables to link the devices together.

Wireless Body Area Networks (WBANs) extend conventional bedside monitoring to ambulatory monitoring, providing a point of care to patients, in hospital-based and home-based scenarios. While wired (RS-232, USB) connections continue to be used, emphasis is being placed on wireless capabilities that enable connected or networked devices. Sensors in WBANs are characterised by their interoperability, security, low power consumption, low cost, and small size, improving the performance of health related services [8]. It allows physicians to diagnose, monitor, and treat patients remotely without compromising standards of care.

The use of mobile devices for health services has changed the paradigm of e-Health. The emergence of new scenarios is being helped by the spread of 3G networks and the future introduction of 4G [9]. M-Health systems are created as a synergy of emerging mobile medical computing, medical sensor technologies, and communication technologies.

The main goal of this work is to provide solutions for m-Health frameworks, proceeding mainly on the communications of medical devices and their integration. It has been done with the implementation of interoperable modules that can work in many configurations to accommodate to the requirements of different scenarios. We have focused on the hospital infrastructure and home health care environments.

On the one hand, our m-Health solutions may help physicians by adapting current health-care infrastructures and existing medical technologies, so that they become m-Health services for pervasive healthcare and wireless health monitoring. To deal with this, typical RS-232 wires have been replaced with Bluetooth and Wi-Fi based wireless modules. In addition, ubiquity is provided by a mobile application that allows the physician to access all information while moving.

On the other hand, m-Health solutions are being implemented for home monitoring of patients with chronic diseases allowing patient empowerment. In this scenario, wireless and mobile communication solutions are provided. In addition, power consumption for communications is reduced by signal processing in reconfigurable hardware for high-performance embedded systems.

II. System Architecture

The term M-Health is most commonly used in reference to mobility, but a complete m-Health system may also include data acquisition, processing and integration. While data is acquired through existing medical devices in this work, wireless technologies are used for communicating with other devices and integrating data into the HIS. As mentioned, we apply m-Health solutions in two different environments.

A. *Hospital Infrastructure*

Our first scenario is oriented to the hospital infrastructure, dealing with wireless communications and ubiquitous monitoring on mobile devices. Traditional medical devices communicate through a serial connection using the RS-232 standard. The wires (RS-232) in the medical devices can be replaced by wireless modules which are transparent to their behaviour. Before the implementation, we have studied three different wireless technologies operating in the unlicensed Industrial, Scientific, and Medical (ISM) frequency band, taking into account that security and encryption plays an important role in medical environments.

Continua Health Alliance has entered into an agreement with the Bluetooth, ZigBee, and Wi-Fi Alliances to facilitate and promote their standards in connected health applications [10]. Products made under Continua guidelines will provide increased assurance of interoperability between devices, enabling them to more easily share information with caregivers and service providers. Certified products promote delivery of healthcare in the home providing independence, empowering individuals and providing the opportunity for truly personalized health and wellness management.

Bluetooth/IEEE 802.15.1 is a short-range low-power radio protocol. It allows exchanging data over short distances (depending on the power class: 100, 10 or 1 meters). ZigBee/IEEE 802.15.4 is a low-cost, low-power, wireless mesh network standard. However, the drawbacks of this technology are its low data rate and its incompatibility with mobile devices. Wi-Fi/IEEE 802.11 targets medium-range and high-data-rate applications. Nevertheless, current smartphones are equipped both with Bluetooth and Wi-Fi, but not with ZigBee. Therefore, in order to include interoperable mobile devices in this framework, ZigBee has been discarded.

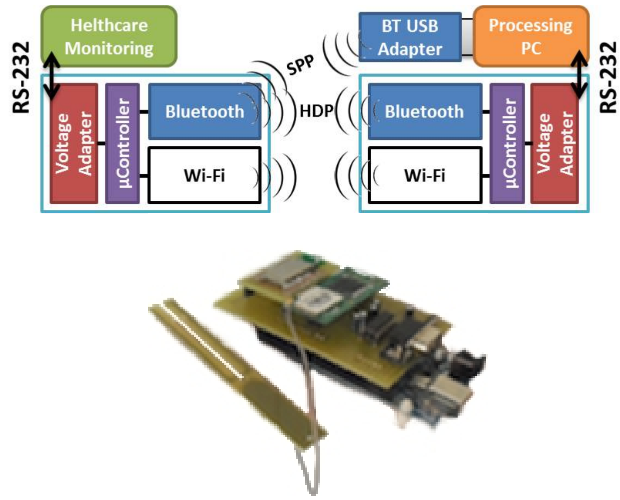

Fig. 1. Wireless module scheme and implementation. Medical devices can communicate using Bluetooth -through a Bluetooth USB Adapter (using Bluetooth SPP) or a equivalent module (usign Bluetooth HDP)- or using Wi-Fi -through an ad-hoc connection or via WLAN using a router-.

The proposed solution consists in eliminating serial wires by including wireless simulators of the wired serial communications (most of the medical devices still communicate by serial interfaces). Bluetooth and Wi-Fi communication modules implemented in this work are described below. Furthermore, a mobile patient monitoring application has been developed to access patient's vitals for pervasive healthcare.

1) Wireless Communication Modules: Two different wireless modules, for Bluetooth and Wi-Fi communication, respectively, have been designed and implemented (Fig. 1). Both of them incorporate an Atmel microcontroller to automate the establishment of the communication.

The first module consists of a Bluegiga WT-12 class 2, Bluetooth 2.1 + EDR (Enhanced Data Rate) module. Bluetooth implements profiles which are definitions of applications and specify general behaviours. In this case, Serial Port Profile (SPP) and Health Device Profile (HDP) are used. SPP emulates a serial cable to provide a simple substitute for existing RS-232, including the control signals. Bluegiga WT-12 also implements the HDP profile with IEEE Agent. HDP is designed to facilitate interoperability of medical devices and fits Continua Healthcare Alliance objectives.

The second module uses a Hi-Link HLK-WIFI-TTL001 module. This solution proposes the simulation of a RS-232 serial communication between two devices via Wi-Fi. As Wi-Fi does not implement a serial port profile, the simulation of the interface is done by the atmel microcontroller. It collects incoming data from the medical device serial communication port and packages it so that it can be retransmitted through Wi-Fi. In this case, data transmission is done through TCP/IP protocol, thus ensuring integrity of the data.

Power consumption of these modules allow them to operate more than two weeks with a 2000 mAh Li-Ion battery or indefinitely with USB alimentation.

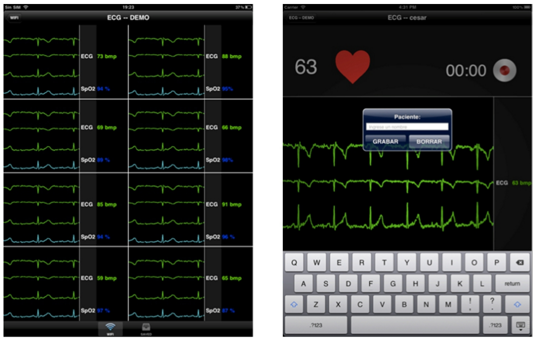

Fig. 2. Mobile Health Application. Visualization of multiple real-time ECG tracings (left) and recording of a single ECG tracing (right).

2) Mobile Health Application: The use of pervasive healthcare solutions may impact directly in decreasing the time spent in the change of contexts. Nurses walk an average of 3 miles (up to 5) per shift, regardless of racetrack, corridor, or radial design facility. Time is spent as follows: 31% of shift in the patient room, 38% of shift at the nurses station, 24% on the unit and 7% off the unit [11].

New hospitals tend to integrate new ICTs devices, so it is easy to introduce mobile devices for pervasive monitoring vitals everywhere in the hospital. For example, ECG signals are commonly monitored in cardiology applications, using fixed recorders for intensive care patients and ambulatory monitors for mobile patients. In this work we propose to introduce a tablet for remote monitoring and routine checkups.

A patient monitoring application which can display biosignal tracings, monitor clinical data and manage alarms from standard or proprietary protocols has been developed [12]. The application can receive and monitor real time data at any location inside the WLAN of the hospital (e.g., it allows displaying ECG leads and heart rate from different patients).

This application also allows to choose and access more data of a particular patient in order to make a more comprehensive monitoring. Finally, the application can store and send data remotely. Data in the form of waveform patterns, bedside alarms, or any other data can be sent to another tablet device with the application installed, for immediate visual interpretation, collaboration, and timely patient care.

B. Home Health Care

Our second application context is an on-going project oriented to the patient. Today, patients are mobile due to the use of new technologies focusing on new roles and enabling "participatory health". Such paradigm, referred to as patient empowerment [13], changes the conventional scenario of patients and physicians into a novel scenario where patients play a greater role in their own health and wellness.

This new scheme includes mobile technologies and delivers the power of communications to the hospital, providing complete continuity of care. The individual participation motivates people to better manage their health. Furthermore, m-Health solutions allow the physician to follow the patient's evolution remotely, improving both the efficiency of the overall health care systems and the life quality of the patient.

In this scenario, remote monitoring can help to improve chronic disease management. However, it is necessary to adapt the different sensors (ECG, SpO2, etc.) to the m-Health context. If the acquisition devices have RS-232 port, this adaptation can be done with the Bluetooth/Wi-Fi communication modules described in section II-A.1 so that data could be retransmitted by a mobile device to the hospital.

Additionally, an on-board module for real-time signal processing can be introduced in order to meet the requirements for power consumption and bandwidth usage. Real-time signal processing can manage the data and detect certain pathologies triggering some kind of alarm, so that it is not necessary to send the complete biosignal data.

In previous work by our group, real-time biosignal acquisition and processing has been integrated into the clinical routine [14]. The solution we now propose in the m-Health framework for home health care, includes a real-time processing module. It is being developed over reconfigurable hardware based on FPGAs and could decrease the amount of data transferred to the hospital.

III. RESULTS

One application of the proposed solutions in this work is a real situation implanted in a speciality center of the town of Fuenlabrada (Spain) called "El Arroyo" where we have worked with staff for cardiology service.

A normal day in this center is described below: a General Electric (GE) MAC 1200 ST [15] is used for acquiring ECG data. In this case, nurses acquire and save data using MAC 1200 ST. Then, information is transferred at the end of the workday to the main PC using a wired serial connection to the unique server computer. The PC application is "CardioSoft" [16] from GE. In the traditional ECG diagnostic procedure, nurse staff connect the RS-232 cable to the PC, and then the MAC 1200 ST starts the transmission to the PC. Some issues have been detected after a preliminary study in order to integrate ICTs. The fact of using a cable to transfer data to a single PC was a problem. The nurse always had to go with the MAC 1200 ST to the central PC and transfer data. In addition, personal staff had to wait until the end of the day to transfer the data. Besides, nowadays, computers tend to be manufactured without serial port. Due to the problems described above, this center wanted to integrate ICTs to include m-Health services.

The modules explained in section II-A.1 allowed to connect the MAC 1200 ST to the PC using a wireless communication. Once the internal connection is established, the computer of nursery staff (master) is ready to be connected with the ECG MAC 1200 ST interface. This proposal was satisfactory in a variety of tests in "El Arroyo". Nurses were allowed to dump the patients data without having to go to the PC room. The only requirements is the coverage, it must be less than 100 meters. The same solution was validated using Wi-Fi, letting to expand coverage of the system. This allowed not have to wait until the end of the workday to transfer all data. A nurse could transmit immediately the record data without further wait.

Day	Transfer technology	Patients transmited	Time spent (min)	Move to PC room
1	RS-232	15	17'30" + 15'	Yes
	Bluetooth	15	17'30" + 15'	Yes
2	RS-232	20	23'20" + 15'	Yes
	Bluetooth	20	23'20"	No
	Wi-Fi	20	23'20"	No
3	RS-232	35	40'50" + 15'	Yes
	Bluetooth	35	14'30"	No
	Wi-Fi	35	14'30"	No

TABLE I
DIFFERENT RESULTS OF THE VALIDATION.

We made tests for three days to validate the robustness of the system. For wired transfer, staff had to move to the PC room every hour or at final hour of workday. For wireless transfer, the first day we moved to that room to confirm that everything was working properly; following days, patients were monitored in different rooms using a coberture less than 100 meters and transmission rate was increased so as to decrease the time spent in the transmission. The results led to a reduction in the time of downloading data to a third. Table I summarizes the type of test and their results.

IV. CONCLUSIONS

The main contribution of the presented paper has been to demonstrate the future potential of wireless technologies in telemedicine and health services.

This paper focused on the design of a modular and scalable system to improve the monitoring and checking of patients in different contexts. The system consists of communication modules, real-time processing and a mobile application. The modules have been validated in different contexts to prove their versatility.

On the one hand our solution has reduced the time spent in transferring biosignals to the server in the hospital allowing nurses to spend more than 31% of shift with patients. In addition, it also allows physicians to increase mobility while decreasing the deficit of health staff and making savings.

On the other hand, nursing homes or assisted living is gaining importance over the last decade. We are integrating wireless and mobile technologies to improve home health care services. The sensors and mobile phones applications are being developed to improve the care of elderly and chronic diseases through effective pervasive monitoring in real time. Real-time signal processing in reconfigurable hardware for high-performance embedded systems is done to reduce communications power consumption.

Nursing and medical staff consider this to be a useful application. In fact, this project has been successfully validated due to the collaboration of medical staff in the design and implementation phases. A broader clinical test will confirm its feasibility and usability.

A future development may apply new compression and signal processing algorithms, such as wavelet techniques, which can be integrated to optimize the performance of the system under different mobile conditions. The new generation of mobile applications will be developed in HTML5, taking advantage of its versatility. Data may be integrated in the HIS when transferred to the hospital, so that HL7 (Health Level 7) integration is necessary in the server side to achieve health care information exchange and interoperability.

The introduction of fourth-generation (4G) mobile communication systems may impact on the evolution of m-Health systems. The modular design of the system should enable telemedicine providers to adapt to 4G standards, which will allow much more data to be transmitted and will be particularly suited to the transmission of several channels of biomedical data.

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