Telemonitoring of Vital Signs – An Effective Tool for Ambient Assisted Living

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Abstract— **Telemedicine and e-health solutions provide (chronic) patients and elderly people services that enhance their quality of life. Advances in wireless sensor network technology and the overall miniaturization of their associated hardware low-power integrated circuits have enabled the design of low-cost, miniature and precise physiological sensor modules. These modules are capable of measuring, processing, communicating one or more physiological parameters, and can be integrated into a wireless personal area network (WPAN). This paper is dedicated to the most complex Romanian telemedical pilot project, TELEMON, that implemented a system for automatic and complex telemonitoring, everywhere and every time, in real time, of the vital signs of persons with chronic illnesses, of elderly people, of those having high medical risk and of those living in isolated regions. The main objective of this pilot project is to enable personalized medical teleservices delivery, and to act as a basis for a public service for telemedical procedures in Romania and abroad.**

Keywords— **telemedicine, telemonitoring, wireless technology, embedded systems, ambient assisted living.**

I. INTRODUCTION

The demographic change and ageing in Europe, seen as a major time aggravated thread to the European societies, implies not only challenges but also opportunities for the citizens, the social and healthcare systems as well as industry and the European market.

Emerging information and communications technologies have considerable potential for enhancing the lives of many older people and effectively approach the concept of persons' wellbeing, by using advances in biomedical wearable sensors, wireless sensor networks and technologies for remote monitoring. In this respect, the paradigm of Ambient Assisted Living (AAL) fosters the provision of equipment and services for the independent or more autonomous living of elderly people, via the seamless integration of info-communication technologies within homes and residences, thus increasing their quality of life and autonomy and reducing the need for being institutionalized or aiding them when it happens [15].

In the UK, for example, health officials believe ICT enabled self-care could potentially reduce general practitioners visits by 30% and hospital admissions by 40%. Moreover, length of hospital stays and days off work could also be reduced by 40%. Successful aging means maintain physical, cognitive, and social activities, live an independent life and maintain a good quality of life. Senior citizens wish to remain living at home for as long as possible, despite the appearance of motor and/or cognitive impairment.

Telemonitoring is one of the alternatives that provide users and their families with confidence and satisfaction, since it allows elderly patients with chronic diseases or very frail to live independently in their own home with direct contact to the professionals, relatives and friends [14].

Our project enables to design a secure multimedia transmission system (medical records, digital images, video, and text) in order to enhance the telemedical consultancy services. The main objective of this project is to enable personalized teleservices delivery and patient safety enhancement based on an earlier diagnosis with medical telemetry using biosignals, images, text transmissions, and also applying the suitable treatment according to the remote medical experts' recommendations [1], [8]. In this way the medical risks and accidents are diminished. The TELEMON system acts as a pilot project destined to the implementation of a public e-health service, "everywhere and every time", in real time, for people being in different hospitals, at home, at work, during the holidays, on the street, etc.

II. MATERIALS AND METHODS

A. *Medical Monitoring*

The main objective of this project is the achievement of an integrated system, mainly composed by the following components in a certain area: a personal network of wireless medical sensors on the ill person (Figure 1), a personal server on the same patient (a Personal Digital Assistant - PDA), and a personal computer (PC). After local signal processing, according to the specific monitored feature, the salient data are transmitted via internet or GSM/GPRS to

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the database server of the Regional Telemonitoring Centre. The personal network of sensors includes at least one medical device for vital signs acquisition (ECG, heart rate, arterial pressure, oxygen saturation, body temperature, respiration), or a fall detection module, all these components having radio micro-transmitters and allowing an autonomic movement of the subject.

The project also approaches the situation of *the mobile patient*. The data processing is done by a PDA with GPS localization, and data transmission is obtained by using the GSM / 3G module of the PDA.

Concerning the application programs, they act and correlate on two levels: a local data processing, near the patient, as well as another processing on database central server. So, the general software architecture is a client-server one, and the project develops a *SOA – Service Oriented Architecture* - which is a standards-based approach to manage services made available by different software packages for reuse and reconfiguration [2]. Services are written to protocols that are interchangeable, unlike many interfaces that are unique to each software application and typically vary by hardware platform, software language, and operating system.

The results of data processing include different locally generated alarms, transmitted to the central server, to the family or specialist doctor, to the ambulance or to a hospital. Other results of on server data processing are different medical statistics, necessary for the evaluation of health status of the subject, for the therapeutic plan and for the healthcare entities. The TELEMON system is built around a database server that receives data from local subsystems and also from mobile subsystems. The transferred information to database server are represented by those data above the limits and by medical recordings. The database server stores the recordings and is capable to send alarms to the ambulance service and patient's doctor. Also, the database server can be connected to another database server, for example a hospital server, in order to send the patient's medical data. The subsystems are connected to the database server through an Internet (if it is available) or a GSM connection.

So, the *Local Subsystem* for telemonitoring of the patient (Figure 1) is built around a PDA, which wirelessly receives data from the patient, process them and send them to the central database.

The following medical devices were built by us to allow a good monitoring of the vital parameters [7], [8], [9], [12], [13]:

a) A *3-leads ECG module* to record and transmit data through a radio transceiver interface. This system allows detection of various abnormalities of electric heart activity, focusing only on those that can be life threatening and thus a medical emergency [10][11]:

- rhythm modifications: severe bradychardia (< 45/min) or tachycardia (> 140/min or even asystola – the heart rate equals 0 for at least 3 sec.);
- recently installed AV blocks;
- signs of myocardial ischemia: new, significant pathological Q wave, elevation of the ST segment > 200 μV or depression of the ST segment < −150 μV, negative T wave;
- enlargement of the QRS complex > 0, 13 sec;
- prolonged QT interval > 0, 45 sec.

The module is recommended to patients prone to heart complications or at risk for myocardial/vascular problems, which represents more than 80% of the elderly population.

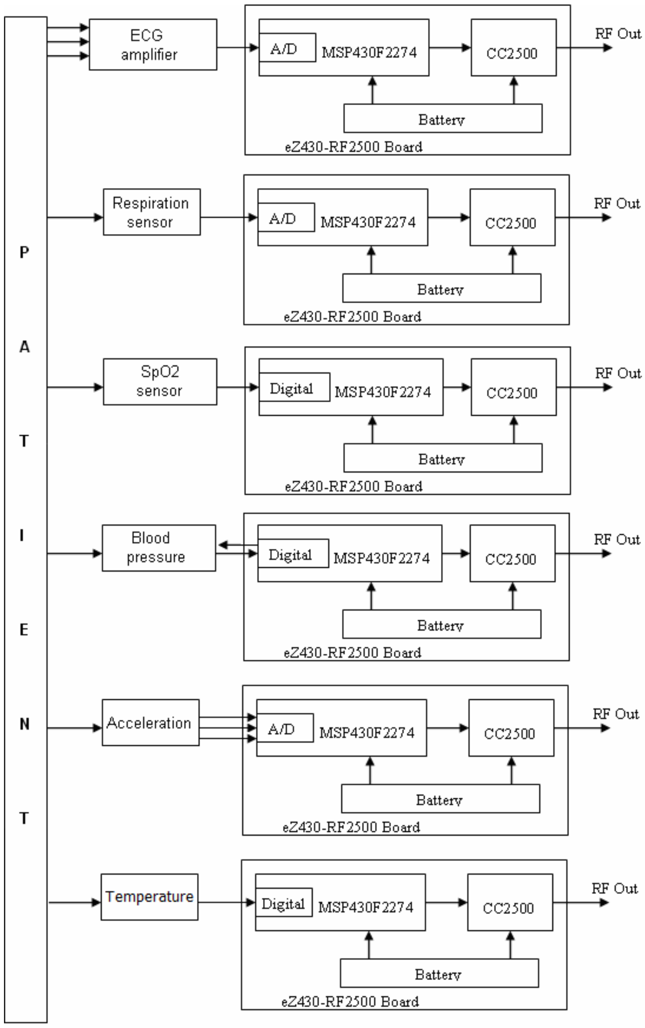

Fig. 1 The personal subsystem for telemonitoring

The 3-leads ECG amplifier is a custom device made by us by using instrumentation amplifiers [17]. It has for each channel a gain of 500, is AC coupled and has a band limited to 35 Hz. The high common mode rejection (>90 dB), high input impedance (>10 MΩ), the fully floating patient inputs are other features of the ECG amplifier. The sampling frequency for the ECG signal was set at 200 Hz.

b) The *arterial pressure module*, with serial interface. This module identifies significant variation of blood pressure such as hypotension (BP < 90 mmHg) or hypertension (BP > 160 mmHg) and is extremely important for elderly persons, who are very prone to this kind of oscillations. Postural hypotension is one of the most frequent situations a senior person must deal with; its complications are severe, impairing the quality of life and becoming life threatening (e.g.: falls, syncope, and stroke). For the blood pressure measurement, a commercially available A&D UA-767PC BPM [18] was used. The blood pressure monitor measures simultaneous blood pressure and pulse rate. It includes a bi-directional serial port interface used to transfer the measurement results to the eZ430-RF2500 at 9600 bps. The measurements of BP and pulse were performed at each 30 minutes.

c) The *oxygen saturation module* (*SpO_2*) and *the respiration module*. Many elderly patients have respiratory insufficiency due to chronic pulmonary diseases, mostly induced by smoking and/or exposure to toxic agents and pollution. The evolution of their respiratory capacity is strongly influenced by weather, exposure to allergens, humidity and compliance to treatment therefore detection of oxygen saturation will allow the caregivers to decide between adjusting oxygen supplementation or seeking medical advice or even call an ambulance for emergency situations. A decrease of arterial blood oxygen < 90% triggers the alarm system.

For the measurement of SpO_2 a Micro Power Oximeter board from Smiths Medical [19] was used. The same board was used for SpO_2 measurement and heart-rate detection. The probe is placed on a finger and includes two light emitting diodes (LEDs), one in the visible red spectrum (660 nm) and the other in the infrared spectrum (905 nm). The Oximeter computes the SpO_2 by measuring the intensity from each frequency of light after it transmits through the body and then calculating the ratio between these two intensities. The Oximeter communicates with the eZ430-RF2500 module through asynchronous serial channel at CMOS low level voltages. Data provided includes % SpO_2, pulse rate, signal strength, plethysmogram and status bits and is sent to the eZ430-RF2500 at a baud rate of 4800 bps.

The sampling frequency for the SpO_2 was set at 1 Hz.

The respiration was detected by using a thoracic belt as a transducer. The belt is placed around the thorax and generates a high-level, linear signal in response to changes in thoracic circumference associated with respiration. The sampling frequency for the respiration signal was set at 10 Hz.

d) The *body temperature module* gives important information about occurrence of fever, especially for persons with mild cognitive impairment who cannot sense temperature modifications (> 38 °C or < 35°C).

For the body temperature measurement a TMP275 temperature sensor was used [20]. The TMP275 is a 0.5°C accurate, two-wire, serial output temperature sensor. The TMP275 is capable of reading temperatures with a resolution of 0.06°C and is connected to the eZ430-RF2500 by using the I^2C bus. The accuracy of the sensor for the 35-45°C interval is below 0.2°C and the conversion time for 12 data bits is 220 ms typically. The sampling frequency for the temperature was set at 1 Hz.

e) The *fall detection module* should be recommended to all senior persons who live alone. Elderly are exposed to often falls due to several causes: postural hypotension (induced by inadequate hydration, cervical spondilosys with vertebrobasilar circulatory problems or even inappropriate medication for hypertension); inappropriate house conditions such as poor lighting conditions, narrow halls or staircases, slippery surfaces which predispose losing balance and fall; sensory disturbances (visual, postural) that induce imbalance and fall; inappropriate shoeing and/or clothing.

An elderly who falls is a medical emergency and recovering his/her health and mental state is extremely important.

The module for fall detection is based on tri-axial ADXL330 accelerometer [21]. Linear accelerations were measured to determine whether motion transitions were intentional. The sampling frequency for the acceleration was set at 25 Hz.

These modules transmit data to a PDA through radio transceivers (eZ430-RF2500 boards), can operate in the 2.4 GHz band, and have 5m /10m range indoors /outdoors.

The eZ430-RF2500 is a complete MSP430 [19] wireless development tool providing all the hardware and software for the MSP430F2274 microcontroller and CC2500 2.4 GHz wireless transceiver [4].

Operating on the 2.4 GHz unlicensed industrial, scientific and medical (ISM) bands, the CC2500 provides extensive hardware support for packet handling, data buffering, burst transmissions, authentication, clear channel assessment and link quality. The radio transceiver is also interfaced to the MSP430 microcontroller using the serial interface.

The USB interface enables eZ430-RF2500 to remotely send and receive data through USB connection using the MSP430 Application UART.

B. Patient Localization

Mobile patients are localized on different maps by using the GPS module of the PDA device worn by those patients and a special application named *TelemonMap*.

The link between the medical data base and the geographic data base is made by means of a specialized tool, the *Project file TelemonMap*.

The geographic data base consists of vector maps (built from different layers) covering the area of possible displacements of patients. We have used such a map for Iasi County, in which the details for Iasi city are at streets and buildings level and is composed by 16 layers. In vector maps the layers are visible or hidden, according to the detail level (map scale).

TelemonMap is a MDI-type application developed in C++ language, by using the menu Microsoft Visual Studio 2008 and displaying different windows.

The synchronization between the medical and geographic data bases is made every 10 seconds by default.

Every generated alarm for the medical status of the patient is automatically transmitted to the geographic data base, from where the position of the patient given by GPS coordinates is transpose on the corresponding vector map.

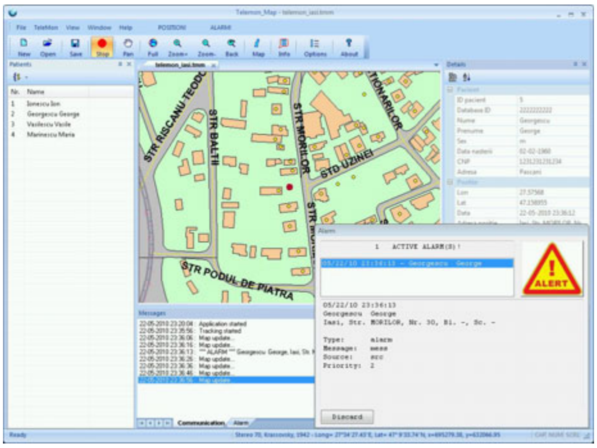

Fig. 2 The patient localization and alarm generating

III. RESULTS

Figure 3 shows *the personal server*, which was implemented by means of a PDA (HTC X7500). The PDA has the following technical specifications: CPU Intel XScale PXA270 at 624MHz, 128MB RAM, 256MB ROM, 8GB HDD, a large TFT display with resolution 640 x 480 pixels, WiFi, GSM/GPRS and Bluetooth (client/host) interfaces and runs Windows Mobile 5 as operating system.

This medical monitor provides transparent interfaces to the wireless medical sensors, to the patient, and to the central server.

Its USB interface is realized by using a serial-to-USB transceiver (FT232BL) from FTDI [9] and enables eZ430-RF2500 radio module to remotely send and receive data through USB connection using the MSP430 Application UART. All data bytes transmitted are handled by the FT232BL chip.

The software on the Personal Server receives real-time patient data from the sensors and processes them to detect anomalies. The software working on the Personal Server (Figure 4) was written by using C# from Visual Studio.NET, version 8. The software displays temporal waveforms, computes and displays the vital parameters and the status of each sensor (the battery voltage and distance from the Personal Server). The distance is represented in percent, based on RSSI (received signal strength indication), measured on the radio power present in a received radio signal).

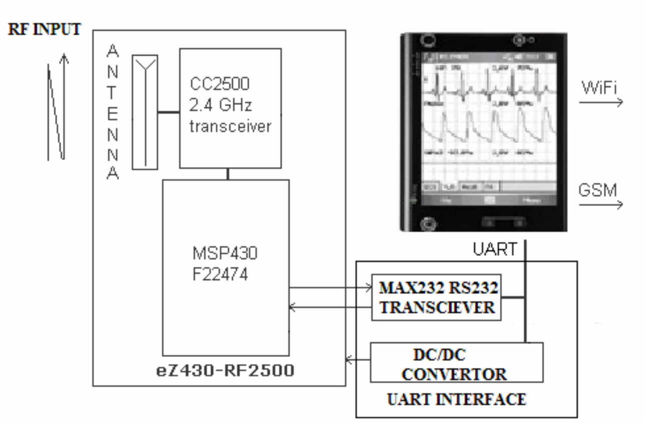

Fig. 3 The Personal server (block diagram)

If the patient has a medical record that has been previously entered, information from the medical record (limits above the alarm) become active and is used in the alert detection algorithm. So, when an anomaly is detected in the measured patient vital signs, the Personal server software application generates an alert in the user interface and transmits the information to the TELEMON Server.

For instance, the following physiological conditions cause important alerts:

- low SpO2, if SpO2 < 90%;
- bradycardia, if HR < 40 bpm;
- tachycardia, if HR > 150bpm;
- HR change, if ΔHR / 5 min > 20%;
- HR stability, if max HR variability from past 4 readings > 10% ;
- BP change if systolic or diastolic change is > ±10% .

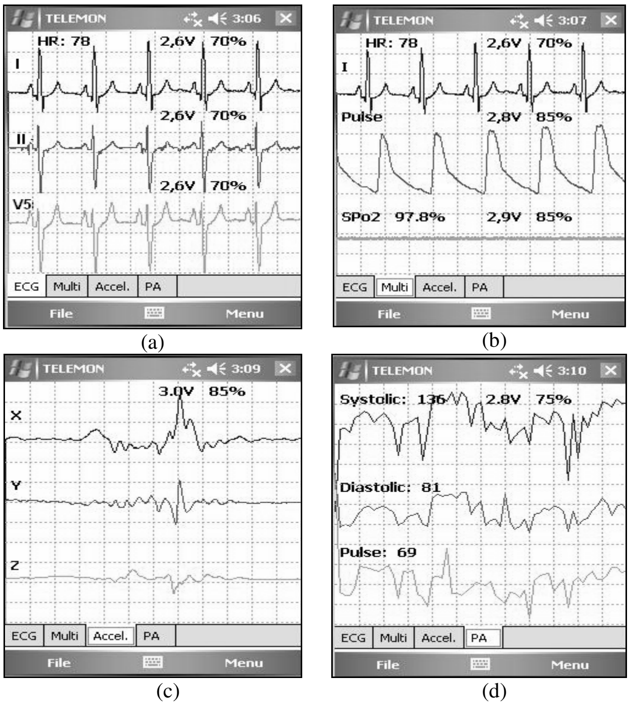

Fig. 4 The Personal server interface: (a) 3 ECG traces, (b) one ECG trace, pulse waveform and SpO2, (c) 3 accelerometer traces, (d) systolic, diastolic pressure and pulse diagrams, measured each 30 minutes

The Personal server can be connected to the database server of the Regional Telemonitoring Centre by using WiFi (default, if available) or GSM/GPRS connections. In both cases the standard TCP/IP protocol is used to transfer data.

The database server of the Regional Telemonitoring Centre is based on SQL Server 2008 platform running on a Windows platform.

The programs are written in Visual Studio .NET 2008 and SQL LITE (for data bases). Basically, the server is composed of a console application and a relational database. The database stores the following patient data: a list of patients and personal information, numerical values of vital signals and alarms, and other medical records related to the patient. The medical records summaries the medical history diagnostics including medications.

The client module comprises the software working on the patient, physician or medical expert computer. The software was written in C# with Microsoft Visual .NET running on a Windows platform and uses the standard TCP/IP protocol to download data from server.

The client module has the following facilities: GUI (Graphic User Interface) for vital signs waveforms, displays the patient's parameters and alarms received from each sensor, management of the patient information and view of clinical records.

While the server is running, the client can start a session from anywhere in the Internet by accessing the server's connection port and providing a proper login and password.

IV. Conclusions

In this paper it is presented a project that is the base for developing a secure multimedia, scalable system, designed for medical teleconsultation and telemonitoring services. The main goal is to build a complete pilot system that will connect several local telecenters into a regional telemedicine network. This network enables the implementation of teleconsultation, telemonitoring, homecare, urgency medicine, etc., for a broader range of patients and medical professionals, including elderly people and those people living in rural or isolated regions [1][3][6].

The Regional Telecenter in Iasi/Romania, situated within the Faculty of Medical Bioengineering, allows local connection of hospitals, diagnostic and treatment centers, as well as a local network of family doctors, patients, paramedics and even educational entities. As communications infrastructure, we have developed a combined mobile-internet (broadband) links.

The proposed system is also used as a warning tool for monitoring during normal activity or physical exercise.

Such a regional telecenter acts as a support for the developing of a regional medical database, which should serve for a complex range of teleservices such as teleradiology, telepathology, telediagnosis, and telemonitoring of different medical parameters. It should also be a center for continuous training and e-learning tasks, both for medical personal and for patients.

In this context, the telemonitoring of elderly people who want to preserve as long as possible their independence but are of medical risk (cardiovascular, respiratory, proneness to falls) represents one of the most important solutions to an ageing Europe.

Besides the medical and technical objectives, TELEMON project also proposes important economic objectives:

- the decrease of budgetary and personal expenses dealing with the unjustified transport of patients to the hospital;
- „zero costs" for the hospitalization in the case of patients who may be treated at home.

Overall, the low cost of the entire system, including its maintenance and operating costs, is entirely justified by the great benefits for health monitoring and care.

ACKNOWLEDGMENT

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