A COMPLEX SYSTEM FOR TELEMONITORING OF MEDICAL VITAL SIGNS

H. Costin\textsuperscript{1,2}, C. Rotariu\textsuperscript{1}, Ioana Alexa\textsuperscript{3}, Gladiola Andruseac\textsuperscript{1}, F. Adochiei\textsuperscript{4}, R. Ciobotariu\textsuperscript{4}
University of Medicine and Pharmacy ‘Grigore T. Popa’ - Iasi,
1. Faculty of Medical Bioengineering;
2. Institute of Computer Science of Romanian Academy Iasi Branch, Romania
3. Faculty of Medicine
4. Gheorghe Asachi Technical University, Iasi, Romania

A COMPLEX SYSTEM FOR TELEMONITORING OF MEDICAL VITAL SIGNS (Abstract): A complex goal in biomedical information technology today is the design and implementation of telemedicine and e-health solutions, which provide (chronic) patients and elderly people services that can enhance their quality of life. Material and Methods: We used wireless sensor network technology, low-power integrated embedded systems and wireless communications, which have enabled us the design of low-cost, miniature, precise and intelligent 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). Results: We have designed, deployed, produced and tested both hardware and software medical sensors for WPAN, dedicated to vital signs acquisition, processing and transmitting, as well as the whole telemedical system for these physiologic parameters monitoring in real time. Conclusions: This paper is dedicated to the most complex Romanian telemedical pilot project, TELEMON, that has as goals the design and implementation of a system for automatic and complex telemonitoring, everywhere and every time, in (almost) 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 final objective of this pilot project is to enable personalized telemedical services, and to act as a basis for a public service for telemedical procedures in Romania and abroad. Keywords: TELEMEDICINE, TELEMONITORING, BIOMEDICAL DEVICES, WIRELESS PERSONAL AREA NETWORK, BIOMEDICAL SIGNAL ANALYSIS.

Ageing of the population has resulted in a sustained increase in family and state healthcare expenses – it is now close to 10% of EU gross domestic product (GDP) and is growing every year. Successful ageing means maintain physical, cognitive, and social activities, live an independent life of one’s own choice and maintain an appropriate quality of life (QoL). Senior citizens wish to remain living at home for as long as possible, despite the appearance of motor and/or cognitive impairment. Some of these individuals require moral and/or physical support 24 hours a day, a
situation difficult to deal with without sustained family support or institutionalization. Solutions supporting independent living at home and outdoors are one of the main alternatives to institutionalization, implying a significant reduction in healthcare costs. 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.

Our project, TELEMON, enables designing of 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, 2). Our project allows persons with different (chronic) diseases and to elderly/lonely people to be monitored from medical and safety points of view. 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.

MATERIALS AND METHODS
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 (fig. 1), a personal server on the same patient (a smartphone), and a personal computer (PC). After local biosignal processing, according to the specific monitored feature, the salient data are transmitted via one of internet, GSM/GPRS or a telephonic line to the database server of the Regional Telemonitoring Centre. The personal network of sensors includes at least one medical device for vital signs acquisition, or a fall detection module, all these components having radio micro-transmitters, which allows an autonomic movement of the subject.

The project also approaches the situation of the mobile patient. Data processing is done by a Personal Digital Assistant or a smartphone with GPS localization, and data transmission is done by the GSM 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 so-called SOA – Service Oriented Architecture – which is a standards-based approach to manage services made available by different software packages for reuse and reconfiguration (3).

The results of data processing are in principal and if necessary 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 locally or 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 re-
A complex system for telemonitoring of medical vital signs

receives data from local subsystems, also from mobile subsystems, and stores them. Also, the database server can be connected to another database server, for example a hospital server. The subsystems are connected to the database server through Internet (if it is available) or a GSM connection.

The following medical devices were chosen to allow a good monitoring of the vital parameters:

a) A 3-leads ECG module to record and transmit data through a radio transceiver interface. This sub-system allows detection of various abnormalities of electric heart activity, focusing only on those which can be life threatening and thus a medical emergency, such as: (i) rhythm modifications: severe bradycardia (<45/min) or tachycardia (> 140/min or even asystole – the heart rate equals 0 for at least 3 sec.); (ii) recently installed AV blocks; (iii) 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; (iv) enlargement of the QRS complex > 0,12 sec; (v) prolonged QT interval > 0,45 sec.

We have adapted algorithms for the extraction of the ECG features based on digital filters (4), especially algorithms for the QRS complex and ST segment detection. The module is useful for patients with heart complications or at risk for myocardial/vascular problems, who represent more than 80% of the elderly population.

b) The arterial pressure module, with serial interface. This module identifies significant variation of blood pressure such as hypotension or hypertension and is very important for elderly persons, who are 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).

As practical solution, a commercially available A&D UA-767PC BPM was used. The blood pressure monitor (BPM) takes simultaneous blood pressure and pulse rate measurements. It includes a bi-directional serial port connection communication at 9600 kbps. A eZ430-RF2500 module communicates with the BPM on this serial link to start the reading process and receives the patient’s blood pressure and heart rate readings. Once the readings are received, the eZ430-RF2500 communicates with the network and transmits them to the Personal Server (PDA). PDA computes blood pressure and defines the status of the patient by using the following blood pressure values (by default), that can be adjusted and personalized by specialized physicians (cardiologists): Hypotension: systolic < 90 mmHg or diastolic < 60 mmHg; Normal: systolic 90–119 mmHg and diastolic 60–79 mmHg; Pre-hypertension: systolic 120–139 mmHg or 80–89 mmHg; Stage 1 Hypertension: systolic 140–159 mmHg or diastolic 90 – 99 mmHg; Stage 2 Hypertension: systolic ≥ 160 mmHg or diastolic ≥ 100 mmHg.

c) The oxygen saturation module (SpO2). A large number of elderly patients have respiratory insufficiency due to chronic pulmonary diseases. The evolution of their respiratory capacity is strongly influenced by weather, exposure to allergens, humidity and compliance to treatment, therefore detection of oxygen saturation is a very useful thing. A decrease of arterial blood oxygen < 90% triggers the alarm system.

The pulsoximeter sensor used is Micro Power Oximeter board from Smiths Medi-
The same sensor can be used for heart rate and \( \text{SpO}_2 \) detection. The probe is placed on a peripheral point of the body such as a fingertip, ear lobe or the nose. The pulsoximeter communicates with the eZ430-RF2500 through an asynchronous serial channel at CMOS low level voltages. Data provided includes \%\text{SpO}_2, pulse rate, signal strength, and plethysmogram.

The use of wireless breathing module is suitable for continuous long-time monitoring of human respiration for a number of medical conditions requiring analysis of respiratory rhythm, sleep-related breathing disorder and ischemic heart disease or can be useful during recovery from an acute event or surgical procedure. Our module uses one of the most usual methods to sense breathing, i.e. using a nasal thermistor (6). The sensor is designed using MSP430F2274 microcontroller with an on-chip 10 bit A/D converter for data acquisition (10 Hz sampling frequency) and CC2500 2.4 GHz wireless transceiver. The thermistor detects changes of breath temperature between ambient temperature (inhalation) and lung temperature (exhalation). The used thermistor is a 0603 SMD type and has as main characteristics: \( R_{\text{nom}} = 10 \, \text{k}\Omega \) at 25°C, \( B = 3380 \), 1% tolerance. The Personal server on patient computes the following parameters: Breathing amplitude - calculated for every breathing cycle as a difference between minimum (Inhalation) and maximum thermistor voltage (Exhalation); Breathing interval – measured between two signal minima; Breathing frequency, calculated as a number of breaths per minute. Normal breathing frequency is 12-20 cycles/minute. We consider two types of respiration: normal respiration, when every breath lasts more than 0.5 seconds; apnea, when the breathing is missing for more than 10 seconds.

e) 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). We used the TMP275 temperature sensor (Texas Instruments). The TMP275 is directly connected to the eZ430-RF2500 module. The accuracy for the 35-45°C interval is below 0.2 °C. The Personal server samples the signal from the temperature sensor once per second and computes the status of the patient for the following temperature values: low temperature – <35°C; high temperature – >38°C; normal temperature – between the above values.

f) The fall detection module should be recommended to all senior persons who live alone. Elderly people are exposed to falls due to several causes: (i) postural hypotension (induced by inadequate hydration, cervical spondilosys with vertebro-basilar circulatory problems or even inappropriate medication for hypertension); (ii) inappropriate house conditions such as poor lighting conditions, narrow halls or staircases, slippery surfaces which predispose losing balance and fall; (iii) sensory disturbances (visual, postural) that induce imbalance and fall; (iv) inappropriate shoeing and/or clothing. Early detection of an elderly who had a fall is of extreme importance for recovering personal health and mental state after such a traumatizing event. Our fall detection module is based on accelerometer technique, that can recognize four kinds of static postures: standing, bending, sitting, and laying. Motions between these static postures are considered as dynamic transitions. If the transition before a lying posture is not intentional, a fall event is detected.
Our method uses the ADXL330 3-axes accelerometer and eZ430-RF2500 Wireless Modules. The ADXL330 is a small, thin, low power, complete, three axial accelerometer with signal conditioned voltage outputs, all on a single monolithic IC. We determine if the subject has fallen if the condition \( a_A = \sqrt{a_{A_x}^2 + a_{A_y}^2 + a_{A_z}^2} > 0.4g \) is valid.

**Fig. 1.** The local subsystem for home monitoring of the patient
The modules (a, d, e, f) were made by our research team, while modules (b) and (c) were chosen from the market and were integrated in the TELEMON system (www.bioinginerie.ro/telemon) (Fig. 1). These modules transmit data to a PDA through radio transceivers (eZ430RF2500 boards), can operate in the 2.4 GHz band, and have 5m /10m range indoors /outdoors. The eZ430-RF2500 is a complete MSP430 wireless development tool (7) providing all the hardware and software for the MSP430F2274 microcontroller and CC2500 2.4 GHz wireless transceiver (8). 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 peripheral interface. The USB interface enables eZ430-RF2500 to remotely send and receive data through USB connection using the MSP430 Application UART.

RESULTS

The personal server was implemented by means of a PDA (Toshiba TG01C) (Fig. 2). This personal medical monitor is responsible for a number of tasks, providing a transparent interface to the wireless medical sensors, an interface to the patient, and an interface 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 (Fig. 3) 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).

If the patient has a medical record that has been previously entered, information from the medical record (limits above the alarm become active) is used in the alert detection algorithm. So, when an anomaly is detected in the measured patient vital signs, the Personal server 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 (HR = heart rate); tachycardia, if HR > 150 bpm; 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. 2. The Personal server (block diagram)
A complex system for telemonitoring of medical vital signs

**Fig. 3.** The Personal server interface: (a) 3 ECG traces, (b) one ECG trace, pulse waveform and SpO2, (c) 3 accelerometer traces, (d) systolic and diastolic pressure from the blood pressure monitor

**DISCUSSION**

In this paper it is presented a project that acts as base for developing a secure multimedia, scalable system, designed for medical consultation 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 (10–14).

The Regional Telecenter in Iasi / Romania, situated in 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 fix-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, that should serve for a complex range of teleservices such as teleradiology, telepathology, teleconsulting, telediagnosis, and telemonitoring. It should also be a center for continuous training and e-learning tasks, both for
medical personal and for patients.
Also, 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 aging Europe. Besides the medical and technical objectives, TELEMON project also proposes important economic objectives: (i) the decrease of budgetary and personal expenses dealing with the unjustified transport of patients to the hospital; (ii) „zero costs” for the hospitalization in the case of patients who may be treated at home.

ACKNOWLEDGMENT
This work was financed by a grant from the Romanian Ministry of Education, Research and Youth, within PNCDI_II program (www.cnmp.ro/Parteneriate), contract No. 11-067/2007.

REFERENCES