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Technical University of Cluj-Napoca, Romania, Department of Automation

IPA - R&D Institute for Automation Center for Technology Transfer Cluj-Napoca, Romania

Tome II

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THETA 17th edition

28th-30th May, Cluj-Napoca, Romania

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FOREWORD

It's our great pleasure to welcome you to the 17th edition of the **IEEE International Conference on Automation, Quality and Testing, Robotics AQTR 2010 - THETA 17th edition.**

The conference follows the tradition of the 16 automation and testing related scientific events, organized in Cluj-Napoca since 1982 under the name THETA- Technologies and Automation Testing. The previous editions – "2008 IEEE –TTTC International Conference on Automation, Quality and Testing, Robotics" have demonstrated the importance of Automation, Quality and Testing, Robotics as part of continuous advancing technologies. A large variety of papers were presented and provided good opportunities for the participants to exchange ideas and share new advancements registered in the field of automation, quality and testing.

This edition of the Conference, organized under the care of IEEE Computer Society – TTTC (Test Technology Technical Council) aegis and reflects the faithful cooperation between R&D institute-IPA and the Department of Automation from the Technical University of Cluj-Napoca.

AQTR Conferences intend to be international forums for the R&D exchanges in the field of fundamental and applied research in automation, quality, testing and robotics. They also bring together researchers and end-users to discuss the current trends and future directions of control and testing technologies and their industrial and social applications in the private and public sectors.

This conference would not have been possible without the hard work of the members of the Technical Program Committee - selecting over 300 papers out of 340 regular submissions. For that, we thank all the reviewers who provided us with such valuable feedback on the submissions.

The AQTR Conference covers a wide range of topics, gathering a community of scientists, engineers, academics and researchers. We have more than 200 registered participants, who come from all over the world, renowned names in their fields of activity.

All these being said, we hope that you enjoy our Conference and provide you with new concepts and ideas in the future "knowledge-based society".

Liviu Miclea　　　　　　　　　　　　Ioan Stoian

tttc IEEE Computer Society IEEE COMPUTER SOCIETY

TTTC: Test Technology Technical Council

TTTC IN GENERAL

PURPOSE: The Test Technology Technical Council is a volunteer professional organization sponsored by the IEEE Computer Society. The goals of TTTC are to contribute to members' professional development and advancement and to help them solve engineering problems in electronic test, and help advance the state-of-the art. In particular, TTTC aims at facilitating the knowledge flow in an integrated manner, to ensure overall quality in terms of technical excellence, fairness, openness, and equal opportunities.

MEMBERSHIP: Membership is open to all individuals interested in test engineering at a professional level.

DUES: There are NO dues for TTTC membership and no parent-organization membership requirements.

BENEFITS: The TTTC members benefit from personal association with other test professionals. They may have the opportunity to be involved on a wide range of committees. They receive appropriate and updated information and announcements. There are substantial reductions in fees for TTTC-sponsored meetings and tutorials for members of IEEE and/or IEEE Computer Society.

TTTC ACTIVITIES

TECHNICAL MEETINGS: To spread technical knowledge and advance the state-of-the art, TTTC sponsors many well-known conferences and symposia and holds numerous regional and topical workshops worldwide.

STANDARDS: TTTC initiates, nurtures and encourages new test standards. TTTC-initiated Working Groups have produced numerous IEEE standards, including the 1149 series used throughout the industry.

TECHNICAL ACTIVITIES: TTTC sponsors a number of Technical Activity Committees (TACs) that address emerging test technology topics and guide a wide range of activities.

TUTORIALS and EDUCATION: TTTC sponsors a comprehensive *Test Technology Educational Program (TTEP)*. This program provides opportunities for design and test professionals to update and expand their knowledge base in test technology, and to earn official accreditation from IEEE TTTC, upon the completion of four full day tutorials proposed by TTEP.

TTTC CONTACT

TTTC On-Line: The TTTC Web Site at http://tab.computer.org/tttc offers samples of the TTTC Newsletter, information about technical activities, conferences, workshops and standards, and links to the Web pages of a number of TTTC-sponsored technical meetings.

Becoming a MEMBER: Becoming a TTTC member is extremely simple. You may either contact by phone or e-mail the TTTC office, or fill out and submit a TTTC application form, or visit the membership section of the TTTC web site.

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1/23-1/25	Int'l Sym. on Electronic, Design, Test and Applications (DELTA), Ho Chi Minh City, Vietnam	N.H. Phuc, A. Osseiran
3/8-3/12	Design, Automation and Test in Europe (DATE), Dresden, Germany	G. De Micheli
3/23-3/24	Workshop on Silicon Errors in Logic - System Effects (SELSE), Stanford, CA, USA	A. Wood, I. Parulkar
3/28-3/31	Latin American Test Workshop (LATW), Punta del Este, Uruguay	R. Velazco, Y. Zorian
4/15-4/17	Design & Diagnosis of Electronic Circuits & Systems Workshop (DDECS), Vienna, Austria	Z. Kotásek
4/19-4/22	VLSI Test Symposium (VTS), Santa Cruz, CA, USA	M. Abadir
4/22-4/23	Workshop on Test of Wireless Circuits and Systems (WTW), Santa Cruz, CA, USA	R. Aitken
5/9-5/12	Workshop on Signal Propagation on Interconnects (SPI), Hildesheim, Germany	H. Grabinski
5/24-5/28	European Test Symposium (ETS), Praha, Czech Republic	O. Novák
5/28-5/30	Int'l Conference on Automation, Quality & Testing, Robotics (AQTR), Cluj-Napoca, Romania	L. Miclea
6/7-6/9	Int'l Mixed-Signals, Sensors, and Systems Test Workshop (IMS3TW), La Grande Motte, France	F. Azais
6/10-6/12	Int'l High Level Design Validation and Test Workshop (HLDVT), Anaheim, CA, USA	P. Mishra
6/13-6/14	Int'l Symposium on Hardware-Oriented Security and Trust (HOST), Anaheim, CA, USA	J. Plusquellic
6/14	Int'l Workshop on Design for Manufacturability & Yield (DfM&Y), Anaheim, CA, USA	R. Aitken
7/5-7/7	International On-Line Testing Symposium (IOLTS), Corfu Island, Greece	M. Nicolaidis, A. Paschalis
7/15	ATE: Vision 2020, San Francisco, CA, USA	E. Volkerink
9/14-9/16	Board Test Workshop (BTW), Fort Collins, CO, USA	W. Eklow
9/17-9/20	East-West Design and Test Symposium (EWDTS), St. Petersburg, Russia	V. Hahanov, Y. Zorian
9/27-9/29	International Test Synthesis Workshop (ITSW), Santa Barbara, USA	A. Jas
10/6-10/8	Int'l Symposium on Defect & Fault Tolerance in VLSI Systems (DFT), Kyoto, Japan	H. Ito, S. Tragoudas
10/31-11/5	International Test Conference (ITC), Austin, TX, USA	R. Press
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11/4-11/5	Int'l Workshop on Design for Reliability and Variability (DRV), Austin, TX, USA	M. Nicolaidis
11/4-11/5	Int'l Workshop on Defect and Data Driven Testing (D3T), Austin, TX, USA	A. Crouch
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TBD	Int'l Workshop on Testing Embedded and Core-Based System-Chips (TECS), Online	Y. Zorian

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QUALITY OF LIFE & E-HEALTH

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Wearable computing for patients with coronary diseases: Gathering efforts by comparing methods

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***Abstract*-Cardiovascular diseases are a prime cause of mortality and morbidity around the world. The World Health Organization names this as a global epidemic identifying it as a big challenge to Information and Communication Technologies that can provide valuable tools to improve population health and well-being.**

In tandem with a strategy to provide information and education to individuals at risk, several projects across the world at national or regional levels are trying to address this challenge.

The HEARTRONIC project developed an innovative system for prevention and early warning by continuous monitoring the heart conditions. This system is wearable by the patient, monitors and analyzes the ECG, and in the event of results that could predict a heart attack or stroke an alert message is sent to a server and then relayed to the responsible healthcare professional. The system uses ECG processing for automatic detection of abnormal functioning. First response actions are taken but the healthcare professionals are always in the control.

The BIOMED-TEL project developed an innovative remote patient monitor that supervises 24 hours/7 days the main patient's vital signals in its environment. These signs are: SpO_2, ECG one derivation, arterial blood pressure (BP), in conjunction with the body vibration acquired from chest zone and, glucose concentration in blood all above mentioned signs being relevant for the health patient status. With the correlation of the signals, the remote monitor is able to dynamical adapt his working regime from local storage of data acquired (as a classical holter) to continuously transmission of data acquired from patient to the hospital server, providing a quick time intervention of the health care professional in case of patient's alarm or emergency situation.

Both projects are gathering efforts by comparing methods in order to assess the best practices and address the technical challenges that came across the development of such useful platforms.

I. Introduction

Cardiovascular diseases (CVD) cause the death of around 4.500.000 people per year in Europe, being the first cause of deaths in this continent. The challenge is to provide a real solution for continuous monitoring and real time prevention, by means of early warning, to people already diagnosed as patients with high risk. The evolution of cardiovascular condition of these patients should be taken under close and real time surveillance. Previously to these efforts the only option to monitor patients 24 hours a day was by hospitalization, which accounts for high costs and poses serious limitations to the patients' quality of life.

The main goal is to develop a solution that allows patients to go on with a normal life, meantime increasing their expectation of life and improving quality. Information and communication technologies (ICT) have already had a significant impact on health care and the delivery of health services. From Telemedicine to electronic health records to RFID to embedded sensors, a variety of health ICTs have been shown to improve operational and administrative efficiencies, clinical outcomes, documentation and information flow in a variety of global settings, from the home to rural health centers to large urban hospitals.

The monitoring process of the vital signals of the patients in their environment is one of the most relevant and advanced technology developed in the field of Assisted Ambient Living (AAL) because it increases the possibilities to assist, to help and even to save the patients' life. The monitoring methods are based on a set of wireless and intelligent sensors placed onto the patient. The systems were designed to be suitable for wearable applications. The set of sensors was interconnected with a data concentrator, this one being linked through the patient PDA to the hospital server [12]. By interpreting the data sent to the hospital server, a physician will be able to survey the vital signs of the monitored patients thus being able to react quickly and correctly if an alarm occurs or an emergency situation appears. During signal acquiring process (acquisition, transmission and processing of the vital signals taken from the patient) it could appear a lot of technical difficulties which can generate an important risk for failures in the patient monitoring procedure [11]. The failures that can appear are related to sensors accuracy, sensor/patient interfaces, analog signal processing errors, conversion from analog to digital and, of course, to the data transmission between the sensor network placed onto the patient, the data concentrator and Personal Digital Health Assistant (PDHA) or Wearable Processing Unit (WPU).

The particularities and differences between both projects could help the other address some of its technical challenges. This paper aims to provide a preliminary research on both ap-

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proaches starting from previous scientific contributions produced [14],[15],[16],[17],and [18], generating a framework for future collaboration. This framework will boost the development on both ends providing the information gathered on a structured fashion.

This paper is organized as follows. Section II presents the motivation and background on cardiovascular diseases. The Concept of Operation and architecture, are presented in section III. Section IV describes the algorithms used to detect abnormal conditions and, finally, in section V, the conclusions and future work are discussed.

II. Motivation and Background

The single most important cause of death in the adult population of the industrialized world is Sudden Cardiac Death (SCD) [3] due to coronary disease. SCD is caused by electrical problems that keep the heart from pumping the right way, whereas in a heart attack a blockage in blood vessels slows or stops blood flow. SCD causes half of all heart disease deaths. Contrary to heart attack, SCD often occurs in people who appear healthy, which can make it difficult to know who is at risk. Treating someone in SCD requires "paddles" to shock the heart, as in for example implantable cardioverter-defibrillator (ICD) therapy.

Chronic coronary artery disease (CAD) [3] is most commonly due to obstruction of the coronary arteries by atheromatous plaque. Patients with CAD represent the majority of patients threatened by SCD. In patients convalescing from myocardial infarction, SCD may be as high as 10% in the following 2.5 years. There are a number of other heart diseases and conditions that can lead to SCD.

Heart diseases and disorders

Heart diseases can be classified in three categories: electrical, circulatory and structural [3]:

-- Electrical heart diseases: Characterized by abnormal heart rhythms, called arrhythmias, caused by problems with the electrical system regulating the heartbeat.

-- Circulatory: High blood pressure and coronary artery disease are the main culprits in blood vessel disorders. The results, such as stroke or heart attack, can be devastating.

-- Structural: Heart muscle disease (cardiomyopathy) and congenital abnormalities are two problems that can damage the heart muscle or valves.

Millions of people experience irregular heartbeats at some point in their lives but most of these episodes are harmless and are not life threatening. However, some arrhythmias are dangerous and cause sudden cardiac death. Other heart diseases can be dangerous in their own right and can increase the likelihood of arrhythmias.

Preventing the causes of SCD is the best way of preventing deaths from SCD and there are a number of common risk factors that help identify potential patients.

There are a number of tests that can be used to determine if someone is in a group that is at high risk for cardiac arrest, including:

--Echocardiogram: Sound waves are used to create a moving picture of the heart. This test can measure the pumping ability of the heart and identify other problems that may increase the risk of SCD.

--Electrocardiogram: Electrodes are attached to the chest to record the electrical activity of the heart in order to identify abnormal heart rhythms. Certain arrhythmias could point to an increased risk of SCD.

--Holter monitor: Walkman-size recorder that patients attach to their chest for one to two days, recording a longer sampling of their heart rhythm. Recorded data are analyzed afterwards for signs of arrhythmia.

--Event recorder: Pager-sized device that records the electrical activity of the heart. Unlike a holter monitor, it does not operate continuously and can be used over a longer period of time. Patients turn on the device whenever they feel their heart beating too quickly or chaotically.

Other tests exist but have to be performed at a hospital or clinic and involve anesthetics. This type of invasive tests is only recommended in very specific cases.

Currently available computerized monitoring systems for in hospital use are mainly based on electrocardiogram (ECG) monitoring. Figure 1. shows a typical ECG signal, with labels for significant time intervals:

--PR interval (from beginning of P to beginning of QRS).

--QRS duration (width of most representative QRS).

--QT interval (from beginning of QRS to end of T).

--QRS axis in frontal plane.

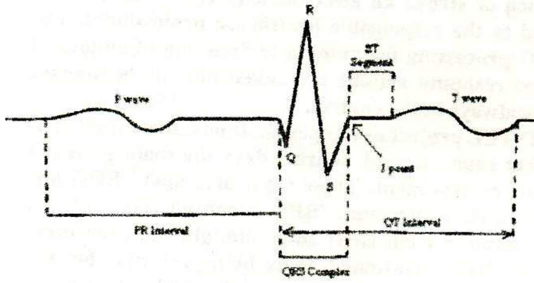

Figure 1. Typical ECG wave with main sections identified

ECG monitoring enables complex diagnosis of arrhythmias, myocardial ischemia and QT interval prolongation. SCD is in most cases related with disturbances in one or more of these parameters.

III. Architectures

HEARTRONIC:

The Heartronic project is a cooperative project involving industry and research, technological and medical partners from several European countries. The objectives of this project are not to redesign cardiology but rather to analyze medical and patients needs, to exploit existing and emergent technologies, and develop non-invasive and reliable systems and safety tools that respond to doctors and patients requirements. These tools should help improving quality of life and increase life expectation in patients from groups with high risk of SCD.

The goal of Heartronic project is to develop a system that can detect, record, and analyze any heart anomaly in real time. Automatic ECG monitoring and analysis is an important part of system however, a mixed initiative approach is used to avoid over-treatment (i.e. the healthcare professional is in the control loop evaluating and validating the results of the automatic analysis).

Twenty five medical conditions, not all directly related to heart diseases, have already been identified as being suitable for application of the Heartronic system. These include, for example, SCD, CAD, diabetes, hypertension, athletic heart syndrome, chronic heart failure, etc. The groups that can potentially benefit from the use of the system include (but are not limited to):

--Convalescing patients from myocardial infarction (especially in the following 6 months).

--Patients awaiting Coronary Artery Bypass Grafting and after the procedure.

--Asymptomatic patients with or without ventricular tachyarrhythmias, who have impaired left ventricular systolic function.

--Patients with known CAD or after Myocardial Infarction with syncope of unknown origin.

--Patients awaiting ICD therapy.

A. Concepts of Operation of the HEARTRONIC System

The HEARTRONIC project aims to develop an innovative system for prevention and early warning of cardiovascular events, at least 2-3 hours advance, by continuous monitoring the heart conditions.

The system will be able to detect any heart anomaly in real time, warn the responsible doctor and send all relevant data to his or hers PC, PDA or smart phone. The doctor will be able to carry out a timely diagnosis, deciding as well the most appropriate intervention to the patient.

This system must be integrated in a wearable and light support like a shirt or an elastic bandage, capable to recognize cardiovascular anomalies and alert doctors and Hospitals in real time.

B. Architecture and Systems Components of HEARTRONIC

The system architecture follows a three-tier based architecture: Client, Application and Data. Figure 2. is a schematic description of the overall architecture.

The client tier contains components such as the Heartronic t-shirt (ECG Sensor array), the Remote Unit (RU), acting as gateway, the Mobile Unit (MU), and a Personal Computer (PC). MU and PCs provide the user interface to the Heartronic application server through wireless connection. An example of a terminal is a PDA. RUs are gateways between the Heartronic wearable processing unit (WPU) and the application tier and are responsible for integrating devices into the platform. These RUs are part of the patient equipment and they are either a PDA (or Smart Phone) with a CF card or an integrated/embedded modem for wireless connectivity.

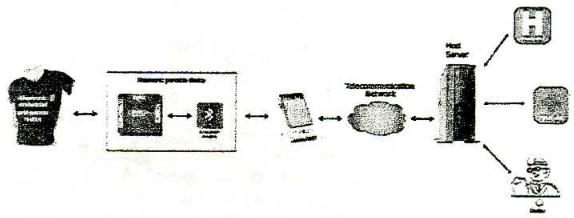

Figure 2. General system architecture

The application (or server) tier contains the Application Server which, by handling data transfer from the client tier to the storage level, makes data access transparent to the client tier.

Finally, the application server is directly connected to a database (DB) server which stores ECG patterns and additional data useful for screening, analysis and diagnosis.

WPU transmits data to the RU using Bluetooth connection while the RU is able to connect to the application server using a GPRS/GSM or UMTS (if available) connection. Both RU (Client tier-Patient) and MU (Client tier-Doctor) are connected to the application server but, in particular circumstances or emergencies, the RU might be able to talk directly to MU in order to send alerts to the doctor using SMS, MMS, or triggering an emergency phone call.

Furthermore, using the PC or MU, the doctor is able to view information on the patient available on the application server, in order to provide remote (mobile) diagnosis and consultation.

1) Heartronic t-Shirt

The Heartronic t-shirt, the ECG sensor array, is a wearable, light and comfortable device for ECG acquisition. There are several alternative methods and technologies for performing an ECG [4],[5]. In order to select the method used for the Heartronic t-shirt, several prototypes were built and several problems were addressed. One of these problems is the placement of the sensors. The placement of the sensors on the body has extreme importance: they have to be placed in order to better estimate Cardiac vector and better attenuate the muscular noise interference. There are some techniques for measuring Cardiac vector components [6], [7].

These problems can be partially resolved using a method of measurement created by Frank, and called Vectorcardiography [8]. Figure 3. shows the electrodes position following Frank's Leads technique. This was the technique selected for the Heartronic t-shirt, not only because from the theoretic point of view it supplies a better approximation of the heart cardiac vector, but also because from the practical standpoint it is less sensible to the electrodes position. Besides, the sensors are easily to place over a t-shirt, for example using a rubber strap (contrary to the classic 12-Lead ECG which is difficult to attach to a single strap).

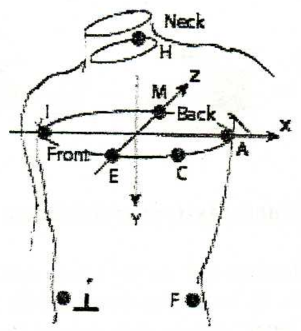

Figure 3. Orthogonal Frank's leads – X, Y, Z (8 sensors)

A drawback is that usually a physician is not interested to have an estimation of the cardiac vector, but they are interested to observe directly the ECG diagrams because they supply all the information needed (patient heart state). However, the three measured differential signals using Frank's Leads provide the projections of the heart carrier on the sagittal, frontal and transverse plane [8]: using Dower matrix [9] these signals provide 12 tracks diagrams (12-Lead ECG). The WPU includes a DSP, so to do such mathematical transformation is not a problem. However the problem could reside in the error associated to this transformation. The DSP processor is also responsible of the first patient diagnosis using algorithms to classify ECG abnormalities (see section IV).

After selecting the technique that will be used for ECG the next step is to guarantee that a good signal is captured, thus limiting noise amplitude. One big problem in common portable electrocardiograph is noise due to motion artifact. Two sources can generate motion artifact: the electrode metal-to-solution interface and fluctuations in skin potential due to skin stretch. The first source of artifact has been significantly reduced with modern Ag-AgCl recessed electrodes, but skin stretch remains a serious problem. Standard methods for reducing motion artifact due to skin stretch require skin abrasion, but this method has significant drawbacks: it causes patient discomfort, it results in more work for the ECG technician, and it can be ineffective for long term recordings.

The special electrode configuration suggested by Frank used for Heartronic t-shirt is less sensitive to motion artifacts and the rubber straps used to fasten the electrodes can help to prevent this kind of signal degradation. Moreover digital filters can perform another important step in this cleaning signal process: we are designing specific filters with infinite impulse response (IIR) and finite impulse response (FIR) directly embedded in the Digital Signal Processor (DSP) unit in order to eliminate this kind of artifacts, along with the noise associated with the power line capacitive effect, at the frequency of 50 Hz in Europe and 60 Hz in the USA.

To reduce ambient captured noise there are at least two possibilities: to screen the t-shirt using a network of electric wires covering the ECG signal wires: in this case the t-shirt could become heavier and less flexible, but the noise should be less critical; to use a network of shielded wires: in this case the t-shirt is more flexible but more sensible to noise so the filtering block should be more efficient than the first situation.

We are adopting this second choice, so the Heartronic t-shirt is composed by an elastic t-shirt with three rubber straps where are attached all Frank's Leads, like it is shown in Figure 4.

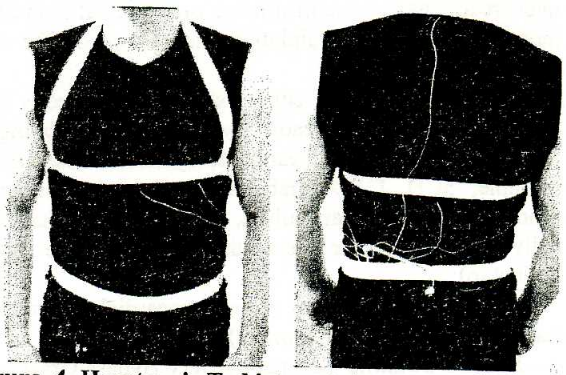

Figure 4. Heartronic T-shirt prototype

The advantages of Frank's Leads configuration are obvious:
--Adaptable to patient anatomy.
--Frank's axes are parallel to anatomy body axes.
--Simplicity of electrodes placement.
--Adaptable for Heartronic t-shirt.
--Small susceptibility to interference.
--Three dimensional ST monitoring (use of Vectorcardiography in ST analysis)

2) Wearable Processing Unit (WPU)

Typical ECG front-end processing algorithms consist of the following phases:

--Signal acquisition and filtering (first as analog filters and then as digital filter on the DSP).

--Initialization, determines initial signal and timing thresholds, positive and negative peak determination, automatic gain control, etc.

--QRS complex detection, the reliable detection of R-peak is crucial for morphological analysis.

--Baseline correction and first diagnosis, to compensate for low-frequency ECG baseline drift.

--ST segment processing, to detect changes in the ST segment.

In order to detect very weak electrical signals from the heart, the WPU must have very high input impedance. A differential mode of amplification is required if the ECG is to be isolated from the large amount of 50 Hz mains interference which is always present. So, as can be seen in Figure 5., the first stage is a differential amplifier, like instrumentation amplifier. The spreading electrical currents create different potentials at different points on the body, which can be sensed by electrodes on the skin surface using biological transducers made of metals and salts. This electrical potential is an alternate current (AC) signal with bandwidth of 0.05 Hz to 50 Hz, sometimes up to 100Hz. It is generally around 1-mV peak-to-peak in the presence of much larger external high frequency noise plus 50-/60-Hz interference normal-mode (mixed with the electrode signal) and common-mode voltages (common to all electrode signals). The right leg driver is necessary because it applies an inverted version of the common-mode interference to the subject's right leg, with the aim of cancelling the interference. Next to this first stage there is a sequence of analog filters, which clean the ECG signal removing noise.

The core of the WPU is a DSP that collects cleaned chest signals and acceleration data. The adaptive resistor network allows obtaining the Cardiac vector components XYZ from captured chest signals. Every component is cleaned by an analog filtering block and then is sampled by DSP ADC. The Bluetooth communication module is used by the DSP if the analyzes produces an alert.

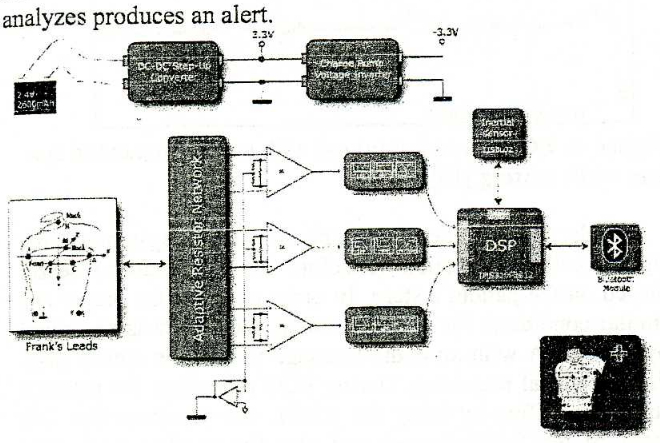

Figure 5. WPU detailed block diagram

3) Remote Unit (RU)

The Heartronic WPU must send patient data to the application server in order to alert medical services. This data is sent from the WPU to a mobile cellular phone, used only for this purpose, and the mobile phone will send the data to the central database.

Depending on the services offered by the telecommunications company, the patient information can be completed with geographic information (localization).

In case it is necessary to update some parameters on the Heartronic WPU, the central server will send the required information to the cellular phone that will deliver it to the Heartronic WPU via Bluetooth.

When some problem is detected in the ECG analysis, the information sent to the RU and from the RU to the application server is the FFT (Fast Fourier Transform) because it contains all needed information in less bytes. This is useful because enables the use of more powerful algorithms in the application Server to find out what problem the patient has and also derive the 12 ECG from the filtered signal.

Important information to be transmitted in case of a severe warning is the location of the patient, which can be derived from the phone. Presently, a rough localization through the number of the GSM or UMTS cell is available, yet very useful in case of emergency, but one should not forget that precise localization technologies are actively developed to be integrated into next generation portable phones, and will provide a very accurate localization.

4) Application Server

The data collected by the Heartronic t-shirt is analyzed by the WPU and, in case of alert the data will be sent to the RU, which will then send the information to the application server, by GPRS or 3G.

The Server will make an analysis of the case and decide to whom the alert should be sent. The addressed person will have to make a diagnosis with all the available information (ECG, patient history and suggestions) and decide on by an action to take, like false alarm, call the patient or send an ambulance to pick the patient. Figure 6. presents a detailed use case diagram of the application.

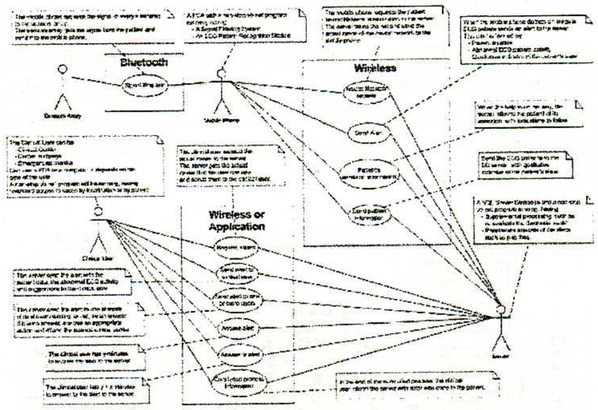

Figure 6. Use case diagram

5) Database

The information collected will be stored in a central database (MS SQL Server). This database will store:

--Patient medical record: personal data, habits, clinical history, devices in use.

--Persons that interact with the system.

--Alerts: actions to take and notifications.

--Parameters for the ECG algorithm: the read raw data (VCG), the obtained ECG data, transformation matrices, parameters for the algorithm and results of the algorithm application.

C. Architecture of BIOMEDTEL system

The architectural platform proposed by BIOMED TEL project corresponds to the requirements of the application in terms of variety and adequacy of sensors, power computing, low power consumption and low price. Based on intelligent interfaces, the system automatically integrates the sensors in „plug & play" mode and also adapts its communication strategy with the hub/dispatcher for cost minimization and for ensuring the reliability and availability of the data link. The architecture of the whole system is organized on four layers and is illustrated in Figure 7.

The *first layer* includes the smart sensors: (i) ECG leads with corresponding pre-amplifier, analog to digital converter and microcontroller, (ii) SpO_2 sensor with its corresponding preprocessing system, based on a microcontroller, (iii) blood pressure monitor with its wireless communication interface, (iv) vibration sensor controlled by ATtiny26 with a programmable filter, (v) the temperature sensor and (vi) glucose sensor.

The *second layer* includes a data concentrator system developed using AVR32UC3 microcontroller that allows a strong power management for all internal drivers and plays several roles, such as: manages the communication channels between itself and the sensors, assures the filtering of the ECG signal, correlates the SpO_2 signal with ECG and vibration signal in order to avoid the artifacts and prepares the telegram that will be transmitted to PDHA, respectively to HS.

The *third layer* includes the PDHA (HTC Hero PDA) that assures the multi-modal interface between the patient and the remote monitoring system.

The *fourth layer* includes a PC as hospital server (HS) connected to the Internet. This server offers an interface to the health care professional that surveys the patients. Into the patients' data base implemented on the HS all the patient's vital signs are stored once per day in normal regime and continously in case of alarm or emergency.

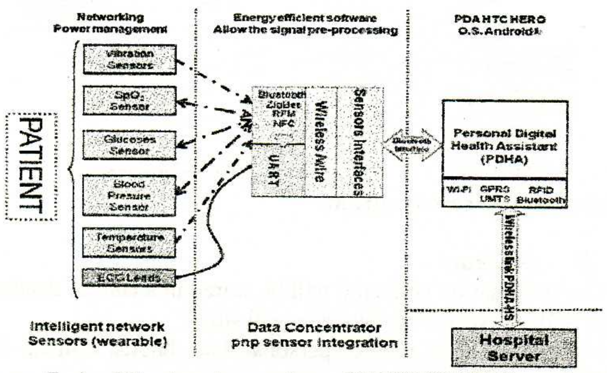

Figure 7. Architectural overview of BIOMEDTEL patient remote monitor

The hardware implementation illustrated in Figure 8. corresponds to the first layer of the above described system. This layer includes all the sensors placed on the patient: wearable ECG Ag/AgCl or stainless steel electrodes, accelerometer sensor, blood pressure monitor and SpO_2 sensor.

The wearable ECG system was designed in compliance with the BS EN 60601/2/25/1995 medical standard for the protection of the patient and was implemented to acquire the biopotential from one bipolar D1 derivation.

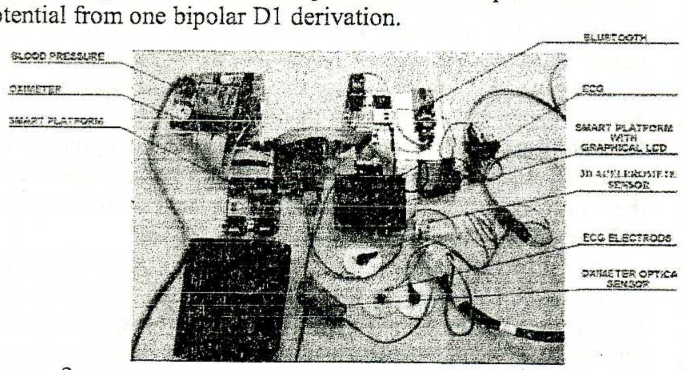

Figure 8. **Prototype of the first layer of BIOMEDTEL project**

The experimental results related to ECG acquisition are illustrated in Figure 9.

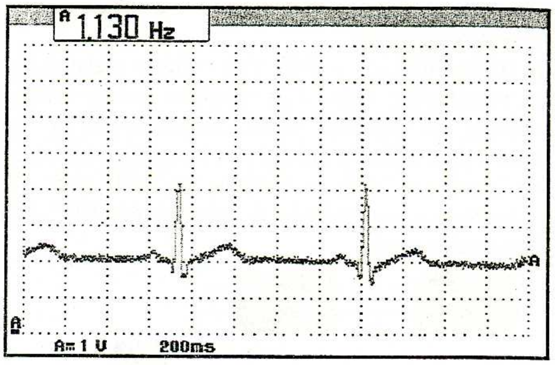

Figure 9. ECG record obtained with our implemented system while resting [19]

In order to avoid the movement artifacts, the system was designed with a vibration (absolute 3D acceleration) sensor placed on the patient's stern. In order to create the proper and similar conditions for ECG recording, the patient is advertised by his PDHA with an audio message to take the correct position for signal acquiring. During ECG recording, the patient's status is verified by using the ADXL 330 accelerometer. The leads of the ECG channel and also the accelerometer were placed onto the same wearable support. Another major aspect is related to the accelerometer sensor which can provide information about pulmonary and cardiac activities such as respiratory rhythm and cardiac rate [14].

The cardiac activity of a resting patient is illustrated in Figure 10.

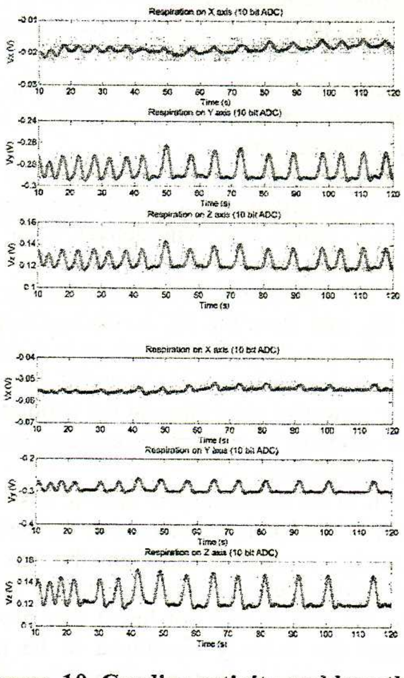

Figure 10. Cardiac activity and breath respiration

The illustrated grey signal represents a not filtered signal and the magenta one represents the corresponding filtered one. From the amplitude of the signals it can be seen that the X axis is not so sensitive at the cardiac activity, the Y axis correctly follows the cardiac activity, the peak to peak amplitude being 30 mV and the Z axis is the most sensitive. In clinostats position of patient Z axis will give information about the local gravitational acceleration. This signal could be used as auto calibration signal for all the axis of the acceleration sensor. These signals are crucial because they can make easier and accurate the detection and classification of the signal records and can improve the process of status detection of the patient.

Also, an important bio-physical parameter is the cardiac rhythm information provided by the blood pressure. To acquire the cardiac rhythm it was used an existing Blood pressure device (VISOMAT400 endowed with an OMRON chipset) that was adapted thus to be able to communicate with a Bluetooth transceiver (LMX9838) which transmits the acquired data to the concentrator able to collect and to interpret them.

For monitoring SpO_2 it was used the classical method developed by Beer-Lambert to analyze the signals acquired by a dedicated sensor with a dual LED (IR and Red) and phototransistor (SF-1011N-Nellcor) placed onto the finger of the patient or at the ear level. This signal is continuously monitored and represents the leading signal necessary to control the regimes of the whole remote patient monitor. In order to offer a high confidence and reliability of the recorded data, this signal was used as reference [15].

For monitoring the glucose level from the blood it was used the DEXCOM Seven instrument, which uses a nano-tube carbon sensor implanted in the belly of the patient. The communication with data concentrator is wireless RFM.

Our set of smart sensors used by the remote patient monitor could be used with high efficiency and accuracy by patients having cardiac, neuronal or metabolic diseases.

IV. ALGORITHMS

HEARTRONIC: ALGORITHM FOR CLASSIFYING ECG ABNOMALITIES

An ECG represents the electrical voltage in the heart during a contraction. Many waves, segments and intervals can be found in the ECG graphic [7]. To find irregular beats, these components have to be searched with signal analysis methods. The ECG front-end processing algorithms encompass 5 phases that were already listed in section 3.B.1 when the WPU was described.

Figure 11. shows an example of an ECG lead I, with the marks of the ECG's components.

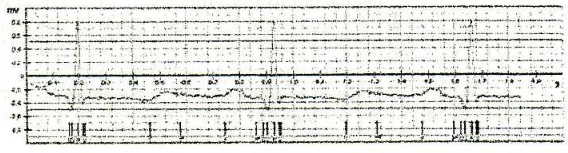

Figure 11. Visualization of an ECG's Lead I example, with components marks

As previously noted, the most commonly used clinical lead configuration is the 12-lead ECG system, which provides twelve waveforms, called leads. To provide such a 12-lead ECG, ten electrodes are placed on the patient's body and the signals from these electrodes are processed to provide the twelve leads.

The Heartronic algorithms do not use 12-lead ECG. Only the Orthogonal Frank's leads - X, Y, Z (8 sensors) are needed [8]. The 12 ECG traces can be obtained by the Frank's Leads Vectorcardiography [9]. The 12 ECG traces can be obtained by the Frank's Leads using Vectorcardiography. Effective filtering algorithms were developed to eliminate harmful baseline fluctuation and possible motion artifacts of the sensors used.

It was assumed that sampling rate is 512 Hz, which is a suitable choice considering that all the information of the ECG signal is contained in the range of frequencies below 100 Hz. The algorithm is composed by several blocks:

--Orthogonalisation - reduces the dimension of the signals processed in latter stages.

--Pre-processing - reduces the baseline wander, power line interference and electromyographic noise.

--Segmentation - finds the individual beats by finding the onset of P wave, the R-peak and the offset of T wave;

--Alignment - reduces changes due to respiration and body position changes.

--Matching - accounts for the remaining variation.

--Decision - takes action if the vectorcardiogram (VCG) loops and there are other anomalies.

Most of the literature concentrates on immobile patient measurements, which is a considerably easier task than the one, where the patient is moving around during measurement. For example, plain heart rate measurement is much less demanding than full ECG analysis. Body position changes, respiration and movement cause physical movement of the heart, which in turn is shown as changes in the measured ECG. What is more, these motion artifacts can be quite severe and may easily cause false alarm. Hence, many change detection methods are very vulnerable to these effects. Consequently, the aim of the first set of algorithms is to be insensitive to this kind of normal variation but sensitive to any abnormal changes.

The sensitivity at which the arrhythmia recognition algorithms should be set is a problem. High sensitivity of the system will be connected with numerous false positive alarms (because of false ST monitoring alarms and muscle artifact simulating ventricular tachycardia). Low sensitivity may result in misdiagnosis of the potentially life threatening conditions.

Furthermore ECG monitoring does not supply sufficient information necessary to evaluate the cardiac function as a pump. It might limit preventive and diagnostic use of Heartronic especially in patients with heart failure.

There are almost no published trials [10] concerning cardiac remote monitoring so it is difficult to develop an algorithm supported by published research.

BIOMED TEL:

The algorithm developed on the data concentrator (second layer) detects the cardiac rhythm by detecting the R wave and after that the R-R intervals from ECG signal. A similar operation is realized for SpO2 signal and the result obtained is compared with the first one. This represents a first verification of the accuracy of the acquired data. A second verification consists in analysis of the signal provided by the vibration sensor. The validation is based on the initial calibration values for the Z axis of the sensor used to detect the orthostatic position of the patient during the ECG signal acquisition. On the third layer of the system the trend of the main parameters (SpO_2 values, cardiac rate, blood pressure and glucoses concentration) is determined. The parameters are correlated using a decision table based on a fuzzy set with above mentioned data. Before home usage of the remote patient monitor, the patient's specific thresholds are settled on PDHA by the physician in hospital. As result of signal analysis the patient monitor will change automatically his functioning regime from normal mode, to alarm respectively to emergency mode. In the first case, the data acquired will be only once per day uploaded to the hospital server, and in case of an alarm occurs, the significant signal will be continuously transmitted to HS. In emergency situation case when more than two threshold values are overpasses, all the signals acquired from the patient will be transmitted in real time to HS. In this case the HS is able to transmit in "real-time" advises of the physician to the patient in order to prevent the possible dangerous situations.

V. Conclusions and Future Work

The development of a wearable system capable of continuously monitoring and analyzing the heart condition of patients with known risk cardiovascular diseases should allow patients to go on with a normal life, while improving its quality and increasing its expectation.

The goal of this collaboration is to improve the results of both projects by means of comparing methods and coming up with better solutions for the technologic challenges.

Heartronic project is more focused on ECG signal processing, using with a large leads number (12) and strong detection of arrhythmic symptoms by intelligent algorithms, comparing with BiomedTel project that is more oriented to analysis of SpO2 signal continuously monitored, and that uses only one derivation for ECG signal. As result of sensor configuration Heartronic project was oriented more to the detailed analysis of acquired ECG signal. In case of BiomedTel the focus is oriented to the correlation between a set of signals acquired from patient and the local signal processing is more simplified.

The interface between the remote unit and hospital server is almost similar for both projects and present also a similar functionality. A special remark could be done related the communication strategy adopted by BiomedTel project, where the PDHA uses a dynamic allocation of the communication channel. In this sense an energy efficient algorithm that scans and chooses the most reliable and efficient communication channel was implemented.

Currently the architectures of both projects presented in this paper are being compared for effectiveness and accuracy and the collaboration is expected to provide new methods to solve technical issues that for the challenges posed.

It is obvious that including new signals to be monitored and also improving the inter correlation between signals acquired in parallel with the development of a strong energy management strategy for all system components will make possible to assure a more safe, available and precise instrumentation that could aid the patients in the future.

Future developments include implementation of such methods on both systems and field tests to assess the improvements.

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