LiveVitals - a low power approach to remote elder monitoring

Dumitru Cristian TRANCĂ, Daniel ROSNER, Răzvan TĂTĂROIU, Dan IORGA
Computer Science and Engineering Department
University POLITEHNICA of Bucharest
e-mail: {cristian.tranca, daniel.rosner, razvan.tataroiu}@cs.pub.ro, dan.iorga@acs.pub.ro

***Abstract* - The current demographic evolution of the world population, especially in developed countries, is constantly exerting an ever growing pressure on the medical system. As the average life expectancy in developed countries is on the rise, and medical breakthroughs in treating severe conditions increase the life expectancy of elder patients, the need for automatic monitoring systems for elder patients is higher the even before – driven by the pressure to monitor a larger number of patients with a relative low number of qualified personnel available.**

The current proposed solutions aims to offer a balance between relevance of measured parameters, correlation of vital signs, autonomy, portability, ease of use and final market price.

Keywords— ***ECG, remote patient monitoring, vital signals, elder monitoring, ECG processing***

I. INTRODUCTION

Given the fact that the elderly population is constantly rising, permanent monitoring becomes a necessity in order to improve life quality and life expectancy for elderly patients that are suffering from illnesses that require permanent monitoring and accommodation of the treatment according to the symptomatic evolution.

The 2012 Ageing Report [1] that was derived from data on demographic evolution inside the EU shows a constant rise of the average life expectancy at birth – by almost 11 years in the 1960 to 2009 time span. For 2008 to 2060, another 6 to 8 years increase in the average life expectancy at birth is predicted. Other reports [2] confirm this data as they show the same steady increase in life expectancy at birth, as well as a steady increase in life expectancy at age 60 (due to improvements in life quality, in medical system and to breakthroughs in medical treatment for various illnesses associated with elder patients).

The present situation is worsened by the fact that in all of Europe the current availability of semi- or fully-qualified personnel for long term supervision and treatment is scarce, and the current population aging situation does little to alleviate this. On the contrary, fewer personnel as well as fewer younger relatives will be available to tend for the elder. Moreover, financial resources for the medical system can also be expected to decline, as a fewer active people will contribute to a medical system that will need to oversee a growing number of patients.

The objective of the current project is to provide a solution for the permanent tele-monitoring of patients that require long term monitoring of the evolution of the vital parameters.

Compared to the existing solutions, this project provides the user with an optimal combination of autonomy, portability and interoperability, at an affordable cost. The proposed system is also focused only on those medical parameters that are relevant for a long-time monitoring process used for tracking the symptomatic evolution present in the most common illnesses associated with elder patients.

II. CURRENT SOLUTIONS

At present there are a series of devices that offer a practical solution for the permanent monitoring of the patients.

One of them is **HRS-I (Human Recording System),** a system made by WIN (Wearable Information Networks) Human Recorder Co Ltd. The device can measure vital parameters such as temperature, movement and ECG signals. HRS-I is a small-sized system that is able to transfer wireless the data from the sensors; the transmission is done in real-time, through a 2.4 GHz module. The data derived from 25 hours recordings can also be saved in the internal memory storage device. The device has the possibility of connecting sensors for EEG, respiration and other parameters that are needed [3]. The system architecture is represented below.

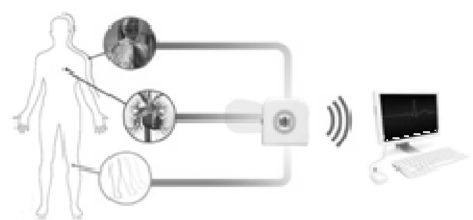

Figure 1: HRS-I [img1]

Another example is the V-Patch Medical System, a small-size, water-resistant device, that has autonomy up to a period of 7 days and can measure ECG parameters by using only one sensor. The data is collected from the sensors and sent to the V-Pod, an embedded-system that contains a micro-processor and memory, stores and analyzes the data. The system can store up to 8 events and can detect the most dangerous 10 types of arrhythmia.

The data is sent from the V-Pod to the V-Cell, which is the portable device that sends the data online. The communication is done in the 2.4GHz band, and the data service provider for Europe is Vodafone [4].

Figure 2: V-Patch system [img2]

Systems like [5], [6] do provide a large number of sensors that cover multiple parameters, but present a rather large physical system, that reduces its long-term usage possibilities, as such systems are difficult for elder patients to carry permanently. On the other hand, systems like [7] offer good ECG measurements with reported good levels of autonomy, but do not offer a wider range of vital signal measurements needed by the medical staff in order to have a clear image of the patient's medical condition.

The systems that are available at the moment are either ultra-portable with a high autonomy, but measure data from a small number of sensors (one or two), or they can measure, store and analyze data from multiple sensors but have reduced autonomy and are larger in size.

III. Suggested Solution – Medical Characteristics

The electrical characteristics of the heart muscle are measured by using electrodes placed on the human body. The electrical potentials from the electrodes in electrocardiography are named leads. The voltage is measured between two electrodes in bipolar lead measurements. There are three bipolar reading measurements: Lead 1 (LA - RA)– negative pole on the right arm (RA) and positive pole on the left arm (LA), Lead II (LL-RA) – negative pole on the right arm (RA) and positive pole on the left leg (LL) and Lead III (LL-LA) – negative pole on the left arm (LA) and positive pole on the left leg (LL).

Considering the voltage droppings between LA, RA and LL , we can conclude that Lead II = Lead I + Lead III.

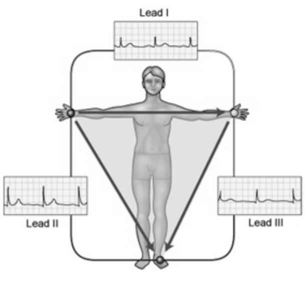

Figure 3: Measuring EKG for unipolar and bipolar leads [img3]

In the unipolar lead measurements, the negative pole is called Wilson terminal or Wilson Pole, and the positive pole is the electrode itself. The Wilson pole is a zero-potential terminal and approximates the average potential in the human body (LA+LL+RA)/3. The Wilson pole is produced by connecting RA, LL, and LA through a resistor network.

There are two kind of unipolar leads: limb leads and precordial leads. The unipolar leads of the limbs are called LA (Left Arm), LL (Left Leg), RA (Right Arm). Because of their low voltages, a high amplification is needed. The amplified or augmented leads are called aLL, aLA, aRA . Precordial leads do not need amplification because they are very close to the electricity source, which is the cardiac muscle. By measuring all of the electrodes and all of the leads, the whole electrical activity of the cardiac muscle can be measured and monitored.

An ECG contains three elements: waves, segments and intervals. A wave can be positive or negative, sharper or softer and the duration of the wave is measured in seconds or milliseconds. When analyzing and ECG, the following have to be measured: the heart rate and heart rhythm, the electrical position of the heart and the form of the P wave, QRS complex and T wave.

The P-wave is characterized by a normally rounded form, or a dysphasic, less sharp one, while the direction is determined by the location of the stimulus and therefore the genesis of the direction of propagation of the wave of depolarization. The PQ segment indicates the delay that is suffered by the electrical stimulus during its propagation at the level of the atrio-ventricular junction. The PQ interval represents the duration of the atrial and atrio-ventricular electrical activity. The Tp wave (Ta) is the result of the atrial repolarization, its vector having an opposite direction with the P wave. The QRS complex has a pointed tips form, its value being given by the algebraic sum of the positive and negative vectors. The QRS complex is also variable and depends on the lead and the electrical position of the heart. The ST segment represents the electrical behavior of the heart at the time when the slow ventricular repolarization occurs. The T wave is the electrical representation of rapid termination of ventricular repolarization, has a rounded shape, asymmetric upward slope is less steep as the path. Its length has a little practical importance; it is usually not measured within routine ECG and has a normal value between 0.13-0.3 seconds. The T-wave amplitude is about 1/3 of the amplitude of the QRS complex and in normal cases does not exceed 0.5mV, exceeding the limits is considered pathological [8].

Pulse-oximetry is an easy to use method for continuously monitoring a patient's blood oxygenation ratio. In medicine this is a very important measurement which is in a close relation to heart disease, and respiration problems.

A pulse-oximeter determines the oxygenation ratio of the blood by comparing the rate of absorption of two light beams of different wavelength (red and infrared), that are absorbed by blood at different ratios, in different quantities, dependant on the oxygen saturation ratio. [4] In patients with COPD and in patients with worsening symptoms or with severe disease, pulse-oximetry measurement is useful for monitoring their health. Also in patients with asthma pulse-oximetry complements peak-flow measurements in evaluation of response to treatment. In acute respiratory infection the measurement of the blood saturation in oxygen is mandatory to detect the severity of the illness and whether patients respond or what is their response in certain treatment [9].

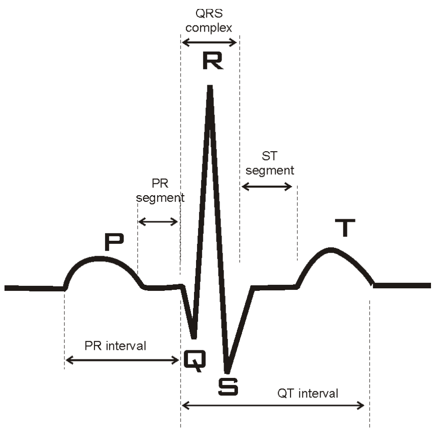

Figure 4: Normal ECG shape

For elder patient monitoring, movement data based on a 3 axes accelerometer can also be of significant medical value. A study made in [10] emphases the need for motion monitoring in elder patient long term monitoring scenarios. In [11] the authors propose an algorithm for deducing the type of activity a monitored patient is involved in based on accelerometer data. This paper also emphases the need for motion monitoring in remote monitoring systems, as this can shade light into the type of activities a person is involved. There are also many scenarios when correlating multiple medical data can lead to better diagnostics. For example, the Cheyne-Stokes respiration is most likely to be detected when the patient is relaxing or sleeping. Thus, a permanent monitoring system that can tell that the ECG is measured at a time of relaxation / sleep is a superior approach in detecting this condition.

Moreover, when dealing with elder patients with cognitive impediments, data about their daily activities is vital in monitoring and assessing their evolution [12].

Body temperature is another important parameter to be constantly monitored. There are series of pathologies that are linked with different fever patterns that can be analyzed using a permanent monitoring system. Given the high number of measurements that can be recorded with a permanent monitoring system, over prolonged periods of time, this approach is far superior to the classic system of a nurse measuring the patients temperature on a hourly bases, and can give a doctor a batter incentive on the patients evolution, especially as the doctor can see the patient's body temperature evolution in correlation with his activities and other clinical parameters.

IV Proposed solution – technical implementation

One of the challenges encountered during the development of the system was to capture, amplify and filter the ECG signal without altering its characteristics, which are essential in the process of diagnosis and monitoring. The main challenge is obtaining a clean ECG signal without a large or energy-hungry system.

The inputs are passed through a first order passive low-pass RC filter that is used for radio-frequency filtering.

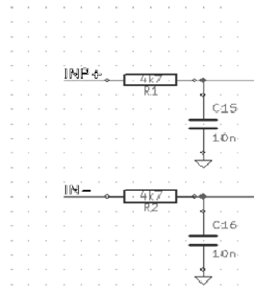

Figure 5: Low Pass RF Filter [6]

$$Gain(j\omega) = |H(j\omega)| = \frac{1}{\sqrt{1+(\omega RC)^2}} \quad (1)$$

The characteristic for the first order filter is

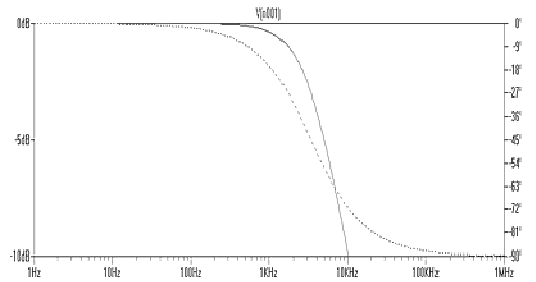

Figure 6: Low Pass filter characteristics

The signal is then passed into the inputs of a high-gain differential amplifier; the two resistors connected in series between terminals 1 and 8 set the gain for the amplifier.

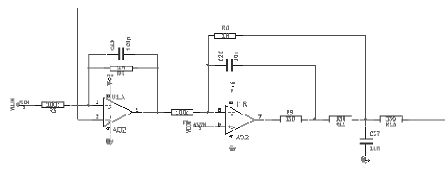

Figure 7: Right Leg Drive Generator

Two-electrode ECG systems typically use a third active electrode, called Right-Leg Drive (RLD), acting as a reference potential for the two measuring electrodes. The RLD uses negative common-mode feedback that tends to bring the input signals near an internal reference voltage. This ensures that the inputs are kept within the common-mode input range of the first amplifier and also provides additional noise rejection.

The amplified signal, now single-ended, is further processed by several stages. The first stage consists of a second-order low-pass active filter using an MCP602 operational amplifier.

An active filter is the only practical solution for the low frequencies that appear in the system presented. Passive filters would require large inductance values that would involve unacceptable dimensions of the components in a practical realization [13].

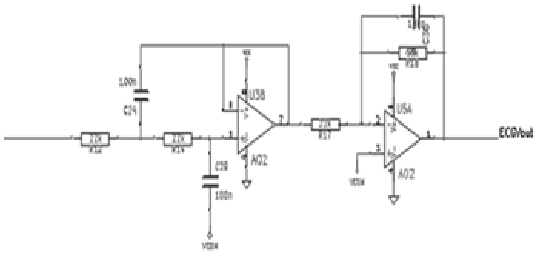

Figure 8: 3rd order Low-pass filter

The Sallen-Key second order active filter has the following topology

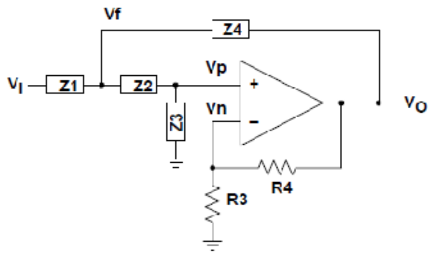

Figure 9: Sallen-Key 2nd order active filter topology [img4]

The transfer function is (2).

$$H(s) = \frac{V_O(s)}{V_i(s)} = \frac{K}{1+\frac{Z_1}{Z_4}+\frac{Z_2}{Z_3}+\frac{Z_1}{Z_3}-\frac{KZ_1}{Z_4}+\frac{Z_1Z_2}{Z_3Z_4}} \quad (2)$$

Where K is the Gain $K = (1 + \frac{R4}{R3})$ (3)

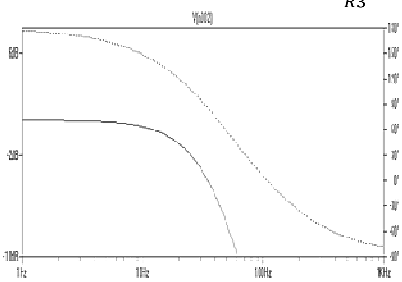

Figure 10: Characteristic of Sallen-Key low-pass filter

A second stage provides amplification as well as additional filtering and drives the ADC input. The whole signal processing block therefore acts as a third-order filter (Figure 8).

The physical circuit is built on a double-sided printed circuit board with one side mainly dedicated to a ground plane. This ground plane assures that every device on the PCB will see the same potential for the ground. The ground plane also ensures good screening from interfering electro-magnetic waves. For maximum efficiency, the cuts in the ground plane due to traces on the back side are kept to a minimum [14].

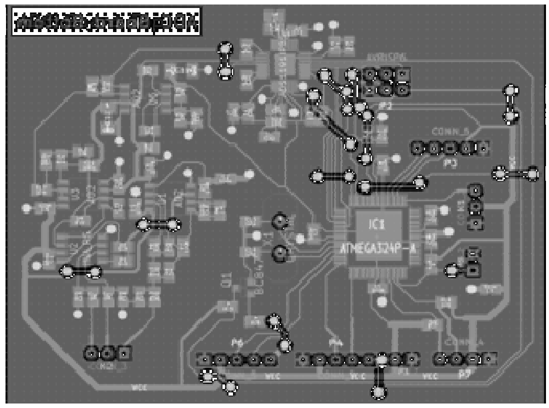

Figure 11: System Printed Circuit Board

The temperature is measured from a TMP 102 sensor, which communicates with the main controller through an I2C interface. The temperature sensor has a resolution of 0.05 degrees Celsius. The acceleration is measured with an analog accelerometer, which provides three voltages (one for each axis) that are read by the main controller via an integrated ADC peripheral.

The system also provides a panic button, that the user can press if they think they are in danger or in need of assistance.

The blood oxygen saturation and the pulse are read separately, from an additional device positioned on the finger of the patient. The data is sent from this device to the MCU that reads it in parallel mode, multiplexed in time. The data is read and sent via UART to the main controller. The main controller after receives aggregates all data and sends it via Bluetooth to the nearest receiver.

The device can be configured to either accept connections from a series of monitoring stations, or to automatically connect to one specific station if it is in the appropriate range. For security reasons, when a device has to pair with LiveVitals is has to have the PIN number of the LiveVitals Bluetooth module.

Considering that LiveVitals has to be a low-power, high autonomy portable device, it is equipped with a Class 2, 10 meter range Bluetooth adaptor. It has an output power of maximum 2.5mW and is used in other similar medical applications. The Bluetooth device does not interfere with other medical equipment that might be used along LiveVitals. [15]

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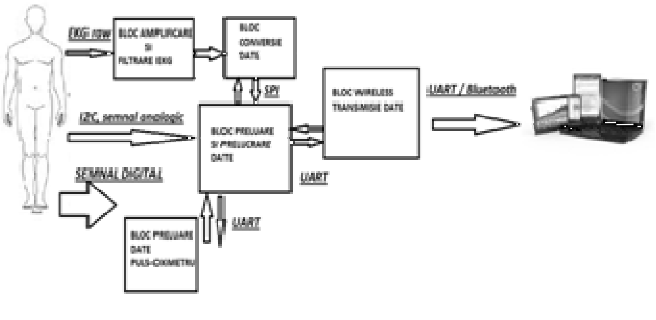

Figure 12: System Architecture

The system achieves low latency in acquiring, transmitting and processing data. A sustained sample rate of 500 sps was demonstrated. As discussed in [15], Bluetooth communication delays are acceptable in medical applications such as LiveVitals.

On the other hand, the distance between the transmitter (LiveVitals) and receiver (smartphone, tablet, laptop, PC, etc) has to be taken in considerations. LiveVitals will transmit data to the nearest receive. In a normal room, the distance between the patient and a receiver will not exceed 5 meters; outdoors, the patient will have the receiver with them (e.g. a smartphone), so a low-power Bluetooth transmission is appropriate for this application. If stronger security is required, our system could also send data via a WSN network, with security strengthen by solutions as [16] or [17].

V. EXPERIMENTAL TESTING

The end result system weights approximately 200 grams and has an autonomy of 72 hours. The charging time is 4 to 5 hours.

The cost of the system for mass production is estimated to be below 100$. The average usable lifetime of the system is estimated at 4 years.

In order to test the systems, a two stage trial was used.

First, we enlisted the help of 12 volunteers, which agreed to use the monitoring system for 3 days. Out of this group, 10 ended up actually using the system continuously for 24 up to 72 hours. The feedback received from them was positive, as the level of discomfort introduced by the permanent wearing of the system was considered “acceptable” by 8 of them, and only the 2 that used the system for just 24 hours considered it too hard to use on a longer term.

Secondly, we used the aggregated data collected from the test subjects and confronted a panel of doctors, in order to assess the quality and relevance of the measured data. Feedback received from the doctors was positive, as they appreciated the aggregated data as being both of good quality (accurate measurements, especially for the ECG) and clinically relevant in terms of parameters measured, frequency and accuracy of measurements.

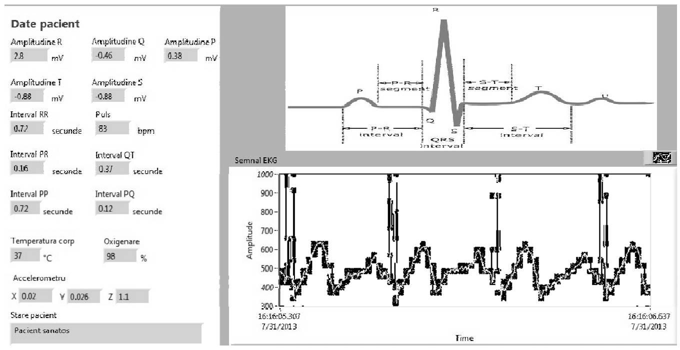

Figure 13: Measured parameters on a laptop interface

VI. CONCLUSIONS

The project represents the architecture of a system that combines tele-medicine with tele-monitoring and allows the permanent control of the essential vital parameters of the patient. The parameters that are monitored can be used to detect possible medical events that present a risk factor. In the case of patients that require constant treatment, adjusted to the symptomatic evolution, the system can provide important data on the patient’s clinical evolution to the physician.

The proposed solution proved to be a reliable approach in remote monitoring of elder patients, offering a superior level of mobility and autonomy while providing all the essential information needed by the medical staff.

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