Modern approach in multiple patients ECG monitoring

Valky Gabriel, Lehocki Fedor

Abstract—**This paper presents a complex system for monitoring of multiple patients at the same time by the means of acquiring the ECG waveforms from human heart. This system is composed of devices for acquisition of ECG waveforms utilizing Bluetooth technology for wireless data transfer, software applications for mobile devices with internet access, server application and client application employing innovative visualization techniques of gathered information optimized for tablet computers and application for management of patient's records. The novelty of our approach is using tablet computers as visualization device instead of professional equipment that integrates both the display and the low voltage amplifier circuits. For this purpose we utilize the HTML5 and WebSockets technology. Our aim is designing a low cost ECG monitoring system including both the hardware and software part.**

I. Introduction

Scope of this paper is oriented towards new technologies and ideas related to the heart activity monitoring and is addressing all the problems connected with designing and creating of cost effective ECG monitoring system. This includes server application, mobile phone applications, web management software, tablet applications and methods used for testing and simulating real patient's heart activity to speed up the development process.

With advances of wireless technology development tablet computers are becoming an integral part of our lives. Lowering the power consumption of communication devices (e.g. using Bluetooth Low Energy technology), it is possible to design new medical monitoring systems. Considering the computational power of modern mobile devices, it is possible to design powerful applications in form of web application instead of developing native applications, which is always a time consuming and expensive task.

For clarity of the paper in second section we shortly introduce the results of published work [1] related to HW for acquisition of ECG waveforms and then continue with description of new developments in our system for ECG recordings.

Manuscript received November 10, 2011. The authors would like to acknowledge the support for research under following projects: Measuring, Communication and Information Systems for Monitoring of Cardiovascular Risk in Hypertension Patients (APVV-0513-10); Analytics Services for SMARTer Healthcare (IBM SUR project); Research & Development Operational Programme for the project Support of Center of Excellence for Smart Technologies, Systems and Services I and II (ITMS 26240120005, ITMS 26240120029), Competence Centre of Intelligent Technologies for Electronisation and Informatisation of Systems and Services (ITMS 26240220072) co-funded by the ERDF.

G. Valky, Slovak University of Technology in Bratislava, Faculty of Electrical Engineering and Information Technology, Ilkovicova 3, 812 19 Bratislava, Slovak Republic (e-mail: gabriel.valky@stuba.sk)

F. Lehocki, Slovak University of Technology in Bratislava, Faculty of Electrical Engineering and Information Technology, Ilkovicova 3, 812 19 Bratislava, Slovak Republic (e-mail:fedor.lehocki@stuba.sk)

II. Hardware for acquisition of ECG waveforms

The hardware part of this solution consists of the data acquisition module and the active electrodes. This module implements all necessary components for analog signal processing, analog to digital data conversion and a Bluetooth module (from ConnectBlue) used for wireless data transmission.

Data acquisition module (Fig.1) is composed of a set of operational amplifiers, which form an instrumentation amplifier. Differential voltage signal with adjusted amplitude is fed into analog to digital converter that is incorporated in the microcontroller. It interfaces the Bluetooth module with analog circuits. The Bluetooth technology was chosen in order to achieve wide range of compatibility with smart phones and low power consumption [2]. Active electrodes [3] used for connection to the patient's body are connected to this module via 6-pin mini-din connector. Electrode system consists of two active and one reference electrode.

The main board of data acquisition module is also double sided, where one side acts as the ground plane. Battery holder and power switch is located on another board that is removable from the main board. This device offers sampling frequency of 300 Hz with resolution of 12 bits. Every sample is transferred through wireless link as two bytes, while the remaining bits are used for synchronization and low speed streaming of device status message. The status message helps to identify the version of ECG module and also contains information about the battery charge level.

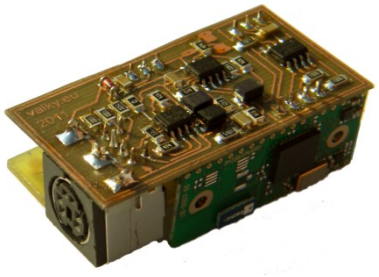

Fig. 1. ECG Acquisition module

III. Testing and synthesis of artificial ECG signal

For testing purposes and for development of complex systems that utilize real-time recorded ECG signal a device for artificial ECG signal synthesis was designed (Fig.2.).

This device is composed of signal generator and resistor divider that attenuates the generator's output into range of 0 - 4 mV. Full operation can be achieved by connecting the three crocodile clamps from this resistor divider to the active electrodes. .

The chosen signal generator is actually oscilloscope DS203 based on ARM Cortex M3 processor, which offers two analog inputs, two digital inputs and a single output. The main reason for choosing this oscilloscope is that it is battery operated and its hardware and software is open source. With this in mind a customized firmware was developed that offers wide range of configuration of the synthesized waveform.

As the basis for generation of synthesized signal the real ECG recorded waveforms were used. This were modified in MATLAB environment by the means of filtration, correction and resampling to the suitable number of samples. Afterwards the real signal was incorporated to the signal generator firmware.

Mentioned firmware allows the user to change the frequency (in Hz or BPM), amplitude, offset and modulation of the synthesized signal. When the frequency modulation is used with the internally stored signal as the modulation source the speed of synthesis is controlled by this signal which produces more natural-like signals. The access to the firmware source code offers the possibility to design new algorithms that imitate real diseases by fluently changing the shape of synthesized signal that would be hard to achieve by using commercially available signal generators.

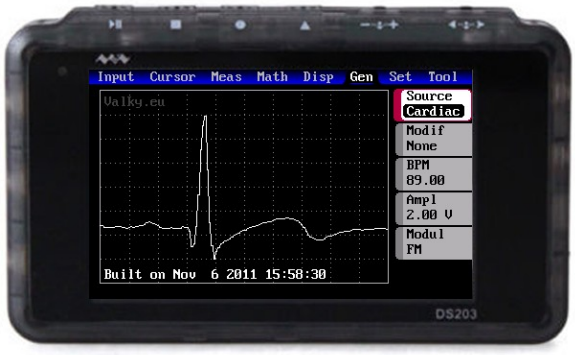

Fig. 2. DS203 with customized firmware

IV. Complex Solution

The purpose of the complex solution design (Fig.3.) is transfer of real time recorded ECG waveforms from multiple ECG devices to the server application. For this purpose applications for mobile phones with internet access and personal computers were designed. By utilizing Bluetooth technology a wide compatibility with smart devices and computers is achieved. These applications create a wireless link with the Bluetooth ECG device and also a wireless link to the dedicated server. All the information received from ECG module is transferred to the server. After processing (calculating the bpm value) and storing multiple streams of ECG data by the server, it makes the data available for further processing by other external applications (from other providers).

By now there are two applications that allow examining the stored ECG data. The first one shows multiple ECG waveforms in real time on one screen and is optimized to run on tablet devices. The second is used for managing the patient's information associated to the particular ECG device. This management application can be also used to examine all the recordings stored on server.

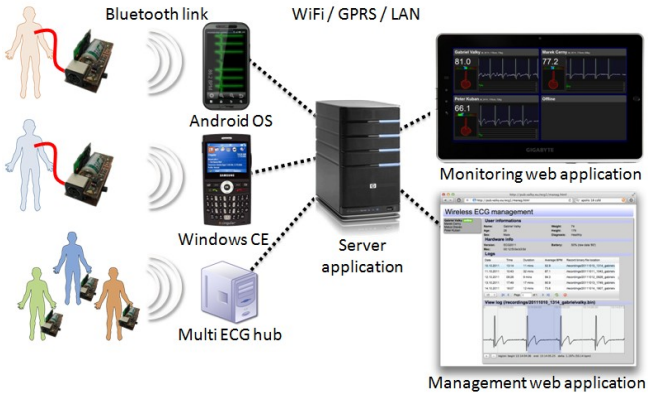

Fig. 3. Complex solution of ECG monitoring

V. Patient Unit Application

By choosing the Bluetooth technology a wide compatibility with mobile devices is achieved. Currently mobile devices with Android and WindowsCE / PocketPC operating systems are supported. Devices with operating system iOS (iPod, iPhone, iPad) require Apple Authentication Co-Processor to be present in the Bluetooth enabled device and are optionally compatible after replacing the Bluetooth communication module of the ECG acquisition module.

A native software application running on mobile device displays and analyses the ECG signal in real time. After setting up the IP address it automatically uploads the waveforms onto chosen server if the wireless internet connection is available. Useful extension might be offline monitoring of ECG and storing data on the mobile device. This may significantly reduce the power consumption of mobile device during related to real time monitoring and data transmission.

The signal analysis employs statistic algorithms and signal transformation from time to frequency domain.

When the arrhythmia or other emergency situation during this analysis is detected, the phone starts a 20 second countdown with sound signalization. When this time interval passes a SMS message is sent to the dedicated recipients (medical personnel, relatives). In case that cause of

emergency was not properly evaluated, the patient has the option to cancel the operation within the 20 second interval by clicking or tapping predefined smart phone button.

VI. Multi user ECG monitoring

Multi user ECG monitoring is implemented as console-based application, which automatically searches for wireless ECG devices that are in range. When a new device is discovered a communication channel to this device is opened after a successful pairing process. This application also opens a new TCP IP socket connection to a dedicated server to which all the received data from ECG device is passed. On this server all the recordings as well as the database about patient's personal information are stored. Advantage of using personal computer as a host device for multi user wireless ECG monitoring is the possibility to connect multiple ECG devices to a single computer. For readability purposes our suggestion is to display not more than 6 ECGs on single screen. On the other hand, for a reliable Bluetooth connection, the patient should be in range of the computer's Bluetooth module. The number of maximum simultaneous connections depends on the device driver and used Bluetooth stack. WidComm Bluetooth stack offers 7 concurrent connections while one connection is reserved for scanning of new devices [4].

VII. Server application

Main task of the server application is collecting of measured waveforms from connected mobile devices or computers, which act as a relay point for transferring data from ECG devices to this server. Every one of these devices is identified by its MAC address, which is unique for every Bluetooth communication module. On this server a MySQL database of patients is maintained. For every patient, there is stored some personal information (name, age, weight…), associated MAC address and a list of stored waveforms. Every waveform points to a file in server's disk drive.

When a new TCP IP socket stream is opened a new file is created and a new record referring to this file is added to the database. Name of this file is composed from the date, time and name of the patient. Application starts to store all the received data in 64 kilobyte circular buffer in RAM. All the data is continuously stored in a 64 kilobyte sized blocks to the computer's disk drive. This approach was chosen to reduce the server's file system load and to provide few last seconds of recorded waveform data for client applications that display the ECG waveforms in real time directly from RAM without accessing the file system. After a socket connection has been lost, this file is closed. There may be many reasons for losing the connection e.g. the ECG device may be switched off, the battery may be low or the WiFi connection may be lost.

VIII. ECG monitoring application

This application was developed for medical personnel needs related to patient health status monitoring. It was implemented as a web application optimized for viewing on tablet devices. By using technologies such as HTML5 (Canvas element) and WebSocket [5] communication platform, it was possible to design an interactive application with advanced functions that is compatible with all the major tablet platforms. This application was optimized to run on iOS, Android, Linux and Windows platform. The main requirement for the target device is a web browser with support of HTML5 and WebSocket (e.g. Mozilla Firefox, Safari, Opera).

Application displays ECG signal from up to 6 sources in real time. When a new ECG device is connected to the server, this event is automatically recognized and patient information is downloaded to this client application and his heart activity being displayed without any user intervention.

Management of displaying of ECG data is covered in next section.

IX. Innovative visualization of ECG waveforms

Innovative methods of visualization (Fig. 4.) of ECG waveforms were employed in the tablet application. Besides the graph view of the waveform and numeric value indicating heart rate in beats per minute (bpm), this value and its variance are displayed in a form of bar-graph. This is a rectangular bar with linear gradient. Left side of this bar corresponds to the value of 50 bpm and the right side to the 110 bpm. For distinguishing a particular value is this bar divided into 6 differently colored intervals. For intervals that correspond to heart resting rate (60-90 bpm) a blue and green has been chosen and values outside this interval yellow and red color has been used. From the ECG waveform, last N beats are analyzed for calculating bpm values corresponding to the time intervals between them. The range between minimum and maximum of these values is highlighted on the bar graph. Wide highlighted area on the bar graph indicates high variance of the heart rate. On the top a series of small triangles are displayed. Every triangle position corresponds to a calculated bpm value. For easy determination of trend of the heart rate (whether it is increasing or decreasing), the triangles are displayed with different colors: white for the last calculated value (last interval between beats) fading to the dark gray for oldest value. Figure 5a shows heart rate with high variance and 5b relaxed state with low variance.

Another visualizing element is a polar graph of ECG wave (Figure 4, depicted in red color). Because the ECG signal can be considered as periodic signal, it is possible to isolate its single period and display it in polar coordinates. By this method all the ECG waves (P, Q, W, R, S, T) are shown on the same position (or at the same angle). Examining shape of this polygon and its changes can help the medical personnel to quickly identify potential problems. When a new beat is detected, last ECG period is displayed in polar coordinates partially transparent, this helps to compare the shape of ECG wave with the previous periods.

The last visualization element placed on bottom of the ECG waveform is a graph of bpm values that displays the heart rate during the last 30 minutes.

Fig. 4. Visualization of single ECG source

Fig. 5. Detail on bar graph

X. ECG Management Application

Patient's personal information, assigned ECG device and all the recordings can be accessed in a management web application (Fig. 6.). Most important element of this web application is a list of all recordings from a chosen patient. Every record is shown as single row in this list. This row contains information about date and time when a recording was started, record duration, average bpm and file path to the record binary file. Administrator can delete, examine or export any record. After selecting a record, this is automatically displayed on integrated waveform viewer allowing the examination of the waveform, zoom in or out, measurement of time intervals or amplitude and to display guidelines. This application was developed using HTML5 [6], JavaScript language and Ajax technology.

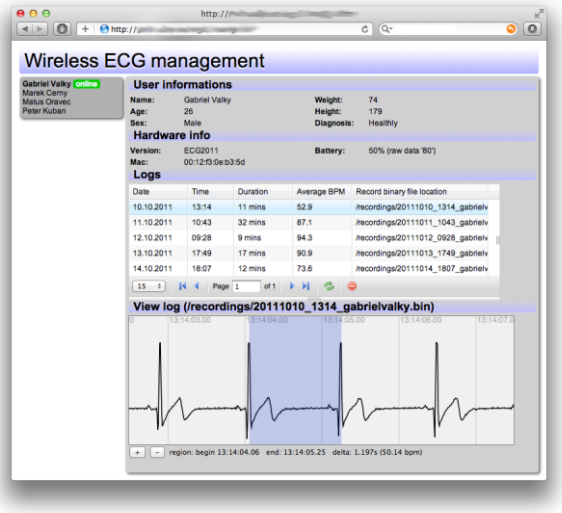

Fig. 6. Management web application

XI. Conclusion

Presented system is a preliminary solution for monitoring heart activity of multiple patients. Special visualization techniques (polar diagram and bar graph of ECG) were designed and tested for quick identification of hazardous changes in heart activity of examined patient.

Further activities include clinical testing of the both ECG module and related software applications in cooperation with National Institute of Cardiovascular Diseases (www.nusch.sk).

We have designed a low cost ECG acquisition module, which is composed out of few universal operational amplifiers, microcomputer and a Bluetooth module. For the visualization we decided to utilize the tablet computers that offer sufficient computational power to display the ECG signal in real time.

By designing both the hardware and software part of the presented system, it is possible to improve the communication protocol to our requirements what would not be possible with commercially available wireless ECG devices with closed or restricted communication protocol. The modular design of the acquisition module also allows us to swap the communication module easily with another to evaluate different options of wireless transfer of ECG waveforms.

This project also shows that complex medical system with waveform viewer can be implemented as web application without Java or ActiveX components using only HTML and JavaScript achieving compatibility with all major operating systems, thus creating a cost effective IT medical solution.

References

[1] G. Valky, F. Lehocki, M. Kovac, "Wireless System for Online Acquisition of ECG Waveforms from Human Heart," 2nd AMA-IEEE Medical Technology Conference, Boston 2011

[2] *Omre, A.H.: "Reducing Healthcare costs with wireless technology"*,Bus. Dev., Nordic Semicond. ASA, Oslo, Norway., 2009, ISBN 978-0-7695-3644-6

[3] *Metting Van Rijn et. al.:"Low-cost active electrode improves the resolution in biopotential recordings", Proceedings of the 18th IEEE EMBS, Amsterdam.,1996, pp. 101-102.*

[4] M. Aiello, R. de Jong, J. de Nes, "*Bluetooth Broadcasting: How far can we go? An experimental study.,"* in Int. Conference on Pervasive Computing and Applications (ICPCA'09) IEEE Computer., 2009.

[5] A. Wessels, M. Purvis, J. Jackson, "Remote Data Visualization through WebSockets," in Information Technology: New Generations (ITNG), 2011 Eighth International Conference on

[6] H. Wenling, H. Yuan, J. Wang, "The research and application of power system visualization based on HTML5," in Electric Utility Deregulation and Restructuring and Power Technologies (DRPT), 2011 4th International Conference on