# Modular development telemonitoring system

Jakub Parak, Jan Dvorak, Matous Pokorny and Jan Havlik

*Abstract*—**This paper presents a modular development telemonitoring system. The system consists of wireless communication and biosignal acquisition modules. These modules are connected to a control unit via an extension board. The control unit is based on STM32 EVO Primer development kit. An integrated accelerometer is used for monitoring of subject's activity. The system features a signal processing and heart rate frequency computing algorithm. A memory card is used for saving the heart rate frequency. A heart arrhythmia alarm and an activity monitor are implemented in the system as well. The system has a simple alarm and a signal visualization program for PC. The modular solution is suitable for other biosignals acquisition and for miscellaneous means of wireless data transfer. The system provides raw signal data for further signal processing. This system was designed mainly for development, research and educational purposes in telemonitoring systems.**

*Keywords*—**telemonitoring, STM32 EVO Primer, biosignal acquisition, biosignal processing, wireless communication, heart arrhythmia alarm**

## I. Introduction

TELEMONITORING systems for monitoring vital signs are very useful in many fields of life [1]. Development of these systems will be of fundamental importance driven by increasing demands. The main reason lies in the aging population of developed countries. In addition to vital signs monitoring, telemonitoring systems should include physical activity monitoring [2]. The implementation of algorithms with ability to recognize life threatening situation is equally important. First and foremost, telemonitoring systems are ideal solution for senior homes, spas or lonely seniors. These systems can be also integrated in smart homes for ambient assistive living [3]. The second option is the use of telemonitoring systems for infants [4].

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The additional group – sportsmen – already arose to the largest one, using commercial telemonitoring products suited for their specific needs [5]. These systems are used for determining performance of healthy person during workouts, trainings or special physical or achievement tests. These systems must work with special algorithms for motion artifacts removing [6]. The telemonitoring of vital signs in combination with precise location of a person in emergency offers new possibilities of quick and accurate intervention for professional agencies. Life-status and location monitoring of emergency and security personnel (firefighters, policemen, and soldiers) can decrease number of casualties or help to find recover those with problems. An ambulance car equipped with telemonitoring systems can send information about patient preoperational health status directly to hospital [7]. Moreover, large group of cardiac patients needs constant monitoring as well, especially after cardiac surgery [8]. Just few examples were enough to prove necessity and timeliness of telemonitoring systems development.

## II. Systems comparison

In many research centers around the world, the telemonitoring systems are being developed. These systems have various conceptions and different designs. They can measure biosignals by using a variety of methods. They have been using different ways of wireless data transfer.

Some of the systems are simple standalone telemonitoring devices focused on special data transfers. These systems usually provide only one type of biosignal. One possibility is to use ZigBee protocol for ECG signal transmission [9]. Combination of Bluetooth and Near Field Communication network is another option for telemonitoring systems [10].

The rest consists of external modules connected to the smart phones, tablets or personal digital assistants (PDA). These coupled devices are offering additional functions for telemonitoring systems.

PDA telemonitoring systems are usually used for measuring electrocardiography (ECG) and photopletysmography (PPG) signals. The biosignal acquisition is done by external unit. A signals transmission to the PDA is done by wires using USB and standard RS232 serial line [11]. Another option is to use of wireless communication modules. In this case, it is necessary to have a special wireless module connected to the signal acquisition unit and PDA [12]. Signals are shown on PDA display and transmitted to management unit by Wi-Fi.

Using Smartphone or tablet there is another possibility how to couple telemonitoring systems. These systems are usually based on Android or iPhone platform. Biosignal sensors are connected to a device directly by Bluetooth or some wireless gateway [13 – 16].

Another method for biosignal acquisition on Smartphones is to use Smartphone for PPG imaging (PPGI). In this case, PPG is recorded by Smartphone video camera [17, 18].

The PDA, Smartphone and tablet solutions are depended on the specific device and platform. Using Smartphone peripherals like video camera (for PPG imaging) does not give the sufficient signal quality for future processing. Simple standalone device can't be extended to measure other biosignals because they are designed for specific (usually single-type) data transfer and signal acquisition.

The main common disadvantage of these systems is that they are not modular. They are designed only to measure the specific signals and can not be easily programmable and modifiable.

The designed system provides a variety of units for different signal acquisition and communication, while modular design allows different combinations. Biosignal acquisition modules are designed to provide preprocessing of analog signal without need of using control unit. This analog signal can be used with other peripherals such as PC based measuring cards.

## III. System Hardware Overview

The systems consist of these main parts: biosignal acquisition modules, wireless communication modules, control unit (STM32 EVO Primer development kit) and extension board for the development kit. The general design of whole system is shown on the Fig. 1.

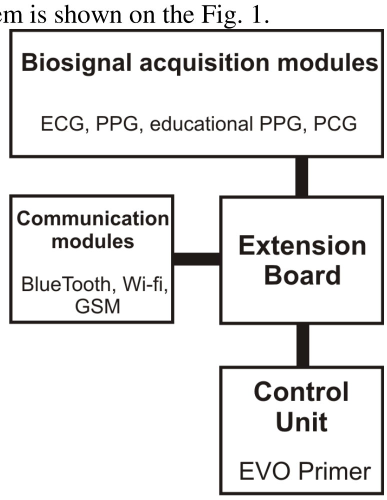


Fig. 1. ECG module

### A. *Biosignal acquisition modules*

Four external modules for biosignal measurements were developed and assembled for this project.

The first module is a 4-electrode device dedicated to measure ECG signals from leads II and III. This module was designed according to the circuit design of professional electrocardiograph [19]. It is created from discrete parts and has right leg driver for active noise rejection. The module has integrated potentiometer for signal offset adjustment. The final design is shown on the Fig. 2.

The second module is designed to measure PPG signal from standard Nellcor finger peg sensor. The module has integrated potentiometer for signal gain and offset adjustment like preceding module. The final design is shown on the Fig. 3.

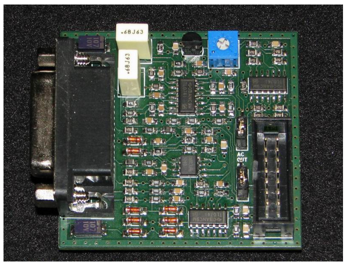

Fig. 2. ECG module

The third module was designed specifically for educational purposes. It demonstrates behavior of optoelectronic circuit dedicated to a PPG measurement. The PPG measurement is done by putting finger between infrared diode and photodiode. Operating point and signal offset is adjustable by potentiometers. This module is shown on the Fig. 4.

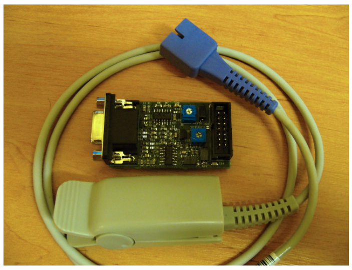

Fig. 3. PPG module with Nellcor finger sensor

The last module is simple audio amplifier with microphone used for recording phonocardiogram (PCG). A stethoscope tube is directly connected to this microphone. Cardiac sounds are useful for explaining relationship between ECG and heart function. This module is shown on the Fig. 5.

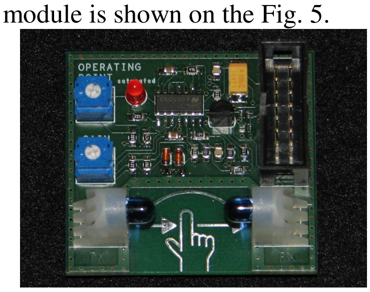

Fig. 4. PPG educational module

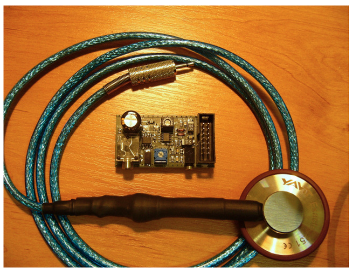

Fig. 5. Phonocardiogram module with stethoscope

The example of signals acquired using Nellcor PPG, educational PCG and FPG modules are shown on the Fig. 6, Fig. 7 and Fig. 8.

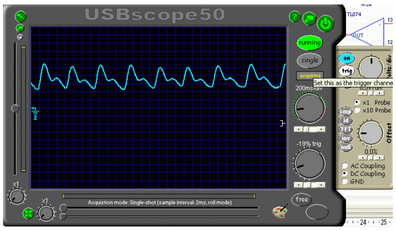


Fig. 6. PPG signal from module with Nellcor finger sensor

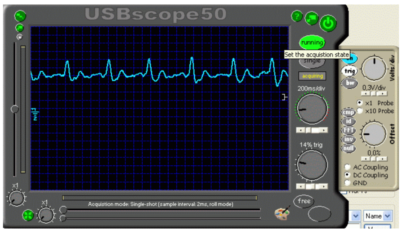


Fig. 7. PPG signal from educational module

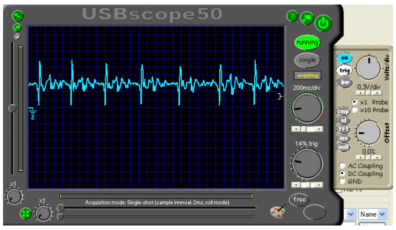


Fig. 8. FPG signal from phonocardiogram module with stethoscope

### B. *Wireless communication modules*

Three wireless communication modules were designed and built for this project.

The first communication module is designed for Bluetooth communication. This module has integrated WireFree KC21 Bluetooth chip. Communication between module and control unit is done by UART. The module has activity indication provided by LED diodes. This module is shown on the Fig. 9.

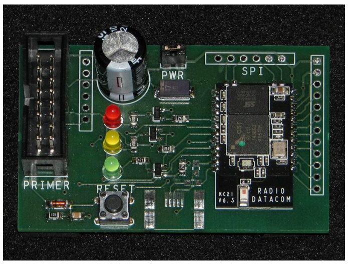


Fig. 9. Bluetooth communication module

The second one is dedicated to Wi-Fi communication. It also uses UART for communication between the module and the control unit.

The last designed module is for GSM network integration.

### C. *Extension board*

The development kit which represents control unit is equipped with extension connector. On this connector, unused peripheral pins of microprocessor and supply voltage from kit battery are accessible. The extension board is connected to this connector. The board provides connectors for communication modules, biosignal acquisition modules and extra battery pack. The extension board has circuit for symmetric amplifier power supply for biosignal acquisition modules. Moreover it has voltage stabilizers useful for power supply of communication chipset. The I2C connector for infrared thermometer and other I2C sensors is also available. External modules can be powered by development kit or external battery. The extension board is shown on the Fig. 10.

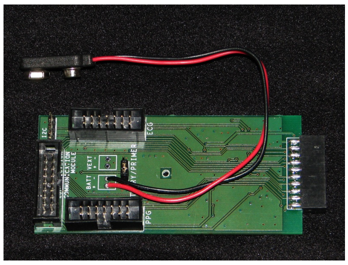

Fig. 10. Extension board

### D. *Control unit*

The development kit STM32 EVO Primer was selected as control unit for this project. The standard kit contains 32-bit microprocessor ARM CORTEX-M3 STM32F103BVET with maximal clock frequency 72 MHz. The EVO Primer Open4 system allows upgrade to higher and more powerful type of microprocessors. This option is available by replacing microprocessor board in development kit. Upgrade of microprocessor unit is important in light of new ARM CORTEX-M4 processor types with floating point units. This feature is particularly important for digital signal processing. The telemonitoring systems can use several kit components – LCD touch screen display, accelerometer, micro SD card slot, joystick button, USB connector, audio codec, buzzer and extension connector.

## IV. Software Implementation

In the control unit, microprocessor software could be divided into following parts: operating system, signal processing libraries, communication and peripheral libraries.

### A. *Operating system*

Development kit uses simple operating system called CircleOS [20]. This system handles single task (application) only. It periodically calls hardware peripherals and application handlers in one loop. The development kit peripherals are controlled by operating system independent libraries. These libraries mediate control for peripherals like accelerometer, SD memory card, display, joystick and others. There is an option to integrate real-time systems like FreeRTOS [21] with the development kit control unit as well. In this case peripheral libraries from CircleOS have to be used.

### B. *Signal processing libraries*

Two signal libraries were developed for telemonitoring system. The first library, called EcgHrTinyLib, is designed for ECG signal processing and filtering. The library has integrated heart rate computing algorithm. The library can process digitalized signal in float decimal point precision. The ECG signal is sampled into the buffer with length of 4 seconds. When the buffer is full, the application handler runs signal processing and heart rate computing algorithms.

The ECG signal processing could be divided into following steps:

1. Normalization and mean value removing,
2. 50 Hz power supply noise removing,
3. Base line wandering,
4. R-Peaks filtering,
5. Energy computing.

The heart rate is computed by algorithm based on finding peaks in signal energy envelope. The final heart rate frequency is calculated based on difference between peak positions in signal energy envelope [22].

The second library is called SignalTinyLib. This library includes several useful functions for signal processing. The functions are focused to compute mean value, to find maximal or minimal value, to do threshold selection or to count delay between peaks in signal.

### C. Communication and peripheral library

The TeleLib is name of library to control dedicated microprocessor peripherals and wireless communication modules. The library extends the STM32 Standard Periphery Library. It initializes the peripherals used by telemonitoring system. The library also implements basic functions for initialization and communication with wireless modules.

## V. Prototype Telemonitoring Device

The telemonitoring system which was described in preceding sections was used to create prototype of telemonitoring device. This device was a crucial part of the Intelligent Primer Nurse project [23]. The whole system is shown on the Fig. 11.

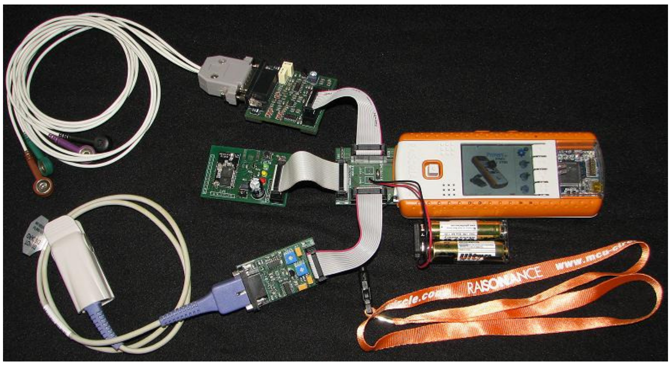


Fig. 11. Prototype of telemonitoring device

The device has been using ECG and PPG modules for biosignal acquisition and Bluetooth module for data transfer. The control unit is using CircleOS and libraries that were described before. Sampled signals are processed by software in the control unit and visualized on the display of control unit with the information about heart rate frequency. The example of ECG and PPG signals displayed on control unit screen is shown on the Fig. 12 and Fig. 13.

The device includes the heart rate arrhythmia alarm which detects low and high heart rates. The thresholds which activate heart rate alarm are set up to 50 beats per minute (bpm) and 100 bpm. The threshold is set to fix values. This type of alarm is suitable for detecting bradycardia or tachycardia. The alarm starts when 5 consequent values are above resp. below the threshold. It works as a semaphore variable in programming. This alarm beeps and informs user about probable heart rate problem, which may cause life threatening situation. The alarm information is transmitted over Bluetooth to a personal computer and visualized in the user interface.

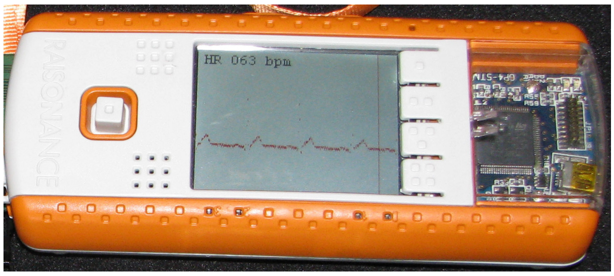


Fig. 12. ECG signal and heart beat value on control unit display

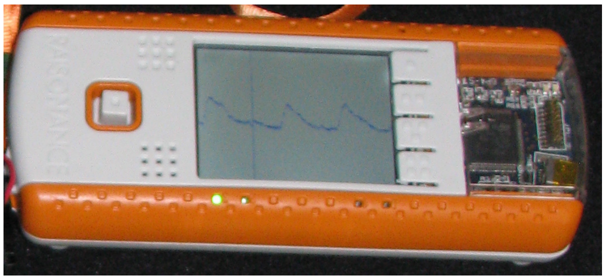

Fig. 13. PPG signal and heart beat on control unit display

Another function is the activity alarm which starts after predefined period of user's inactivity. This alarm works like vigilance button in a locomotive, which must be pushed by train driver periodically. For deactivating the alarm, a user has to shake the control unit or click appropriate button within 30 seconds. The movements are detected using the integrated three axis MEMS accelerometer. The acceleration is computed like a size of the vector from all three axis. The lack of user's response means triggering of acoustic signal and alarm signal to the computer connected via Bluetooth. It is possible to change the Bluetooth module for GSM or Wi-Fi module with same functionality.

The information about heart rate with time marks is logged onto the flash card about every 4 seconds. If the device is connected to a computer via Bluetooth, heart rate, selected signals and the alarm flags are visualized real time on the PC by custom software. The advantage of the Bluetooth is that in PC it is represented like standard serial port with Tx and Rx buffers. The implementation of the Bluetooth in PC application is very easy. The sampled signal data are transmitted as a RAW data. The user interface is composed from a simple real-time graph, alarm signalization boxes and Bluetooth serial port configuration options. The PC software was created from open source applications and components which are available on the Codeproject pages [24, 25]. The screenshots from PC software are shown on the Fig. 14.

The device is intended mainly for future research and education purposes in telemonitoring and medical electronics.

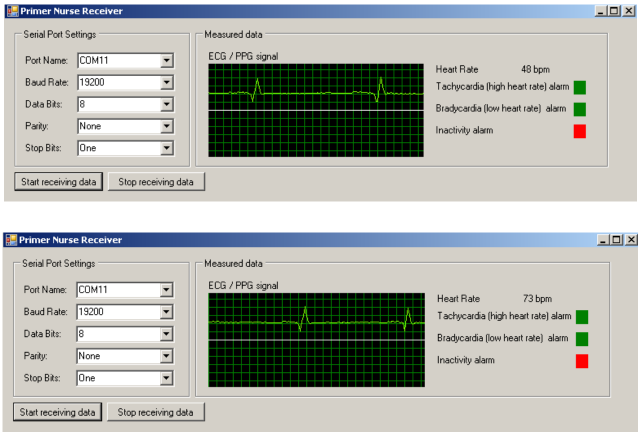


Fig. 14. PC visualization software screenshots

## VI. Conclusion

The modular telemonitoring development system has been designed and later created, with opened possibilities of future expansion. The functions and advantages of this system were demonstrated on a simple telemonitoring device prototype.

The modular solution of this system provides possibility of future system expansion with other modules: sensors for biological signal acquisition or modules for wireless data transmission, as well as location-module with GPS functionality.

The independent development platform and easy upgrade of system resource provides robust tool for developing telemonitoring systems algorithms. These include signal processing or data classification algorithms.

The described system is the initial step on the way to a more complex final system, which will be able to acquire a lot of more vital signs using network of compact sensors and which will be able to detect life threatening situations of monitored person and send alarm signals to operating personnel.

Moreover, the simplicity of the system provides the easy way to use the system for educational purposes in the field of telemedicine, telemonitoring and assistive technologies.

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