Modular Hardware Design and Realization for Vital Signs Monitoring

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Abstract. Remote vital signs monitoring is attracting more and more attention as the population in developed countries is aging, and as the chronic diseases appear more frequently in the population. Smart mobile technologies and miniaturization in electronics have enabled fast development of systems for remote monitoring of vital signs. This paper presents a hardware solution of a mobile device for remote monitoring and shows that the mentioned issues can be addressed and efficiently solved. The project focused on long term measurement of heart rate and the Intelligent Primer Nurse project are introduced in the paper.

Keywords: telemedicine, telemonitoring, assistive technologies, heart rate, electrocardiography, plethysmography

1 Introduction

Information and communication technologies have become inevitable and almost inseparable parts of our lives. One of the fast developing areas is remote patient monitoring that uses devices to remotely collect and send data to a monitoring station for interpretation. Such "home telehealth" applications might include a specific vital sign, such as blood glucose or heart ECG or a variety of indicators for homebound patients. Such services can be used to supplement the use of visiting nurses. This area attracts more and more attention as the population in developed countries is ageing. Especially in this area we can find a lot of mobile applications based on wearable sensing systems (wearable sensors, body area networks, etc.). They enable measuring and collecting vast amount of data of individuals. This multi-parametric data may include physiological measurements, medical images, biochemical data, and other measurements related to a person's activity, lifestyle and surrounding environment. There will be increased demand on processing and interpreting such data for accurate alerting and signalling of risks and for supporting healthcare professionals in their decision making, informing family members, and the person himself/herself.

Although many issues have been successfully solved and introduced either in applied research or in development of prototypes or final products there are still many problems on the waiting list. Nowadays we can measure relatively unobtrusively many physiological parameters on a human body: electrocardiogram (ECG), heart rate, breathing rate, body temperature, blood pressure, energy output, etc. [1]. There have been performed many clinical trials, e.g. [2, 3] assessing the usefulness and efficiency of telemonitoring systems. However the task of data processing and especially evaluation and interpretation remains still challenging. It has many reasons, especially if the signals are recorded while the persons perform their daily activities in standard environment and not in a noise free laboratory. The data contains noise and artefacts, both from the body itself (movements, worse contact of sensors to body) and environment. Thus the task of noise and artefact removal is not yet fully solved and remains open for the future research and development. Another challenging and open issue is standardization of data formats (i.e. the ECG, electroencephalography, and other medical devices measuring biological signals generate proprietary data formats which are usually not publicly known thus it is impossible to integrate such devices into larger systems because the signals can be processed only by software delivered by the device producer), data transfer protocols; security and data privacy. Recently there have been published many papers analyzing these problems, comparing existing standards and recommending future standardization activities, e.g. [4]. In [5] there has been proposed a general architecture of this type of systems respecting existing standards in communication between individual modules. It covers the whole chain from data acquisition / measurement over data collection, identification, transformation up to evaluation and storage in an EHR system. To allow the "plug-and-play" approach the interfaces must be based on well defined standards. We have in mind especially following categories: ISO units for measurement of physical quantities, ISO IEEE standards in communication, standard file formats in software area, HL7 standards on the side of information systems.

2 Hardware Design and Realization

General concept of the presented telemedicine system is based on several requirements. The most important ones are:

- system modularity
  One of the most important requirements is to have a modular system. This concept presents a possibility to make quick and easy changes of the system design.
- and easy-to-use system.
  Another requirement is to have an easy-to-use telemedical kit. It is very important, because it enables to rebuild the system for new applications with low effort.

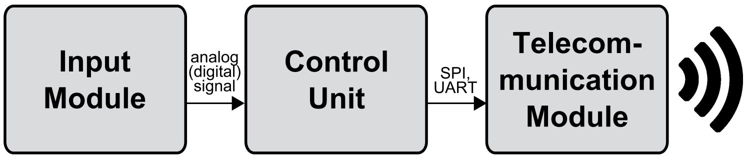

Fig. 1. General concept of the system

The presented system is modular and could be divided into three main parts – input modules, control unit and telecommunication modules (see Fig. 1). The main task of the system is to sense several vital signs like electrocardiograph (ECG), blood pressure (NIBP) or oxygen saturation (pulse oxymetry, SpO2), to process acquired signals and to communicate them to a PC based system (desktop PC, laptop or computer network access point) using any type of standardized wireless technologies such as Bluetooth, WiFi or GSM. The choice of vital sign monitored by the system and the choice of wireless technology used for data transfer are based on the intended application of the system.

Input modules transduce measured biosignals to electrical value, especially analog voltage (however any type of digital data as input value is also possible). The output of these modules could be one or more dimensional signal. It means the control unit behind the input module has to be able to process more signals at the same time, for example leads I to III for ECG signal processing or red and infrared signals for pulse oxymetry measurement.

The control unit is a core of the whole system and has to perform more tasks simultaneously. The most important ones are:

- to acquire input analog signals and to convert them to digital data;
- to process these signals and/or to parameterize them;
- to prepare data packets according to defined communication protocol;
- to control the communication line (handshaking the line) and to send the data;
- and to provide the user interface of whole system.

Communication modules are the last part of the system. The main task of these modules is to support the signal transmission between the control unit and PC based system on the level of the physical layer. The handshaking of the line is controlled by the control unit and/or PC based part of system.

The communication interfaces between the modules are strictly defined, the modules are reciprocally inter-changeable. It means it is possible to choose measured signal (for example ECG, NIBP, SpO2) and the type of connection (Bluetooth, WiFi, GSM), choose appropriate modules and set-up the user-defined system quickly and easy. The data format is well defined and satisfies the basic requirements on interoperability [6].

All modules are realized using standard components mixed on surface mount and through-hole technologies. The PCBs are designed as four layer boards, with two signal layers and two layers for power supply and shielding.

The hardware realization of the telemedical system is supplemented by software libraries in our design. The prepared software libraries include code libraries for control unit, pre-prepared firmware set-ups for communication modules and software application for the desktop PC. This application serves as a basic gateway from the system to the PC based platform and provides easy way to set-up parameters of transfer and initial visualization of received data. The role of prepared software libraries is to support users in developing their own project without detailed knowledge of registry implementations in each module and assembler coding and also without additional requirements on time and effort.

3 Applications

The designed and realized telemedical system could be used as a basic platform for many applications in the field of assistive technologies, telemonitoring of vital signs, as a supervision system at home and institutialized care for the sick, disordered or elderly people etc.

The system is also able to transfer the raw data and the aggregated data. Based on the application demands it is possible to choose the communication protocol and the method of data processing.

3.1 Long Term Measurement of Heart Rate

A long term measurement of heart rate (HR) is the most common method of vital signs monitoring. A lot of cardiac abnormalities could be diagnosed from the long term record of the heart activity. For these reasons the long term recording of heart activity is used not only for medical purposes, but also during psychical and physical stress testing. During the physical stress tests the recordings of acceleration and heart rate are frequently performed.

There are a lot of methods how to obtain and process the ECG signal and how to compute the HR from the signal. Unfortunately, only few methods are implementable in small portable devices due to the lack of computational performance in these devices. For that reason the method for processing of ECG signal with very small computational demands was designed and implemented in our project. The raw ECG signal is normalized firstly and the mean value is removed. After the normalization the 50 Hz filtering is applied using the biquad band stop and also the filtering of breathing activity artefacts is applied using the 0,5 Hz Butterworth high pass filter. Finally, the signal preprocessing is completed with the R–peaks filtering using the Butterworth band pass filter with passband 15 Hz to 20 Hz.

After the signal preprocessing, the energy of ECG is computed. This operation enhances the R peaks in the signal. Finally, the integrator filter is applied to the signal. The filter smooths the signal and highlights the R-peaks. After

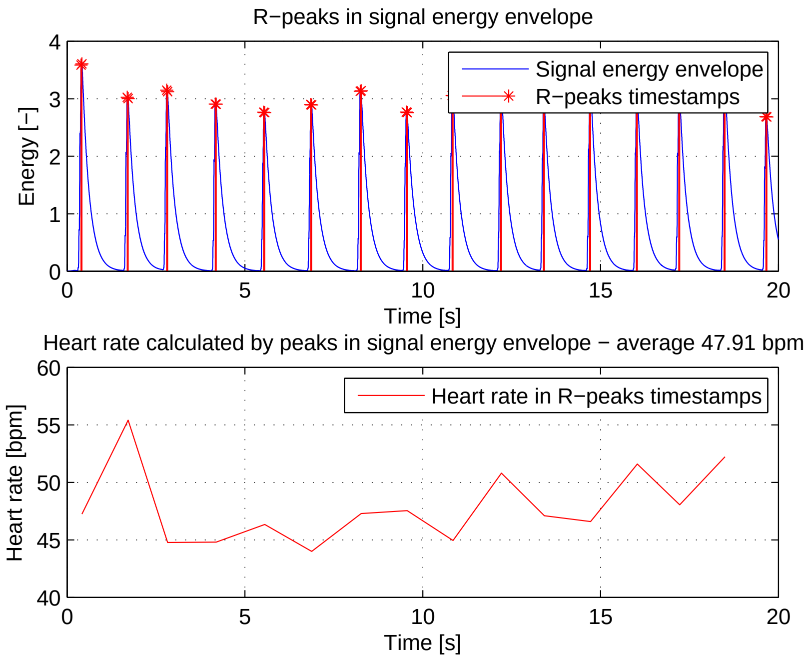

Fig. 2. The smoothed ECG signal, localized R-peaks and the computed heart rate

this operation the R-peaks are localized by the thresholding and the HR is computed from the R–R intervals. The signal smoothed by integrator, the localized R-peaks and the computed HR are shown in Fig. 2.

The realized device was evaluated during the stress test containing running, walking and idle standing in the park. The professional HR meter Polar F7 [7] was used as a reference device for the evaluation. The comparison of results from the own developed and Polar F7 is shown in Fig. 3.

The results from the realized device are fully sufficient, the main advantage of the device is the possibility to store signals for future processing on a SD card or to transfer them to a superordinate system.

3.2 Intelligent Primer Nurse

This particular application focuses on the design and development of the device for monitoring vital activity. The realized device is able to monitor vital signs continously and to activate alarm if the signs are not in the specified range. It means the device is something like a personal and portable vital signs monitor similar to the monitors in intensive care units. The target group of users are chronically diseased, elderly and other threatened persons.

The device is based on the EvoPrimer [8] development kit, the new version of STM32 Primer2 kit. The electrocardiography (ECG) and photopletysmography

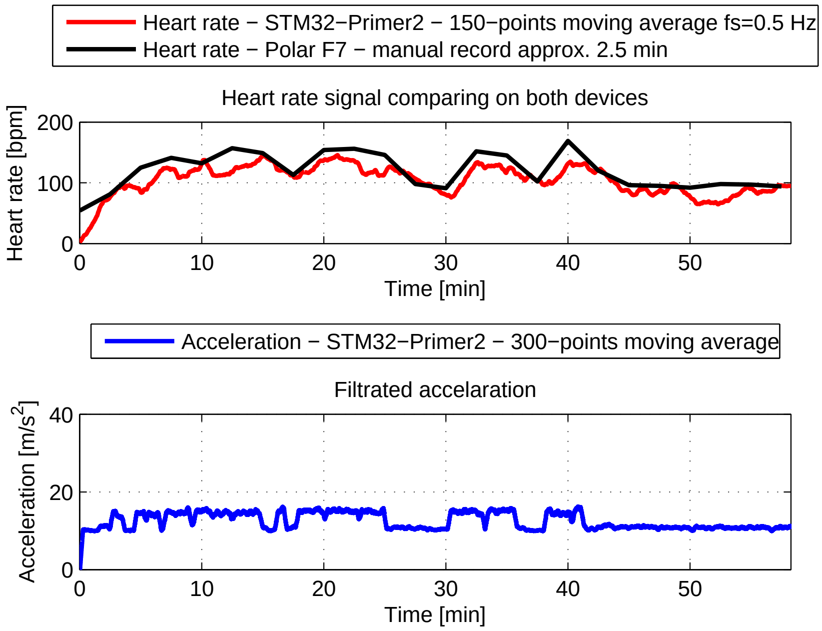

Fig. 3. Comparison of the signals from our device based on STM32-Primer2 with the signal from Polar F7 during running, walking and idle standing

(PPG) signals are acquired by the device described above and then they are sampled and processed by the software in the control unit. The signals are displayed on the screen in real time. The behaviour of the signals is supplemented with the actual value of heart rate.

The heart rate alarm, which detects low and high heart rates is implemented in the device. The thresholds, which activates alarm are 50 bpm (beats per minute) and 100 bpm. The alarm informs the user about probable heart rate problem, which may cause life threatening situation.

Another alarm that is implemented is the activity alarm. The alarm starts when the sensed user has no activity for a long time interval. This alarm works like vigilance button in the locomotive. The user has to move, or to click primer button after every 30 seconds to deactivate the alarm. The movements are detected by the build-in accelerometer.

The information about heart rate with time marks are logged on a flash card every 4 seconds. If the device is connected to a computer via Bluetooth, the heart rate, selected signal and alarm flags are visualized by a special software on the PC in real time.

3.3 General features and future applications

The presented applications are not the only possible ones. There are many other applications in the field of assistive technologies, telemonitoring of vital signs and telemedicine where the realized system could be used. For example, the system is easily applicable for vital signs monitoring and classification of urgent states, falls detection and alarms and also as a surveillance system in home and institutionalized care, smart homes etc. The main advantages of the system in these applications are the mobility, the portability, the robustness and the modularity. The processing currently performed on a PC can be relatively easily implemented on an iPad, tablet or smart phone. Optimized version of the algorithms can be implemented in embedded systems, too.

4 Discussion and Conclusion

We have focused in the paper on the description of the hardware solution of the mobile device for remote monitoring of vital signs. The data communication and storage in a PC satisfy the requirements laid on medical data privacy [9]. We have not discussed in detail the mobile processing application. However, the processing that is basically performed on a PC can be performed in the same way on a mobile platform, either smart phone or tablet. Based on the literature review and practical experience, we have designed and implemented standard communication from the sensing part up to the processing modules. Modularity and strict definition of interfaces is the basic requirement for implementation of new input modules into the system. An example of planned modules is transthorasic bioimpedance measurement. For practical use, the system must satisfy additional requirements, namely small power consumption, small in size, lightweight, and long battery life. On the side of software development, there is necessary to design new more efficient signal processing methods, filtration and classification techniques that will be implementable in embedded systems. The measured data is in bit format, accompanied with the information about type of the data (ECG, blood pressure, FCG, etc.), sampling frequency, and other information if required. The software libraries support development of applications. Interfaces of software modules are also standardized. Thus the output of the processing module can be easily sent to an information system or EHR system. We have in mind that correct mapping of acquired data onto a data model that describes electronic patient record is a very important issue, especially with respect to future development and possibility to sense and store far more larger volumes of heterogeneous physiological parameters at a single patient. Interoperability may significantly influence effectivity both of design and development of an integrated system and of its routine operation. It will become more and more important with the development of telemedicine, home care and possibility of remote monitoring of patient state. As the technology is developing very quickly we have to assume that new types of sensors and devices will appear. The newly designed and developed systems must be necessarily created as open modular systems allowing direct connection of the new sensors and devices without any need of modification of the communication and data input. Possibly new data processing module will be added. Integrating information acquired from different sources and implementing it with knowledge discovery techniques allows medical and social actions to be appropriately performed with reliable information, in order to improve quality of life of patients and care-givers.

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