Portable Data Logging System for Long-Term Continuous Monitoring of Biomedical Signals

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***Abstract*—The described portable data-logging system is intended for continuous and long-term monitoring of the heart rate variability (HRV). For this purpose, the system enables the acquisition of the following signals: RR interval calculated from the electrocardiogram (ECG), body and environment temperature as well as the state of the event marker (EM) button. The attained small dimensions (90 × 50 × 15 mm) and small weight (100 g), together with the leather bag and the fastening belts enable the portable device to be worn comfortably during the measurement time. The user-friendly PC software enables the management of all required pieces of information about subjects and measured signal data.**

I. Introduction

Recording of physiological and psychological variables in real-life conditions is useful in treatment of patients with chronic disorders or health problems. It is also useful for studying healthy subjects' responses in every-day situations. Continuous acquisition of biomedical signals during every-day life requires specific measurement methods and instrumentation. Measurement methods must be non-invasive and should not interfere with a subject's day-to-day activities. Portable instrumentation has to have the following characteristics: small dimensions, small weight, low power consumption and high memory capacity.

The acquisition and monitoring of electrocardiogram (ECG) in uncontrolled conditions is of great importance for contemporary cardiology diagnosis. The so-called Holter systems [1] are used to perform this task. The storage capacity of such devices usually ranges from 24 to 48 hours. Given the frequency content of the ECG signal (125 Hz), sampling frequency is usually minimally required (250 Hz) for minimization of memory requirements.

Heart-rate variability (HRV) analysis is a tool used extensively in contemporary biomedical and psychophysiological research with a purpose to assess cardiac autonomic control [2]. It has been noted that HRV depends on body temperature [3]. A representative discrete-beat series (RR series) of HRV is obtained from the ECG, and it is defined as the time between two consecutive R peaks (Fig. 1). In order to obtain the required RR interval time resolution of 1 ms, the sampling frequency has to be minimally 1 kHz.

The purpose of this paper is to provide a description of a portable data logging system that enables monitoring of particular biomedical signals, concerning HRV, continuously during long time periods.

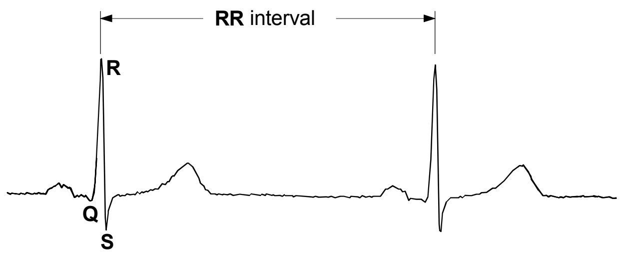

Figure 1. Typical electrocardiogram (ECG) with definition of the QRS complex and RR interval

II. System Description

The system consists of the following separated parts:

- ECG electrodes and temperature sensors,
- portable data logging device,
- communication interface and battery charger,
- PC with the developed software.

Block diagram of the developed system along with the proposed placement of ECG electrodes and of temperature sensors on a subject is presented on Fig. 2. In the presented realization, the system enables the measurement of the one channel ECG signal and of two temperature signals - body and environment temperature. ECG signal is measured using three surface self-adhesive electrodes, which are placed on a subject's chest. Temperature sensors are represented by NTC thermistors enclosed in a stainless-steel housing.

Raw ECG signal is filtered and processed for QRS detection in real time. Successive RR time intervals expressed in milliseconds are stored on the memory card together with other signals.

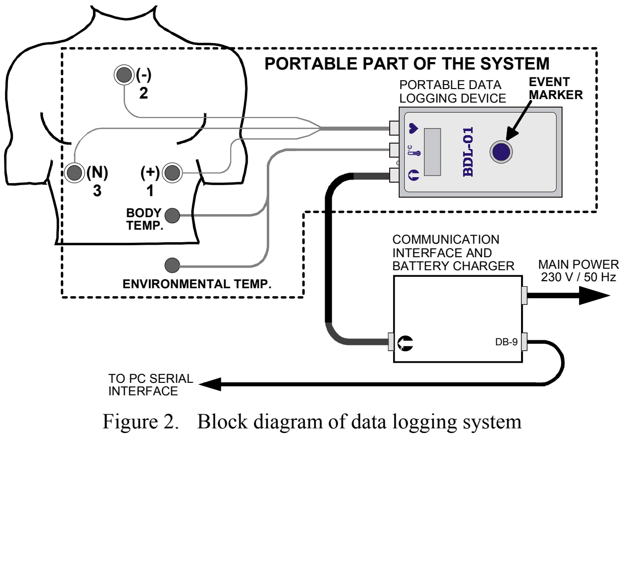

Figure 2. Block diagram of data logging system

During measurement, the subject carries only the portable data-logging device (further in the text: portable device), which is connected to the ECG electrodes and the temperature sensors (Fig. 2). The portable device is placed in a comfortable leather bag, which is fastened to subject's body with belts.

During real-time monitoring, measurement setup or data transfer, the portable device has to be connected to the communication interface and battery charger device (further in text: communication/charger device), which is connected to the PC through the serial interface. Data transfer intervals depend on the autonomy of the portable data-logging device, which is generally limited by battery and memory capacity. In the present system, battery capacity is the limiting factor. The battery endures 5 days without recharging. Simultaneously with the transfer of stored data to the PC, the batteries can be recharged. The user can switch the battery charger ON or OFF.

It is important to point out that data acquisition in the portable device is not interrupted even during data transfer to the PC. This feature enables continuous measurement, limited only by the durability of the self-adhesive electrodes. Since the present realization of the portable device is not enclosed in a water-resistant case, measurement is also necessarily interrupted during activities in which the device is in contact with water (swimming, shower).

III. PORTABLE DATA LOGGING DEVICE

The portable data-logging device consists of the following parts (Fig. 3):

– analog interface,
– microcontroller,
– SmartMedia™ memory card,
– power supply.

The device is enclosed in a plastic case, whose dimensions are 90 × 50 × 15 mm. The weight of portable device amounts to 100 g.

A. Analog Interface

The analog interface enables the measurement of one ECG and of two temperature signals.

ECG measurement (♥) is carried out by using three surface self-adhesive electrodes placed on the subject's chest. The concrete position of electrodes (Fig. 2) is determined in order to fulfill two requirements: higher amplitude of measured QRS complex (to make easy QRS detection) and lower artifacts caused by EMG activity. Electrodes (+) and (-) are connected to the differential input of the ECG amplifier, and (N) is used as a neutral electrode. The electrodes are connected to the portable device through shielded cables in order to protect the measured signal against electrical noise from the environment. The cable shield is driven by the common voltage of the differential amplifier through the voltage follower. This reduces parasitic capacitance that appears between the wires and the shield and therefore prevents input impedance decrease [4]. The neutral electrode is connected to the "driven right leg" circuit in order to minimize the power line interference [4]. Bandwidth of the ECG amplifier is set to the 1.6 to 37 Hz interval in order to emphasize the QRS complex [5] and to minimize the base line drift caused by motion artifacts. The input dynamic of the ECG amplifier is 3.5 mV. The ECG cables are connected to the portable device through a connector with a fastening system to prevent accidental disconnection caused by subject's movements during his daily activities.

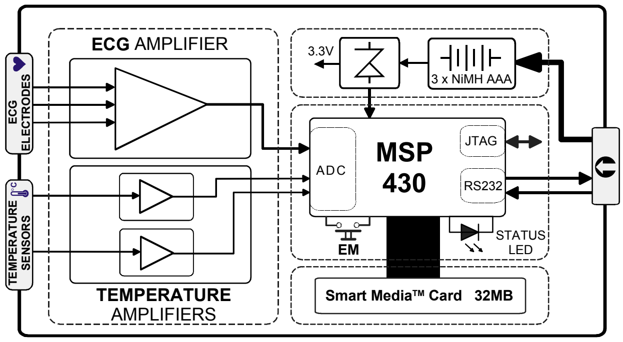

Figure 3. Block diagram of portable data logging device

Temperature measurement (°C) is carried out using two NTC thermistors (BetaCurve Interchangeable Thermistor Series I, type 100K6A1B, manufacturer BetaTHERM). These NTC thermistors have temperature tolerance of ±0.2 °C in the 0 to 70 °C temperature range and are interchangeable. To obtain the required temperature tolerance of ±0.1 °C, all thermistors are calibrated and the calibration curves are stored in the look-up table.

B. Microcontroller

The core of the portable device consists of a low-power Texas Instruments microcontroller (MSP430F149) [6]. The microcontroller features a 16-bit RISC architecture, ultra-low power consumption (less than 1 mA in active mode and about 1 μA in standby mode), a 60 KB on-chip flash memory, 2 KB RAM, 8-channel 12 bit A/D converter, and a dual UART. MSP430 is an "In System Programmable" (ISP) microcontroller, which enables easy firmware debugging through the JTAG connector.

ECG signal is sampled with a sampling frequency of 1 kHz. Each converted sample is stored in the memory FIFO buffer and used for QRS detection. After R-wave detection, successive time intervals between two R-waves (RR interval), expressed in milliseconds, are stored in the temporary storing buffer. Very robust QRS detector software is developed for the purpose of detecting the R-wave, enabling reliable detection in presence of very high motion artifacts.

Temperature signals are converted every 10 s and also stored in the temporary storing buffer. The event marker (EM) button is connected directly to the microcontroller I/O pin. Its status is sampled with a 1 ms resolution and the time (expressed in milliseconds) of every change (0 to 1 and 1 to 0), is stored in the temporary storing buffer.

Signal LED (Fig. 3) flashes shortly every 2 s when the portable device is turned ON. In future development, we plan to use it for signalization of different statuses (for example: low battery, memory full, etc.).

Every portable device has its own ID number, which enables the PC software to distinguish them.

C. SmartMedia™ Memory Card

The SmartMedia™ memory is organized in blocks and pages [7]. When the temporary storing buffer size exceeds one page (512 bytes), the data are transferred from the buffer to the SmartMedia™ memory card. The Flash File System manages the data on the SmartMedia™ memory card. Its purpose is to manage the file allocation table (FAT) as well as the information about bad-blocks on the memory card.

Reading and writing on the memory card can take up to 100 ms. During that time, in order to obtain a uniform sampling rate of the measured signals, data acquisition and processing remains uninterrupted since these tasks are performed by different threads. The real time operating system is developed to support multithreading.

The capacity of the memory card used in the portable device is 32 MB. This capacity enables continuous data storage during about 20 days, depending on a subject's heart rate and on the usage frequency of the EM button.

D. Power Supply

The portable device contains three AAA size NiMH rechargeable batteries serially connected yielding a voltage of 3.6 V. Since the system requires 3.3 V, the voltage is stabilized using a micropower voltage regulator LP2951 (National Semiconductor). Besides a very low quiescent current (75 µA typ.) and a very low dropout voltage (typ. 40 mV at light load and 380 mV at 100 mA), this regulator features an error flag output which warns of a low output voltage and is used for a power-on reset in our system. The second feature is represented by a logic-compatible shutdown input, which enables the regulator to be switched on and off. This feature is used in our design to avoid mechanical power switch. The portable device can be turned off by control of PC software. Power-on is initiated simply by connecting the cable to the communication connector ∩ (Fig. 2, Fig. 3).

IV. Communication Interface and Battery Charger Device

The basic requirements and limitations concerning the portable device were small dimensions and small weight. Due to these requirements, only the minimum number of features needed for proper functioning has been implemented. That means that the communication connector (∩) had to be directly connected to the serial port of the microcontroller (signals RX and TX), and no circuitry for battery charging exists in the portable device. The physical layer for RS-232 communication and the intelligent NiMH battery charger are placed in a separate box (communication interface and battery charger device, Fig. 4).

The multi-channel RS-232 driver/receiver MAX232 ACPE (Maxim) is used for serial communication with the PC. The communication speed is 115200 kbaud.

A fast-charge controller MAX712 (Maxim) is used for NiMH battery charging. MAX712 terminates fast charge by detecting zero-voltage slope. The charging current is adjusted to C/2. During the fast charge process, the signal LED on the communication/charger device (Fig. 4) lights red. After the termination (completion) of the fast charge, MAX712 switches to trickle-charge state, and the signal LED lights green. The charging process starts whenever the user connects the portable device to the communication/charger device. In order to prevent battery overcharging in case of frequent connecting/disconnecting of the portable device (for some short tests), the user can disable the charging feature by the CHARGE ON/OFF switch.

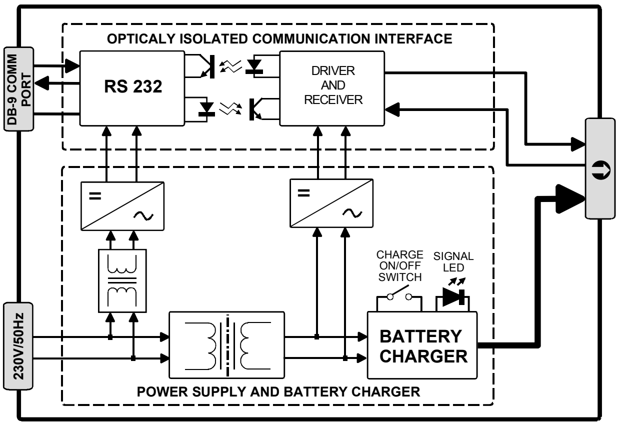

Figure 4. Block diagram of communication interface and battery charger

The communication/charger device features one very important characteristic of the data logging system, regarding subject safety: galvanic isolation of the portable device from main power during communication with the PC and battery charging. A special transformer which fulfils 5 kV primary/secondary isolation is used for the battery charger. The optocoupler HCNW4506 (Hewlett Packard) is used for the isolation of the communication data lines. This device can endure 5 kVrms during 1 minute and has 15 kV/µs minimum common mode transient immunity at 1500 V voltage peak.

V. PC Software

The PC software is developed for the Microsoft Windows operating system (9x/NT/ME/2000/XP). The software features:

- real time monitoring of all measured signals,
- database (stored signals and information about subjects),
- measurement setup,
- communication port setup,
- switching off of the portable device,
- SmartMedia™ file system formatting (only in administrator version).

User interface consists of three main windows:

- Monitor (Fig. 5),
- Subject (Fig. 6),
- Measurement setup and data transfer (Fig. 7).

A. Monitor Window

The monitor displays all measured signals in real time (Fig. 5) and enables functionality check of the portable device prior to the beginning of measurement. By inspecting the ECG signal, the user can also check if the electrodes are placed in the right positions and possibly change the positions in order to obtain a better signal for reliable QRS detection. One may notice the efficiency of the QRS detector in the Monitor Window – small markers under the ECG signal represent time indicators of R-waves detected by the portable device QRS detector

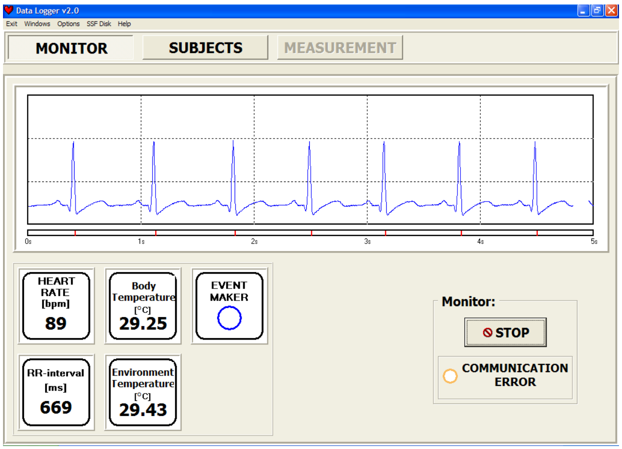

Figure 5. User interface of portable data logger monitor

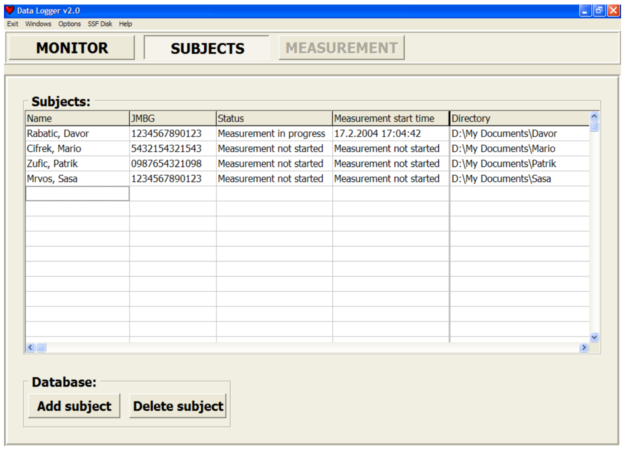

Figure 6. User interface for subject's data

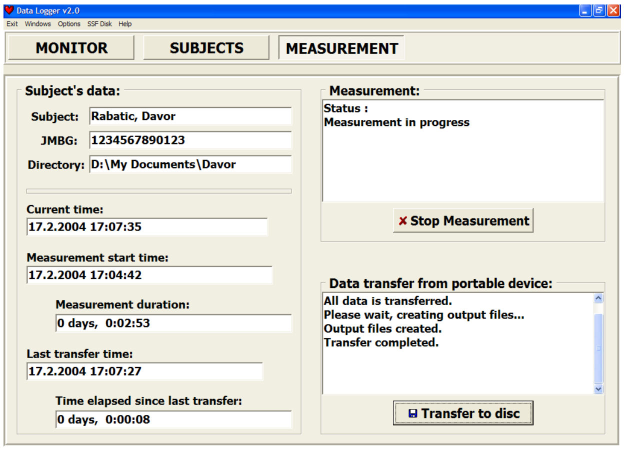

Figure 7. User interface for measurement control

software. In the lower left part of the window, one may find information obtained from the portable device: current RR interval and heart rate, body and environment temperatures and the state of the EM button. In the lower right part of the window, one finds a button for starting and stopping real time data acquisition as well as a visual indicator of communication errors.

B. *Subject Window*

The subject window (Fig. 6) enables adding of new and the removal of existing subjects using buttons placed in the lower left part of the window. On this window, one may also find information about measurements (measurement start time, measurement end time, time interval since the last data transfer and the name of the directory where the data are stored).

C. *Measurement Setup and Data Transfer Window*

Measurement setup window (Fig. 7) opens by double-clicking on a subject's row in the Subject Window. The users can use the buttons in this window to start/stop measurement and to transfer the stored data from the portable device to the PC database. The data are stored in the PC in a format compatible with standard spreadsheets and statistical software. The stored data are divided in smaller files containing data collected during two hours. There are three types of files, regarding contents: RR interval data files, temperature data files, and event marker data files.

VI. Conclusion

The presented portable data-logging system is suitable for continuous long-term acquisition of particular biomedical signals during day-to-day activities. In the presented realization, the portable device memorizes some parameters concerning HRV (RR intervals calculated from ECG, body and environment temperature) as well as the state of the event-marker button. The advantages of the system are the attained small dimensions (90 × 50 × 15 mm) and the small weight (100 g). The developed user-friendly PC software enables managing all required information about subjects and about the measured signal data. In the presented system, the autonomy of the portable device is limited by power consumption and battery capacity and lasts for five days. The autonomy regarding memory capacity (about 20 days) can be further increased by using the currently available SmartMedia memory cards with higher capacity.

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