VITAL SIGNS RECORDER FOR MEDICAL EXERCICES AND SPORTS

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Abstract: A portable device designed for in-field recording of biosignals is presented. The recorder is provided with three bipolar channels digitising at 200 Hz and lacks of interpretive intelligence. The captured data is send in real time via serial communication interface using AT commands, or stored in the internal memory for delayed transmission. Two operating modes are implemented: scheduled acquisition sequence and remote control. Although the recorder was first intended for remote monitoring in cardiology, we also have first positive results from such application areas as medical supervision of sportsmen and pregnancy monitoring.

Introduction

The remote monitoring of various vital signs is currently one of the most spoken topics [1, 2] and extends from specialized monitors for clinical use to home care devices accessible for anyone [3, 4]. First networks of continuous monitoring for people at cardiac risk are already commercialised in US and Europe [5, 6, 7]. The capturing devices analyse the electrocardiogram and send the alert message in case of abnormalities. Although the need for spread interpretation intelligence is justified by keeping the communication costs as low as possible, considering resources limitations of a wearable computer, the percentage of false alarms is rather high.

An alternative for continuous monitoring is the triggered 'on demand' acquisition method, widely used in ECG event recorders. However, most commonly used independent devices risk to miss an electrocardiogram when patient in pain is unable to start the capture session. The advantage of remotely controlled device is thus twofold:

- the signal is transmitted without delay and the reanimation may be immediate if necessary,
- the acquisition is controlled by the experienced staff with consideration of previous results.

Certainly, remote monitoring is not limited to the home care applications. Staying still in the field of cardiology, the use of battery operated wireless recorders removes the constrains on patient mobility during stress test and cardiac rehabilitation as well as the need of protective galvanic isolation for human-contacting circuitry.

The portable ECG recorder was developed in our Laboratory on demand from cardiology researchers and had to comply with the following criteria:

- three simultaneous channels sampled at 200 Hz,
- on-line wireless transmission of recorded signal,
- autonomy for at least 24 hours of operating.

Since the recorder was designed for medical experiments, the lack of build-in interpretive algorithm was one of the primary assumptions. Surprisingly, combined with a basic set of remote configuration commands, this opened the large area of applications extending far beyond the cardiology. The research completed with use of the recorder include:

- muscle fatigue assessment during training of downhill ski competitors,
- uterine contraction detection based on abdominal potentials in patients at risk of premature delivery,
- the investigation of influence from environmental stress to the physiology of domestic animals.

During all the development process we carefully observed the requirements of international standards for medical devices and electromagnetic compatibility [8, 9, 10]. Although the prototype of our recorder is not intended for development to the commercial product, we consider it as a potential background for future, more specialised monitoring devices.

Materials and Methods

The recorder was developed around the popular circuit from the *MicroConverter* family [11] integrating analog to digital converters, serial communication interfaces, internal flash memory and a '51-type processing kernel running at 2,7V. The on-chip PLL-adjustable oscillator with the Fast Interrupt Response feature is very useful in a portable device where the power management is critical. The block diagram of the recorder's circuitry is displayed in figure 1.

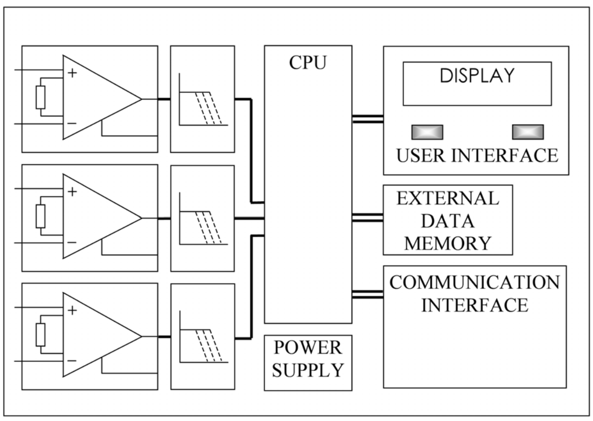

Figure 1: The block diagram of the recorder's circuitry

The internal non-volatile memory is used to store the recorder configuration. Therefore, the device status, the data organization and other settings are not lost on power failure.

The external memory (basic: 512 kB) is used for data storage in the recording mode and acts as a data buffer in the interactive mode. This function prevents from the loss of data when the transmission channel is temporarily not available. Third function of the external memory is the closed loop buffer used for defined length of pre-trigger data. The data preceding the recording request has principal importance in many medical applications. The external memory capacity lasts for ca. 12 minutes of data, but thanks to the use of SPI interface, it is easily extensible with use of MMC or SD memory card to over a week of record.

The recorder is equipped with an alphanumerical LCD module intended for displaying messages to the user. The recorder can display an automatically or remotely selected message from the pre-compiled set or display any text received from the communication party. The user interface is completed with two programmable push buttons whose functions is displayed in the LCD. In case the recorder is applied in animals, the buttons are ignored and the LCD is remotely switched off for the sake of energy saving.

The communication interface uses the bi-directional UART that could be directly connected to a computer serial port. In this particular application, however, the communication port is intended for a wireless connection via external mobile telephone. For this purpose all the modem initialisation sequence [12], including the destination telephone number has to be stored in the configuration area of the internal flash memory. Except for data transmission, the communication channel is used for sending the textual messages to the user and the configuration data to the device. In both cases the sender telephone number acts as a password in order to prevent any unauthorized access to the recorder. Some examples of remote configuration commands are displayed in table 1.

Table 1: Examples of remote configuration commands

mnemonic	data format	action description
getdatonc	15 datalength	Starts single immediate acquisition of datalength seconds
getdatseq	16 datalength datainterv	Starts multiple acquisitions of datalength seconds repeated every datainterv minutes
stopseq	96	Stops acquisition sequence
dispmsg	21 msgnumber	Displays message msgnumber in the LCD

The analog circuitry repeats the same architecture in each recording channel and uses micropower (230 μW) instrumental amplifiers with rail-to-rail input and output signal swing. This approach maximizes the usable dynamic range of the a/d converter even for low supply voltage. The analog inputs are FET-based and protected by 10mA ESD diodes against the overvoltages up to 20V. The effective input voltage range can be set by the software from ±2mV to ±16mV in order to cover all the area of applications. The digitisers provided in a *MicroConverter* chip guarantee 12-bits resolution (4096 levels) and 1 LSB nonlinearity over expected temperature range. The anti-aliasing filters are designed as active 4-th order with a cut-off frequency of 100 Hz.

The recorder was designed using surface mount components (SMD) and double layered printed circuit board. The top layer contains digital components and voltage controllers while the bottom layer is reserved for analog circuits. The high immunity to the electromagnetic interference was achieved thanks to the minimum length of signal wires. Although, the recorder size was taken into the consideration, further reduction by up to a half of current size is possible. The general outlook of the recorder electronics is displayed in figure 2.

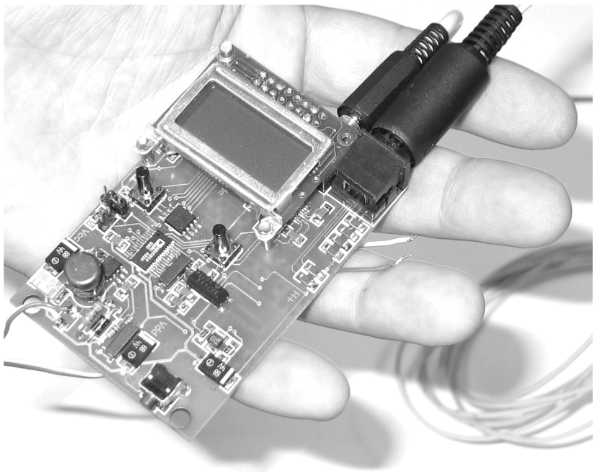

Figure 2: The general overview of the recorder electronics board.

Results

In all applications of vital signs recordings, the signal quality is of crucial importance. Therefore extensive testing must be made in order to confirm the recorder's ability to deliver a medically meaningful signal representation. The electronic circuitry was subject to tests performed in accordance to the appropriate IEC standards [8, 9, 10] for ECG recording devices. Tests of the developed vital signs recorder were performed in two stages:

- test of the circuitry and measurements of basic electrical parameters,
- test of the software and correctness of implemented communication protocols.

The electrical tests were performed on a single prototype device in a specialized laboratory complying with national measurements standards. As the transmission channel is digital and bit-accurate, the electrical tests of wireless communication were limited to the electromagnetic compatibility and interference immunity issues. The parameter set and testing procedure used were typical for ECG long-term recorders. Main results of these measurements are displayed in table 2.

Table 2: Selected results of recorders electrical tests

parameter	value	conditions
1 LSB linearity range	-1.87 ÷ 1.83 mV	2mV range
CMRR	92 dB	DC ÷ 100 Hz worst case
bandwidth	0.03 ÷ 100 Hz	-3 dB
voltage noise (ref. to input)	8,3 μV	0,1 ÷ 10 Hz
channel crosstalk	-77 dB	DC ÷ 100 Hz worst case

The only form of signal processing implemented in the recorder is checking for input range overflow leading to setting data markers and to optional automatic adjustment of pre-amplifier's gain. For high signal amplitude the input voltage range is extended by a factor of two at a price of absolute measurement accuracy. This approach frees the remote computer from controlling the input range for unknown signals.

In the second stage of testing, the software of the prototype needed several updates in order to fulfil all the user's expectations. Particular attention was paid to the correctness of remote command interpretation in any condition. Another set of tests was necessary for fixing the device behaviour in variable throughput of the transmission channel. The measured signal integrity was checked with use of the built-in memory that was written in parallel to sending data and then compared with the bitstream transmitted through a wireless channel. Various conditions were used for these experiments: different time of the day as well as different surroundings from rural areas to city centre.

Since the device was considered as a general-purpose vital signs recorder various remotely controlled and time-dependent operation modes are provided. The aim was a maximal degree of flexibility and optimisation of the use of wireless channel. Nevertheless, the input sensitivity and the number of recording channels limit the device application area.

The following procedures are common for all applications and were thoroughly tested:

- scheduled acquisition to the memory,
- scheduled acquisition and transmission over a GSM telephone in various conditions,
- acquisition and transmission initiated remotely over a GSM telephone,
- displaying of a textual message sent over a GSM telephone
- changing of the configuration memory contents over a GSM telephone.

The tests were performed on a single recording device connected to the Siemens S55 mobile telephone. Second telephone was used as a GSM modem for a PC computer running the signal storage and device control software. Recorder's software was easily updated thanks to the in-circuit programming featured by the *MicroConverter* chip.

For the final release of the software, the test results confirm the correct support of such events as transmission break, multiple connection retries, unauthorised access detection and refusal, data stream redirection etc. The power supply monitoring enables the data-save shutdown and wake-up with reporting to the supervising remote station. Unfortunately, sudden power failure (battery disconnection) is too fast to be serviced correctly. In such case, however, the device configuration and the file system is fully retrieved after the restart.

Discussion

Except for satisfying the requirements of technical specifications for electrocardiographs, the recorder was evaluated in several applications including daily activity and intensive training of sportsmen. All the processing resources were used for the communication and adaptation, thus no data processing is performed 'on board'. Such approach, being a kind of limitation in specialized tasks, is in fact the advantage of our outcome opening wide area of application for this universal device. The recorder, initially designed for monitoring tasks in electrocardiology, was found useful as a simple uterine contraction detector and thanks to a wireless connection is believed to solve the very common problem of working women at risk of premature delivery. On the other hand, first results from the research in assessment of muscle fatigue in sports exercise makes possible an objective measure of human physical workload and optimal management of vital resources.

Several problems emerged during the design and testing of the vital signs recorder. A majority of them could be resolved by increasing the processing power. Unfortunately, it is not possible currently without the growth of power consumption, and therefore limiting the autonomy time. The second version of similar recorder, designed around the PDA computer, is already under construction in our laboratory.

Conclusions

The three channels recording device co-operating with a bi-directional wireless communication channel was developed and tested in our laboratory. Thanks to the 'transparency' to the signal, it may be used as a general-purpose vital signs monitor in home care networks with centralised interpretation intelligence. An important advantage of the recorder is the remote control of almost all its functions without relying on patient's skills in extreme circumstances.

Acknowledgment

This work was funded by AGH Univ. of Science and Technology, grant No: 10.10.120.39

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