Design of Very Precise and Miniature Low Power ECG Holter

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Abstract. *This paper presents design of very precise and miniature low power ECG Holter, which is enriched with sensitive 3D accelerometer, impedance measurement circuit, real-time clock, trigger etc. Total power consumption is optimized with respect to the best balance between performance and operating time. The work presents selected results demonstrating the high quality and universal usability of the proposed system.*

Keywords: ECG, Miniature, Low Power, Accelerometer, Integrated Respiration Impedance

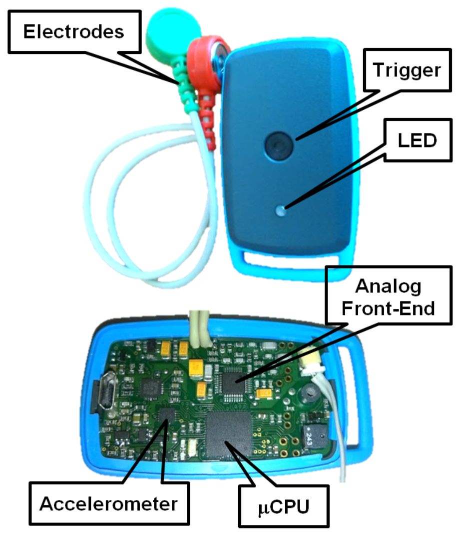
1. Introduction

Human healthcare is intensively dependent on prevention and early diagnostics. Hectic lifestyle of today's world however pushes people to overcome these health problems. The repercussions of hasty life style will be delivered years later and will also impact the average health of people living in modern world. In order to improve the overall home healthcare and peoples interest in their condition improvement, new smart systems and promising automated diagnostics methods are broadly being researched. Raising computing power of new microprocessors, production of novel low price integrated chips and continual development of measurable health parameters sensing technics influence the expansion of new integrated medical devices very positively. Devices for daily health monitoring are important for the end consumer, but also for many research groups [1, 2]. This paper introduces design of ECG Holter which uses latest advances in high-tech electronics. Except for very precise measurement features, which characterize this device (high gain, low noise, multi-probe measuring), some special features as low voltage and ultra-low power consumption were reached in order to achieve its longer performance for daily use. Following the requests of practice the Holter was enhanced by precise accelerometer, respiration measurement circuits, real-time clock, trigger button and optical and acoustic signalization. For online monitoring it is possible to build in a ZigBEE module and connect Holter wireless to PC or mobile phone.

2. Subject and Methods

The system (Fig. 1) is primary designed for 24 hour daily monitoring of ECG. It can be useful in many clinical applications including diagnosis of arrhythmias, ischemia, or heart failure. Thanks to built-in accelerometer and respiration monitor it can be also very helpful in telemedicine, sports and fitness, including event, stress and vital signs monitoring. The Holter is based on analog font-end ADS1292R, microcontroller ATxmega128A3 and acceleration sensor LIS3DH. The ADS1292R is 2-channel, 24-bit, delta-sigma analog-to-digital converter with a built-in programmable gain amplifier, internal reference, an on-board oscillator and respiration impedance measurement function [3]. The ADS1292R incorporate all features commonly required in portable, low-power medical electrocardiogram, sports, and fitness applications. Power consumption of one channel is only 335 μW. The ATxmega 128A3 is low power, high performance 16-bit μ-controller featuring 128KB flash program memory, 2048-Byte EEPROM, and up to 32 MIPS throughput at 32MHz. The device is capable of achieving extremely low power consumption, which is required by both portable electronics and battery-powered applications [4]. The LIS3DH is an ultra low-power high performance 3D linear accelerometer belonging to the “nano” family. The device features ultra low-power operational modes that allow advanced power saving and smart embedded functions [5].

All components were chosen on top state of the art with respect to the lowest power consumption while retaining the highest possible performance. Total power consumption of designed ECG Holter is 3 mA (on 250 SPS). By using standard 120 mAh Li-Pol battery the system allows operating time of 40 hours. Ideal working time (25 hours) can be achieved on 500 SPS. Thanks to microcontroller implemented HRV detection algorithms, ECG Holter can be switched in HRV mode (only HRV peaks are detected) for extended operation time of few days. Data is stored in CSV format to built-in 4 GB SD card, with possibility of conversion to +EDF format. The Holter is fixed to the human body using pre-gelled disposable Ag/AgCl electrodes. Optical signalization and trigger button is installed on the top of Holter. Acoustic signalization and micro USB connector for recharging, data transfer and parameter set is located on the reverse side. Holter is equipped with real-time clock for time-log management. The ECG Holter offers two low-noise, high resolution ECG channels, where one channel can be used for respiration monitoring, so the system allows simultaneousness multichannel signal acquisition of ECG, acceleration and respiration. The acceleration is measured 3D with 16 bit data output (standard system use mostly 8-bit only), where the sample rate is identical to sampling rates of ECG sensing. Respiration circuits are primarily concerned for monitoring of chest impedance, but as you will see, it can be easily modified for electro-dermal activity (EDA) monitoring. To get versatile system, gain and sample rate of Holter are selectable.



TECHNICAL PARAMETERS OF ECG HOLTER

Number of Channels	2
Programmable Gain	1, 2, 3, 4, 6, 8 or 12, Low-noise
ADC resolution	2x 24-bit, no data missing
Sample rate	125 SPS - 8 kSPS
MCU	16 bit AVR, 32 MHz SRAM 8 Kbytes EEPROM 2048 bytes
Built-In	Respiration
Acceleration sensor	3D, 16 bit data output, ±2g/±4g/±8g/±16g
Supply voltage	1x Li-Pol 120 mAh, over 24h stamina (on 500 SPS) charging time: 20min
Temperature range	0 – 70 °C
Electrodes	Disposable Ag/AgCl
Connectivity	Micro USB
Data storage	Integrated 4 GB SD card
Output data format	CSV, EDF+
Weight	20 g
Dimensions	37 x 25x 15 mm

Next features: RGB LED and acoustic signalization, trigger button, real-time clock

Fig. 1. ECG Holter design.

3. Results

Designed sensor system was tested on a wide range of experiments, where ECG parameters like: P, Q, R, S, T amplitudes, RR, PR, JT, QT, QTc time intervals, T wave symmetry, HRV spectrum and EDR algorithm were analysed in detail. As an example, simultaneous testing of designed ECG Holter to a reference device is presented in this paper. As reference device in all experiments NeXus-10 MKII from MindMedia was used. NeXus-10 is a versatile portable and advanced system for physiological research [6]. In Fig. 2 you can see ECG and respiration signal without any additional filtering or postprocessing. The electrode configuration is shown in Fig.2. During this phase of experiment, proband was in siting position. Both ECG signals offer high quality - clear QRS segment, P, T wave etc. The respiration signals are very similar. Small differences may be based on different physical principles. ECG Holter uses evaluating of impedance between two electrodes on chest top and reference system uses evaluating of the rib cage volume using standard chest belt.

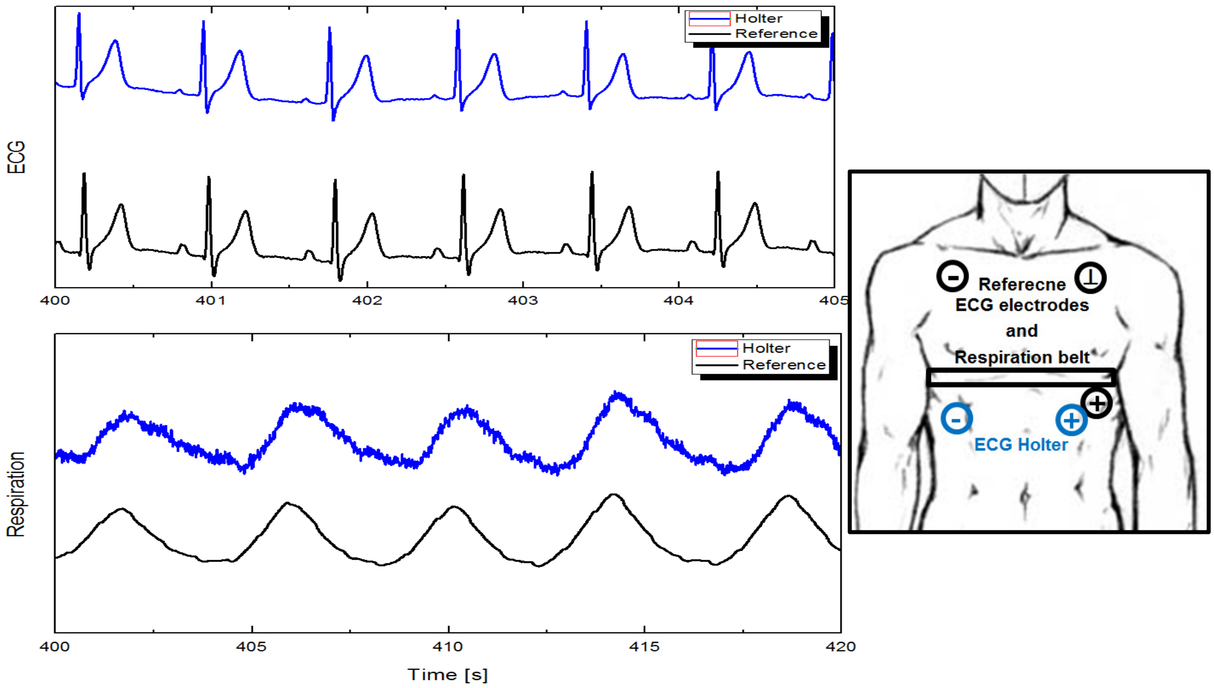


Fig. 2. Simultaneous testing: ECG and respiration signal.

As mentioned earlier, our ECG Holter has built in very precise 3D accelerometer. We can apply it for classical measurement of probands body movement and activity (Fig. 3). Using 16-bit accelerometer we can even measure more sophistic parameters, like cough pass and some brand new physiological parameters, like amyostasia monitoring (so called mechanomyography). If we measure ECG in chest area we can even monitor mechanical heart activity with implemented accelerometer (Fig. 3 - zoom). For example we found that time-shift between ECG and acceleration signal corresponds to physical or mental excitation of proband.

Integrated respiration impedance measurement function can be easy modified for EDA monitoring. We need only to remove DC signal part (Fig. 4). Using this simple method, when we use 2 separate channels (4 cable configuration), we can simultaneously monitor ECG and EDA, which is very often requested by psychology researchers. In Fig. 5 you can see our implementation of such system in SMART clothes. In the system we used commercial conductive fabrics and threads.

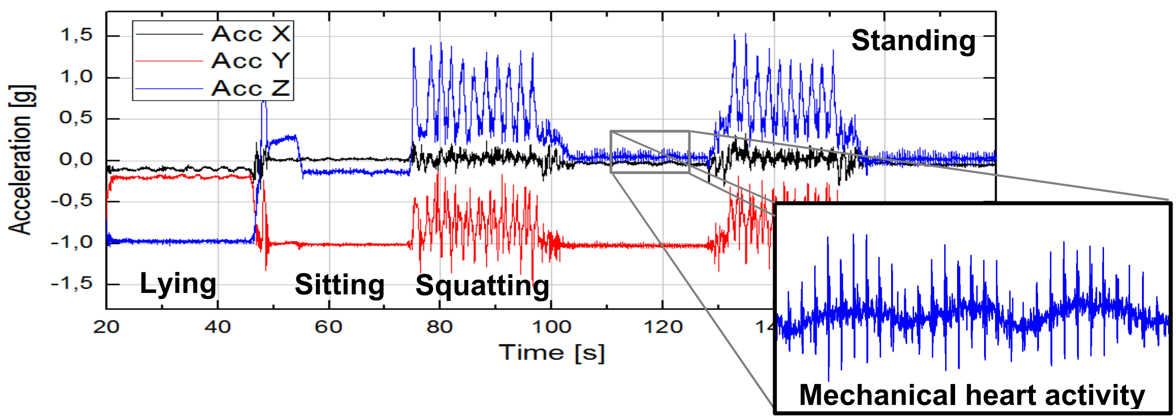


Fig. 3. Acceleration experiment with ECG Holter.

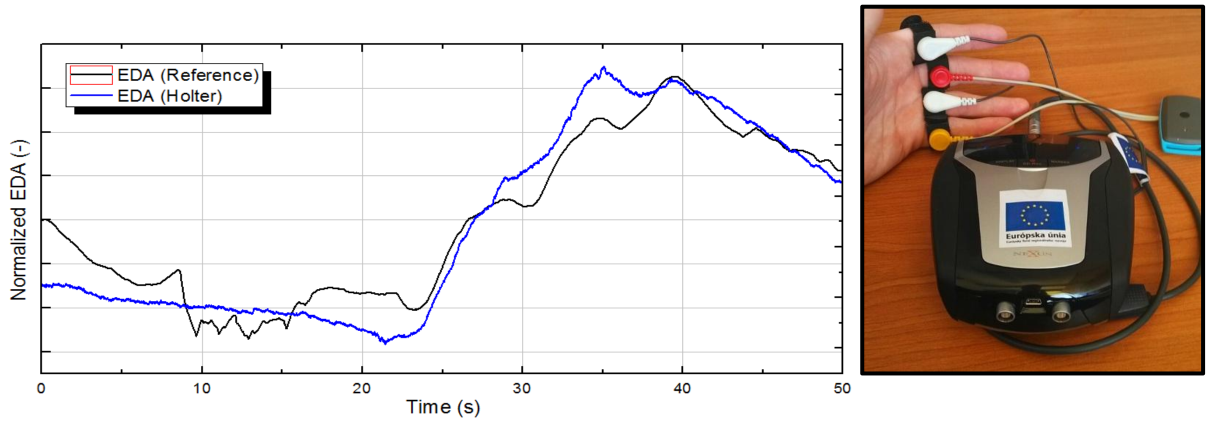


Fig. 4. Application of ECG Holter in EDA measurement.

4. Conclusions

Fig. 5. Smart T-shirt.

High quality and scientific potential of designed smart system was experimentally proven. Obtained results clearly proved high stability. Thanks to implementation of precise accelerometer, impedance circuit, real-time clock etc. is possible to use the Holter in more complex physiological experiment like standard Holters. Together with ultra-low power consumption the novel device is very suitable and promising for long-term testing and medical monitoring. There is also possibility of development of new healthcare diagnostic methods using developed ECG Holter. Integrated medical electronic system field provides great opportunities and continual developing potential for life quality enhancement.

Acknowledgements

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References

[1] Penders J, Altini M, van de Molengraft J, Romero I, Yazicioglu F, Van Hoof C. A low-power wireless ECG necklace for reliable cardiac activity monitoring on the move. In proceeding of the 33rd Annual International IEEE EMBS Conference, Boston, 2011.

[2] Chuo Y, Marzencki M, Hung B, Jaggernauth C, Tavakolian K, Lin P, Kaminska B. Mechanically Flexible Wireless Multisensor Platform for Human Physical Activity and Vitals Monitoring. *Biomedical Circuits and Systems*, *IEEE Transactions on*, 4(5): 281-294, 2010.

[3] Texas Instruments (2012). Low-Power, 2-Channel, 24-bit Analog Front-End for Biopotential Measurements (Rev. B). [Online] Available: http://www.ti.com

[4] Atmel (2014). Datasheet - 8/16 bit Atmel XMEGA A3U Microcontroller. [Online] Available: http://www.atmel.com

[5] STMicroelectronics (2010). MEMS digital output motion sensor, ultra low-power high performance 3-axes "nano" accelerometer. [Online] Available: http://www.st.com.

[6] MindMedia (2012). NeXus-10 MKII
[Online] Available: http://www.mindmedia.info/CMS2014