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Research Article

Pre-Processing of Multichannel Biomedical Signals Based on Information-Measuring Systems

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Abstract

In the paper has considering the possibilities of creating hardware and software of circuits, algorithms and software for processing and recognition of biosignals. And also, the creation of a circuit, algorithms and software for the system for picking up, processing and selecting biosignals. The aim of the research is to develop a method, an algorithm, and a complex of applied programs for automatic recognition of electrocardiographic signals to improve the efficiency of diagnostics of cardiovascular diseases. The object of research is systems for measuring, analyzing and selecting biosignals.

Keywords: Biomedical signal; Digital filtering; EEG; ECG; Gastrogram; Enterogram; Filter coefficient; visualization; Non-invasive method; Software; Interference suppression

Introduction

Biopotential (bioelectric potential) is a spaced electrical potential arising from the interaction of charges due to chemical reactions in cells. Back in the 19th century, it became clear that muscles, during their work, produce a certain amount of electricity. Subsequently, such biopotentials were recorded during the work of the muscles of the heart (myocardium), nerve and brain cells (neurons). The first electrocardiograms were recorded by Gabriel Lippmann using a mercury electrometer. The experiments were continued by Willem Einthoven [1, 4], proposing the basis of modern ECG systems - bipolar collection of heart biopotentials. The beginning of research related to the registration of brain biopotentials was laid in 1875 as a result of the discovery by Richard Caton of the determination of electrical signals on the surface of the brain of animals. Later, in 1924, Hans Berger, using a galvanometer on paper, recorded a curve describing biopotentials taken from the surface of the head using needle electrodes [3, 5].

With regard to the development of the elemental base, the emergence of new technologies, the equipment for recording and picking up biopotentials has also undergone a cardinal change. From mercury and galvanometric analog research low-quality systems to modern digital high-quality computer systems for functional diagnostics and rehabilitation [2, 6, 9].

Functional diagnostics by measuring biopotentials is a highly accurate non-invasive screening examination method and therefore is widely used. In this research, we were examined the creation of a circuit, algorithms and software for modern systems for picking up, processing and selecting biosignals [7, 10].

Related work

A significant part of scientific research in this area is devoted to improving biosignal processing algorithms and tools J.Pan, W.J.Tompkins, S.Malla, P.S.Addison, A.Oppenheim, F.Crea etc. In addition, R.Hemming, K.Blatter, D.Dajion, S.D.Kurgalin, S.M.Arbuzov, I.S.Gubarev, E.O.Ivanko and in a number of works has shown the effectiveness of using the ECG apparatus of the heart rate trajectory for automatic detection and analysis of physiological processes [5, 8, 10].

Anumerous of scientists and researchers of the Republic of Uzbekistan V.K.Kabulov, B.N.Khidirov, A.Abdukayumov, Kh.N.Zainidinov, J.X.Djumanov, U.R.Khamdamov and others, who contributed to the development of research in the direction of digital processing and diagnostics based on the recognition of biomed signal parameters [4, 5, 11].

Capture and pre-processing of biopotential signals mainly for data input of the biopotential meter was carried out in the following way. The quality of functional diagnostics and rehabilitation systems depends, first of all, on the quality of pickup of primary biosignals. The quality of the primary captured biosignal depends on the connection scheme, analog pickup and signal amplification. The input part of a modern biometer should consist of a simple, usually first-order RC low-pass filter (LPF) with an input circuit overvoltage protection circuit and a high-impedance (> 50..100MOm) buffer stage. The first requirement is determined by two factors, the resistance in the RC filter circuit limits the current through the overvoltage protection circuits, thereby protecting this circuit from failure, and the second factor limits the frequency range of the input signal by removing unnecessary high-frequency components from its composition. Since the subsequent analog-to-digital conversion has a comb (repeating) frequency response, which leads to a repeated overlap of the frequency range of the input signal i.e [12].

This filter acts as an anti-alizing filter, thereby eliminating aliasing or aliasing effects on the signal. Usually, biopotential removal (withdrawal) is carried out using a passive (cut with gold or silver or silver chloride) cutaneous electrode installed at characteristic points of the biological object. The electrode, in contact with the skin (epidermis), creates an additional resistance, which can be 10..100kOhm, therefore a high impedance (> 50..100 MOm) buffer cascade is required to remove the biopotential from this point without loss. Informative is not the absolute value of the biopotential at a certain point, but the difference of this potential relative to a certain reference (indifferent) point, which requires a differential (differential) amplification of the signal. A certain constant polarization potential appears at the contact points of the skin electrode, and the difference between these potentials. Can reach ± 300 mV with a minimum level of the useful biosignal of 1..100 μV [13, 4]. Therefore, a separating capacitor must be installed at the input in order to remove the DC component or provide a wide dynamic range of over-image (300+300)/0.001=600 000 ≅ 2^{20}) not less than 20 bits [5, 9]. Thus, the input part of any modern biopotential meter looks like in Fig. 1.

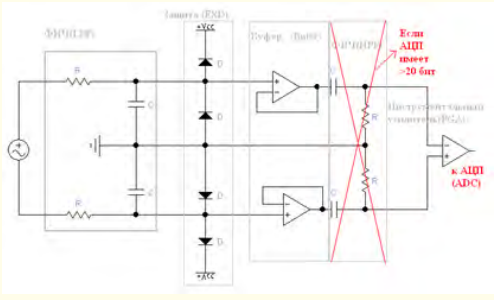

Figure 1: Diagram of the input part of one channel of the biometer.

Significance of the system

Using a sigma-delta ADC in a biometer first of all solves the problem of the input range. The DC component at the input of the biometer is compensated by additional bits of the sigma-delta ADC. The latter provides 19-20 significant digits in the required frequency band, that is, it covers the dynamic range of the input signal by at least 110 dB. It becomes possible to completely abandon the high-pass filter with its large-sized highly stable capacitors - a set of high-quality digital high-pass filters is implemented in software or, in general, the work is carried out with a zero lower frequency, which is typical of devices for scientific research.

The microcontroller used to register bio signals must have the ability to process digital signals (DSP), high speed, large memory and rich peripherals. This criterion is well met by 32-bit STM32 processors with the Cortex M4 (3) core of ST Microelectronics. In this implementation, in addition to a rich communication interface (USB, SPI, etc.), there is a real-time clock timer, an interface for the LCD module, an interface for the touch screen (touch panel), and an automatic direct memory access device (DMA) and the priority system of singing (Interrupt).

In modern bio-meters, the number of channels is 8 - 24 channels [5, 6]. With the development of technology for the production of very large integrated circuits (VLSI), a commercially available element base has appeared that implements the principle of sigma-delta (Δ-Σ) analog-to-digital conversion in one microcircuit with 8 channels, a fully (or partially) complete (front end) input part for implementation biometers [2, 5, 12, 14].

Table 1 shows the main parameters of these VLSIs. Of these VLSI, the most suitable due to its completeness and technical characteristics (Table 1) is the VLSI from Texas Instruments (Texas Instruments) ADS1299 [14]. This VLSI with a complete analog interface and sigma-delta ADC has a high resolution (24-bit), is largely based on the principles of digital signal filtering, which reduces the requirements for analog signal filtering and does not need to use instrumentation or other amplifiers. Application of ADS1299 as a multichannel biopotential meter and each of the eight inputs of this VLSI contains a differential patient's body (Fig. 2).

Thus, knowing the current (6 ± 1.2 nA) through the patient, you can evaluate the quality of the electrode connection to the patient (without taking into account the polarization potential of the electrode - skin, which in modern electrodes is a few millivolts), for example, (51кΩ+51кΩ)*6 nA≅0.6 mV (Fig. 2). PGA gain can be programmed from 1 to 24 times (1,2,4,6,8,12,24) and ADC sampling rate from 250 to 16000 times per second (250,500,1000...16000) at ADC clock frequency 2.048 MHz.

Specifications	***Name of VLSI***			
	ADS1299	***AD7768***	***LTC2448***	***RHA2216***
Number of differential measurement channels	8	8	8	16
Pre-Gain (PGA) [Size]	1,2,4,6,8,12,24	no	no	200
ADC capacity [bit]	24	24	24	absent
Maximum bandwidth (BW) [Hz]	0 .. 4193	0.. 110800	0.. 1696	0.02..20000
Average noise level given to the input (RMS Noise) [μV]	0.40(BW=524Hz), 1.66(BW=4193Hz)	1.85(BW=430Hz), 1.94(BW=3500Hz)	2.8(BW=430Hz) 23(BW=1696Hz)	2
Power [V]	5 and 3.3(or 3.3)	5 and 3.3	5	3.3
Power consumption per channel [mW]	5	9.375	5	0.5
Common Mode Rejection Ratio (CMRR) [dB]	120	120	120	85
The presence of the bias potential of the reference (indifferent) electrode (BIAS)	available	absent	absent	absent

Table 1: Table of the comparison of the main parameters of VLSI.

In the VLSI ADS1299, a mechanism for the combined operation of several ADCs for the creation of measurements with more than 8 channels (divisible by 8) is invented. To create a general bias of the potential of the reference (indifferent) electrode (BIAS), it is necessary to connect the BIASINV inputs for all VLSIs and turn on the power (Power UP) for the amplifier of the bias circuit in only one device from the output of which the signal is removed [14] (Fig. 3)

The control and transfer of the digitized data from the ADC of the VLSI ADS1299 to the host processor is carried out through the serial port interface according to the SPI standard to create a multichannel biometer (more than 8), it is necessary to cascade several ADCs of the ADS1299 VLSI as shown in Fig. 4 [13, 14]. The measured data of one ADC channel, consisting of 24 bits (3 bytes), is transmitted via SPI, in two's complement code, with the most significant bit at the beginning of the bit stream (MSB). The format of the ADC output code of one channel when the analog part is powered from +5 Volts and the reference voltage Uref = 4.5 Volts for different values of the PGA gain is given in Table 2.

As shown in Table 2, the full range (dynamic range) of the ADC measurement varies with the gain of the input programmable instrumentation amplifier (PGA) from ± 4.5 V to ± 187.5 mV. Also, the sampling step by signal level varies from ± 0.536 μV to ± 0.02235 μV. Of course, a high value of the gain factor provides a higher sensitivity (less noise), but at the same time the dynamic range of the ADC is reduced and the ADC can overflow ("off scale") due to a constant interelectrode potential or poor contact with the skin. In the continuous digitizing mode, data is transmitted via SPI in 24 bit packets consisting of a 24-bit packet status and eight 24-bit ADC samples (3 bytes status + 8 channels each of 3 bytes) = 3 * 9 = 27 bytes. If three ADCs of the ADS1299 VLSI are connected in series (Daisy chain), then the host processor for one SPI sampling should receive 3 * 27 = 81 bytes. In this case, the transmission rate of the SPI channel in the 500 samples per second mode must be more than 500 * 81 * 8 = 324000 Hz.

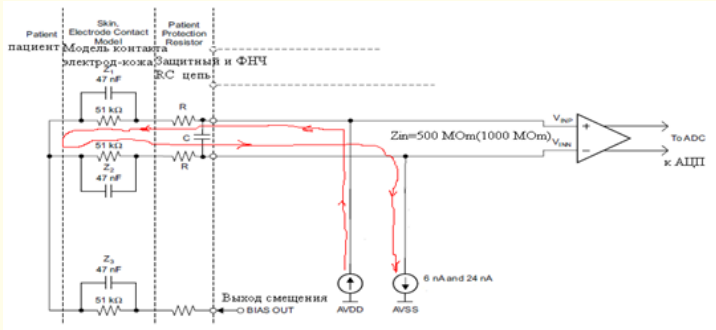

Figure 2: Diagram of an exemplary model of one channel of the created biometer based on ADS1299.

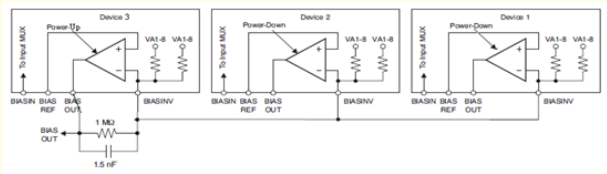

Figure 3: Scheme for creating a common bias signal (BIAS) of a multi-device (3 ADC devices) version of a biometer based on ADS1299.

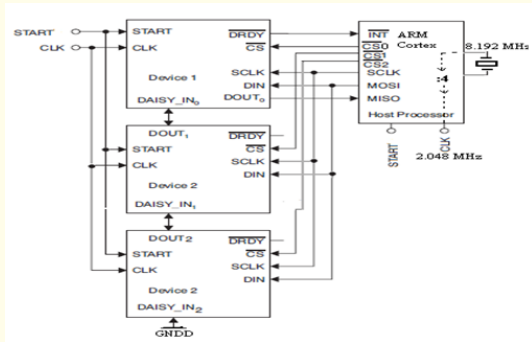

Figure 4: Daisy chain of several ADS1299s for control and data exchange between ADC and host processor via SPI.

The status of a packet consisting of 24 bits (3 bytes) has the following structure: 1100 (sync character) + 8 bits (state of the register of negative lead comparators LOFF_STATN) + 4 bits (state of GPIO ports). It is important to remember that after receiving this packet, you can always check the synchronization symbol and find out the correctness of data exchange between the host processor and the ADS1299 VLSI via SPI.

Coefficient of performance of PGA	*Input differential signal, VIN(AINP – AINN)*	*Ideal output code (Hex)*
1	≥+4.5 В	0x7FFFFF
	+4.5 / (2^{23} – 1)≅+0.536 мкВ	0x000001
	0	0x000000
	–4.5 / (2^{23} – 1)≅ –0.536 мкВ	0xFFFFFF
	≤ –4.5 (2^{23} / (2^{23} – 1))≅ –4.5 В	0x800000
8	≥+4.5/8=562.5мВ	0x7FFFFF
	≅+0.067 мкВ	0x000001
	≅–0.067 мкВ =6/89	0xFFFFFF
	≤ –562.5мВ	0x800000
12	≥+375 мВ	0x7FFFFF
	≅+0.0447 мкВ	0x000001
	≅–0.0447 мкВ	0xFFFFFF
	≤ –375 мВ	0x800000
24	≥+187.5 мВ	0x7FFFFF
	≅+0.02235 мкВ	0x000001
	≅–0.02235 мкВ	0xFFFFFF
	≤ –187.5 мВ	0x800000

Table 2: Correspondence of the value of the ADC output code for the limit values of the measured biopotential (excluding internal noise and nonlinearity of the conversion).

The digitized signal of biopotentials from the ADC pre-processed, stored and transferred for further processing and decision making to computer systems via USB or wireless (Bluetooth or WiFi). In a single chip (System-on-a-Chip, SoC) or single-chip microcomputers with digital signal processing (DSP) are well suited for these purposes. ST Microelectronics has released microcontrollers based on

the ARM Cortex-M3, STM32 core. These devices set new standards for performance and price, the ability to execute hard real-time control algorithms with low power consumption. STM32F4 is a Cortex-M4, which is a direct successor to Cortex-M3 (STM32-L1, F1, F2) and differs from it mainly in the core with the presence of DSP (digital signal processor) and FPU (floating point unit). The STM-32F407VET6 microcontroller meets all the above requirements and has 196 KB of RAM, 512 KB of ROM (FLASH), an ARM 32 Cortex M4 CPU core with a maximum internal clock frequency (Max Clk) of 168 MHz. As an LCD screen, a touch screen 2.4 TFT LCD 240x320 (240 * 320 = 76800 pixels) is used, which has an ILI9341 LCD controller and an XPT2046 touch function controller. This display through the parallel interface FSMC-controller STM32F4, easily connects with the microcontroller, providing it with a color (18-bit color = R 6 bits + G 6 bits + B 6 bits = 262144 colors) touch screen display with a diagonal of 2.4 inches. And the XPT2046 touch controller connects to the STM32F4 through one of its three SPI communication ports. Signals of biopotentials from the cutaneous electrodes go through the connectors to the "Protection unit" of the system (Fig. 8), which protects the hardware unit from electrostatic discharge. Then the signals go to the "Signal block", where they are amplified according to the algorithm, ensuring maximum sensitivity and analog-to-digital conversion. "Signal block" consists of 3 eight-channel ADCs with built-in differential amplifiers. The sampling rate is 500 Hz.

Also, this block generates a BIAS signal - the patient's potential. The "MK block" (microcontroller) controls the operating modes of the device. The signal in digital form comes here from the signal block, is processed, buffered and sent to the PC through the "Communication block". Also, the signal can be saved to a Micro SD memory card using the "Memory Block".

Conclusions and recommendations

As a result of the research, algorithms were developed, programs on the basis of which a multifunctional medical diagnostic bio-meter was built on the basis of a modern element base, measuring natural or induced biosignals.

The recommended VLSI with a complete analog interface and a sigma-delta ADC has a high resolution (24 bits), is largely based on the principles of digital signal filtering, which reduces the requirements for analog signal filtering and there is no need to use instrumental or other amplifiers.

And also, at the moment, as an effective technology, the use of digital diagnostics in virtual medical devices, having created with its help a multifunctional diagnostic system, will allow at the early stages to determine the risk factors for cardiovascular diseases by a non-invasive method. The production of such multifunctional medical diagnostic bio-meters can reduce material costs in production and, accordingly, reduce the cost of the product.

References

1. AAMI Standards and Recommended Practices, Biomedical Equipment. AAMI. Arlington, Virg. V. 2, 4th ed (1993): 230.
2. Analog Device. "8-Channel, 24-Bit, Simultaneous Sampling ADC, Power Scaling, 110.8 kHz BW". AD7768-7768-4 Data Sheet (Rev. B) (2016).
3. Bokeria LA. "Modern non-invasive diagnostic tool in cardiac surgery: a rational approach a brief way to diagnosis". Federal guide. Reducing mortality caused by socially significant diseases. Annals of arrhythmology 4 (2010).
4. Djumanov JX., et al. "Development of the method, algorithm and software of a modern non-invasive biopotential meter". Daegu, South Korea (2020): 24-26.
5. Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) (2021): 95-103.
6. Djumanov JX., et al. To the questions of the creation of a modern non-invasive biopotential meter. International Journal of Advanced Research in Science, Engineering and Technology 7.2 (2020).
7. Intan Technologies. "RHA2000 Series Amplifier Arrays". Datasheet (2010): 1-29.
8. Heart-vascular prevention. National recommendations 2011. Heart-vascular therapy and prevention 10.6 (2011).
9. Rajabov FF and Abdurashidova KT. Typical solutions for the construction of modern electrocardiographs (ECG). Tashkent, Tuit -Bulletit 2.46 (2018): 42-55.

10. Rajabov FF., et al. "The issues of creating a computer bio-measuring and noise suppression methods. Muhammad al-Khwarazmiy Descendants". Scientific-practical and information-analytical journal. Tashkent 1.3 (2019).
11. Ruttkay-Nedetski Problems electro cardiologic evaluation of the impact of the autonomic nervous system to the heart. Bulletin of arrhythmology (2001): 56-60.
12. Linear Technology Corporation," LTC2444/LTC2445/LTC2448/
13. LTC2449 - 24-Bit High Speed 8-/16-Channel ΔΣ ADCs with Selectable Speed/Resolution". Datasheet (2004).
14. Texas Instruments, "Low-Noise, 8-Channel, 24-Bit Analog Front-End for Biopotential Measurements ADS1299". Datasheet (2012).

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