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One-channel EEG monitor for tracking the depth of narcosis

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Abstract. Complications in designing of one-lead electroencephalographic (EEG) monitor for tracking the deepness of narcosis are discoursed. Connection between the level of narcosis and statistical attributes of the bioelectric signal is disclosed. Electric circuit of the developed EEG monitor is discussed. Obtained recordings of the EEG and ECG signals are shown.

1. Introduction

It is important for success of the invasive medical intervention to make the human body impervious to any form of external influence such as surgical incision or suturing. Narcosis has analgesic effect which prevents execution of spontaneous protecting mechanisms of the body and occurrence of the pain shock. For this reason local, regional and general narcosis became ubiquitous in clinical practice.

Local narcosis [1] is applied in particular for the analgesia of small organs or body tissue areas: in dentistry, odontology, cosmetic surgery, and also in military medicine (camp conditions). Regional narcosis is broadly similar to the local technique and used for the anesthesia of large organs: arms, legs, spinal column; also during the cesarean section.

In case of complex life-critical surgical intervention the general narcosis is implemented. General narcosis leads to myorelaxation, deceleration of the neural activity, absence of pain and loss of memory (amnesia) during operation. During the surgical operation with general narcosis it is necessary to control the arterial pressure, oxygen saturation of blood, body temperature, chemical composition of the inhaled and exhaled gases (capnogram monitoring in particular), and also to record an electrocardiogram (ECG) and electroencephalogram (EEG) [2].

2. Problem statement

General narcosis requires the monitoring of the depth of unconscious state, in which is immersed the nervous system to promptly define anesthesia awareness during operation and also to prevent critically deep coma [3] [4]. However the deepness of narcosis can be determined only by means of the specialized clinical accessories.

This task can be resolved with the usage of the electroencephalographic signal (EES) that reflects the state of the brain neurons. When the depth of narcosis is increased, the band of the EES moves lower through the axis of frequencies due to intensification of the delta rhythm. The delta waves features magnitude in the order of hundreds of microvolts and typical band from 1 to 4 Hz. Computer aided identification of the narcosis stages requires estimation of the entropy of the EES in frequency and temporal domains and normalization of the calculated values to a unified measure [5–7].

One of the measures that became de-facto standard in clinical monitoring is the Bispectral (BIS) Index, established by Aspect Medical (now part of Covidien) [8]. The algorithm which used to compute BIS index discovers the correspondence between various harmonics in the EES [9]. Specifically, BIS index reflects the level of synchronization between the sine waves in the EES, along with the conventional Fourier spectra of the signal.

Another commonly used measure is the Entropy index – a statistical attribute of the signal evaluating the state of chaos in the EES [10]. In accordance with the Entropy's approach, the EES is not a simple combination of the harmonic waves but a nonlinear, stochastic system. The Entropy index exploits several statistical methods: Shannon [11], spectral [12] and approximate [13] entropy. A mass-produced Entropy monitoring module was developed by Datex-Ohmeda (GE Healthcare) [14].

In [15] was justified that both the BIS index and the Entropy are adequate methods to define current depth of sedation and to discern the different levels of narcosis.

3. Proposed solution

A professional multilead EEG monitor is not an indispensable instrument for recording the EES with the goal of acquiring data for tracking the level of narcosis. It is quite satisfactory to employ the EEG monitor with just one bipolar lead recording the electric potential difference of two electrodes installed on the forehead. The third electrode is applied as a reference point and connected to the earlobe.

Electric circuit of the designed one-lead EEG monitor (figure 1) includes several stages: high common-mode rejection instrumentation amplifier INA333 with several pull-up resistors ($R_{\text{pull-up}}$) and the gain resistor R_G, common-mode voltage buffer [16–18], 0.2 Hz low-cut filter, mains hum rejection filter [19], 150 Hz roof filter, and a successive approximation voltage-to-code transducer the serial data output [20]. The power supply for this circuit includes two accumulators (each has typical output voltage of 3.7 V). First accumulator is connected to the EEG monitor and discharged, thus provides long-play energy source for stable functioning of the device. Meanwhile, the second accumulator gathers the electric charge from the mains power line through the charging unit composed from a step-down transformer and diode rectifier (charging voltage of 4.2 V). When the output voltage of the first accumulator is reduced to 3.3 V, the EEG monitor is switched to the second full charged accumulator; herewith the first accumulator is switched to the charging unit. This charging technique provides reliable noise-free source of electric power and ensures the galvanic isolation of the EEG monitor from the industrial power line [21].

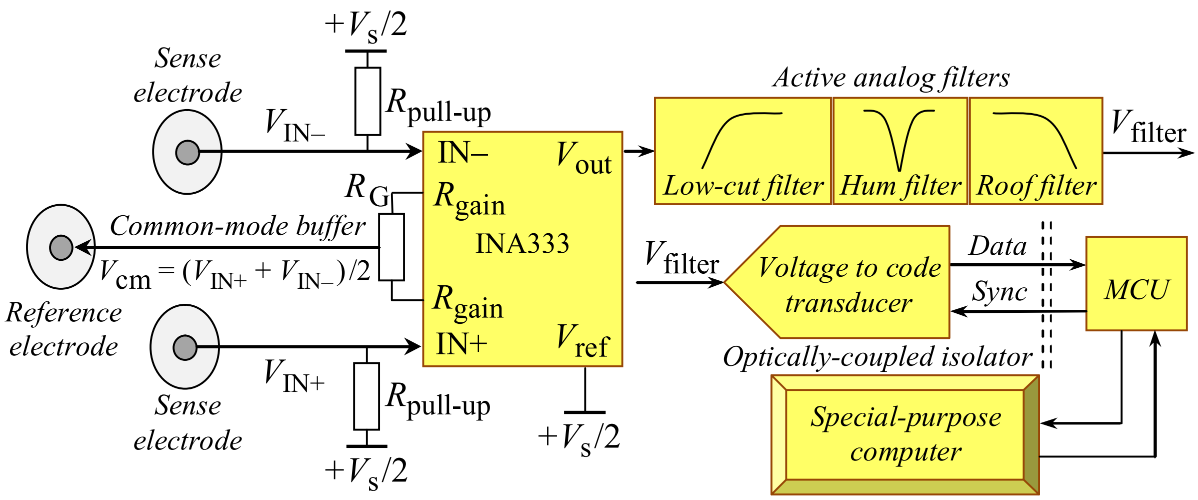

Figure 1. Components of the EEG monitor

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The EEG monitor is connected via optically-coupled isolator to a microcontroller (MCU) with the core based on the ARM Cortex M3 architecture. The EES transformed by the voltage-to-code transducer from the analog field to digital domain is received by the MCU and reconfigured into data stream suitable for the RS-232 standard. Then MCU transmits EEG data to a special-purpose computer with the Qseven Conga-QMX6 (ARM Cortex A9 core) controller board running Linux-like operating system. The program running within Linux environment computes the entropy index of the EES and displays how this index is changed over time [6] [7]. Computed entropy index as a function of time, the EES recording itself and the Fourier spectra of the signal are contributed to making the right estimation of the required concentration of anesthetic agent during operation.

4. Discussion of results

With the aim to verify the functionality of the designed EEG monitor the acquisition of the EES and also the ECG signal (ECS) was conducted; the recordings of the received signals are shown below. Sample frequency during the experiment was 2 kHz: it is more than enough for applying of the moving average filter (32 points for the ECS and 16 points for the EES). The all waves of the PQRST-complex of the ECG [22] are clearly visible in figure 2. The EEG registered on the test subject with open eyes (figure 3) contains waves with higher frequencies than the EEG recorded in case of closed eyes (figure 4). Low disturbance superposing the acquired EES includes the mains hum 100 Hz and 150 Hz waves accompanied by small amount of thermal and fluctuation noise. The software adaptive algorithm could be exploited to reduce the level of noise over the signal.

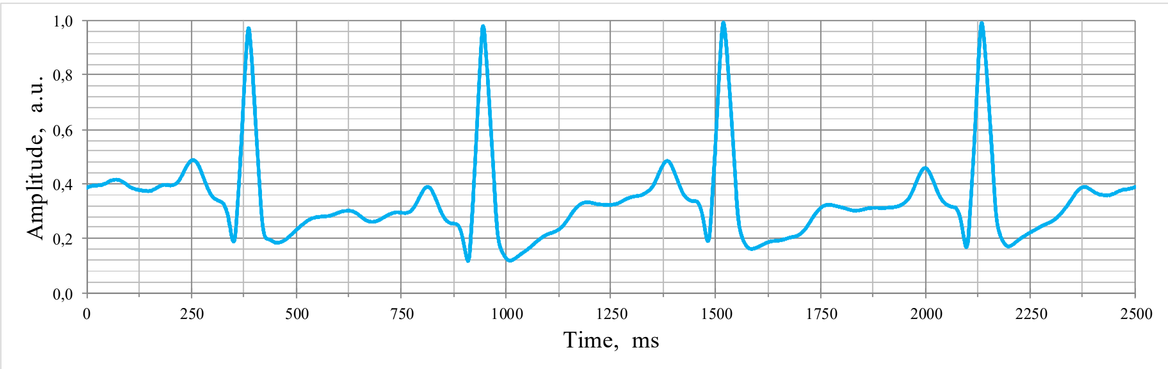

Figure 2. Fragment of the ECS record

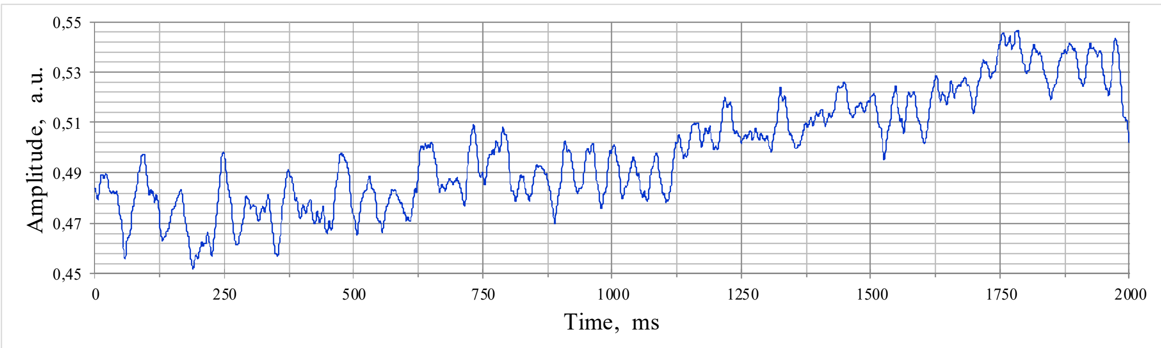

Figure 3. Fragment of the EES record (eyes open)

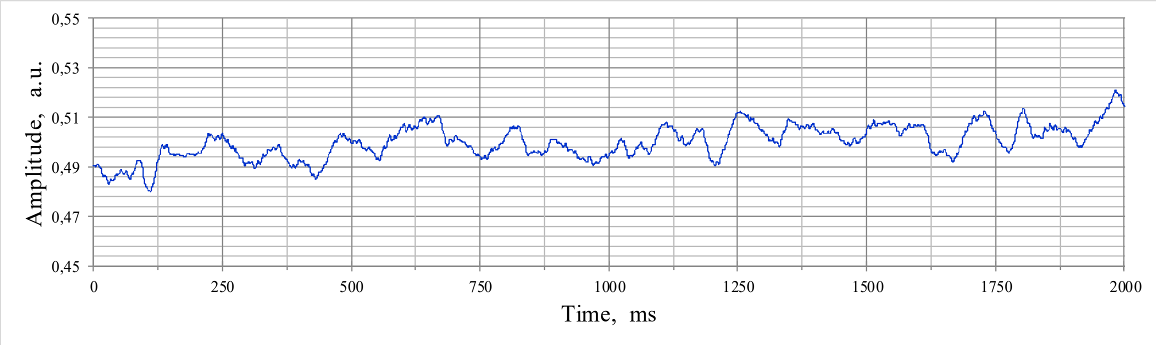

Figure 4. Fragment of the EES record (eyes closed)

5. Conclusion

Designed EEG monitoring module allows continuous and reliable recording of the bioelectric activity of the human body such as EES and ECS. It is assumed to integrate the developed EEG monitor into the narcosis monitoring module «Sapus» which is produced by the research and manufacturing facility «Red Guardsman» located in St. Petersburg, Russian Federation.

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