Single-channel electroencephalograph for monitoring the depth of anaesthesia

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Abstract. Peculiarities in development of single-channel electroencephalograph for monitoring the depth of anaesthesia are discussed. Relation between the depth of anaesthesia and different parameters of the electroencephalographic signal is shown. Structure and features of the developed device are described. Results of device’s testing are presented.

1. Introduction
It is necessary during surgical procedures to make the patient insensitive to any kind of external impact. Anaesthesia prevents the appearance of pain sensations and associated physiological protection mechanisms that hinder the surgical intervention [1]. Usually there are local, regional and general anaesthesia. The last type of anaesthesia is associated with the inhibition of human consciousness that presents in the lack of pain sense, muscle relaxation and memory loss at the time of surgery.

2. Problem definition
Usually it is necessary to control blood pressure, peripheral capillary oxygen saturation and also to record an electrocardiogram during anaesthesia. In case of general anaesthesia it is extremely important to monitor the depth of artificial sleep, in which is immersed the patient to prevent as sudden awakening during surgery as well as excessively deep narcosis [2]. The main difficulty is that the depth of anaesthesia is not discernible without special medical equipment.

This problem can be solved with the use of electroencephalographic (EEG) signal that reflects the activity of the brain. In a state of deep anaesthesia, the spectrum of the EEG signal is shifted to the low frequency range due to the delta rhythm emergence. The delta rhythm has relatively high-amplitude (around a hundred µV peak-to-peak) harmonics with frequencies less than 4 Hz. Automated determination of the depth of anaesthesia involves calculation of different parameters of the EEG signal in time and frequency domains and reduction of the obtained values to a single scale [3].

One of the scales that used most often in clinical practice is the Bispectral Index (BIS), developed by Aspect Medical Systems, Inc. [4]. BIS analysis is a method which explores the correlation between the different sine waves in the signal [5]. In particular, BIS analysis quantifies the level of synchronization in the EEG signal, along with the traditional frequency and amplitude parameters.

Another frequently used scale is the Entropy which is a statistical parameter representing the order of chaos in the EEG signal [6]. Regarding the Entropy’s methodology, the EEG signal is not just a
summation of sinus waveforms but a chaotic, nonlinear system. The Entropy scale utilizes following algorithms: the spectral entropy [7], the approximate entropy [8] and the Shannon entropy [9]. A commercially available Entropy monitor is produced by General Electric Healthcare (formerly by Datex-Ohmeda [10]). It has been shown [11] that both the Entropy and BIS are similar and reliable indices to detect different sedation levels and to distinguish between the steps of anesthesia.

3. Suggested solution
Registration of the EEG signal with the aim of obtaining information for monitoring the depth of anaesthesia does not require the use of a multichannel electroencephalograph. It is sufficient to use the device with a single bipolar channel, which registers the difference between two potentials on the frontal region of the scalp. Electric potential of the mastoid process is used as a reference.

Developed EEG monitor (see figure 1) consists of an input stage with instrumentation amplifier, several active analog filters [12-14] (lowpass, 50/60 Hz notch and highpass), and an analog-to-digital converter (ADC) with serial interface.

![Figure 1. Structure diagram of the EEG monitor.](image)

The device is powered by two lithium-ion batteries, one of which is connected to the electroencephalograph and ensure its operation, and the second is charged from an external power source. When the first battery runs out, the device is connected to the second charged battery while the first battery is connected to an external power source for charging [15]. This method provides safe power supply with very low noise.

The electroencephalograph via the serial interface with galvanic isolation and then via a general-purpose microcontroller is connected to an application-specific computer based on an embedded processor module. The microcontroller serves as a bridge: serial synchronous data stream from ADC is converted to most convenient form for reception. For example, universal asynchronous receiver-transmitter interface lets simply receive data by means of virtual communication port driver installed on computer.

The computer software calculates the parameters of the EEG signal and displays the coefficient corresponding to the depth of anaesthesia [16]. Calculated coefficient together with the EEG signal...
recording helps the anaesthesiologist to determine the necessary dose of anaesthetic and thus prevents the negative outcomes of the surgery.

4. Results and Discussion
In order to examine performance of the developed device the electric cardiac signal (ECS) registration was performed. The electrocardiogram (ECG) which was obtained in the course of the experiment is presented in figure 2. The upper part of the R-peak [17] is cut due to high magnitude of the input ECS (in comparison with the EEG signal), low supply voltage and high overall gain \(2.5 \times 10^3\), which in total cause short-time saturation of the output stage’s operational amplifier. Weak noise modulating the recorded ECG consists of 50 Hz and 100 Hz harmonics supplemented by practically negligible thermal noise. Signal-to-noise ratio can be increased with digital processing, e. g. with the transversal and averaging filters.

![Recorded ECG](image)

**Figure 2.** Recorded ECG.

5. Conclusion
Developed EEG monitor provides accurate and reliable registration of biomedical signals. This device will be used as part of the anaesthesia breathing system «Orphey» manufactured by PJSC «Krasnogvardeets» (Saint Petersburg, Russia).

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