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Embedded EEG signal acquisition systems

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Abstract

The aim of this work is to present newly developed electro-technological and signal processing EEG signal acquisition systems with increasingly advanced functions. EEG Electroencephalogram (EEG) signals are the recorded potentials of the collective activity of synchronized cortical cell populations chained to an external system.

Keywords: EEG; Smart Active Electrode; Wireless Embedded System; Signal Processing; BCI;

1. Introduction

The recorded biological signal conditioning is a successive analog and digital transformation. These transformations are necessary to provide signals for efficacious signal processing and pattern recognition methods. Electronic devices used in conditioning procedures should not influence or should influence in a controlled manner the useful components of the signal [1], [2], [3]. It is necessary to eliminate the noise as much as possible in a way that keeps the integrity of the biological frequency range of the significant oscillations [5]. One of the most important subsystems in signal conditioning is the use of the amplifiers or pre-amplifiers [6]. The amplifiers have the aim to increase the power of the signal, to a level useful for the following steps of conditioning. The amplitude of the recorded bio-signals is very low (of μV order) and the value of signal-to-noise ratio (SNR) is low as well. The different types of noise are superimposed on gainful components. The gainful components are carrying the necessary information for further visualization or control tasks [7]. The different noise types are connected to secondary (not considered important here) biological events, to the noise generated by electronic devices (probabilistic dislocation of electric charges within electronic components) and also to the noise generated by the

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biological tissue-electronic contact (their relative dislocation) [8]. Moreover, the variation of the external electromagnetic field has its own contribution to the perturbation linked noise level. In all recordings and signal conditioning methods we must consider the effect of the 50Hz noise of power suppliers [10]. An important objective of this paper is to describe the improvements of the EEG signal acquisition systems using efficient signal conditioning proceedings (increased amplification factor and SNR value).

2. The structure of the measuring chain

The quality of the used methods and solutions in bio-signal processing, ensure the efficacy of the proposed information extraction. The structure of a recording technology has five modules (see Fig. 1):

These modules are:

1. The electrodes used in bio-signal recordings must satisfy three quality conditions: the polarizing tension between metal (electrode) and skin (scalp) must be as low as possible, the contact impedance must be as low and stable as possible and the fluctuation in time of the polarization of an electrode must be much reduced [12].

2. Analog conditioning of bio-signals: it is achieved by using a chain of amplifiers and analog filtering devices with an effect upon the basic parameters of a bio-signal (amplitude and frequency). The main goal is to create the optimal parameter structure for the whole measurement chain (including the analog-digital converters, and the reduction of noise, caused by the electrodes).

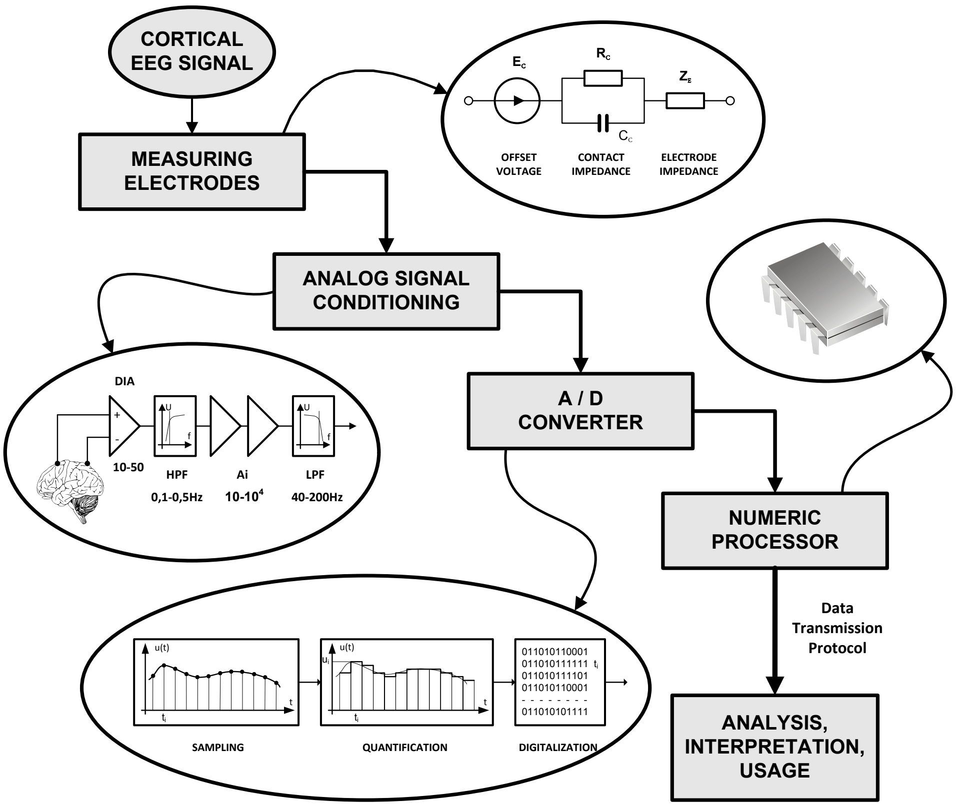

Fig. 1. The structure of EEG signal recording methodology

The analog chain contains a differential pre-amplifier, a high-pass filter and levels of low-pass filters [13]. The quality conditions for the pre-amplifier are: the common-mode rejection ratio of a differential amplifier (CMRR) as high as possible and a low value of the offset of current drift. A high amplifying factor is expected from the successive levels of the amplifier, a low distortion of phase and amplitude of the signal and, if it is possible, a galvanic isolation of the patient and the rest of the recording equipment. The analog filters must limit the frequency band of the signal. This is important for the analog-digital conversion and to eliminate noise, interference and parasite (alien) signals.

3. Digital conditioning of bio-signals: The first step in digital conditioning is made through the analog-digital converter. This transforms an analog signal into a digital one using a properly defined sampling frequency. The used steps are: the sampling (in time), quantification (discrete values of amplitude) and digitization (binary code consideration for samples). The two main parameters are the sampling frequency and the binary resolution. The sampling frequency (Shannon theory) must be, within a limit as big as possible to constrain the quantification (rounding) error. The binary resolution must be big to reduce the digitizing (truncation) error and also to reduce the amplification coefficient of the analog chain. At this time, there is only one type of analog-digital converter able to provide a comparably big resolution asked by bio-signal recording expectation. This is based on the principle of Sigma-Delta modulation, over-sampling of the signals and the use of low-pass digital filters with decimation. The over-sampling of the signal can scatter the noise components upon a bigger sampling band. Within this band the noise power will be distributed to higher frequencies and the noise power within the bio-signals useful frequency band becomes considerably lower.

4. Numeric processor: pre-processes the digital signals. This is important before sending them to a central module for analyzing storage, interpretation and global use of information. The basic functions used at this level are: the use of spectral analysis for information identification, digital signal processing based on mathematical algorithms and signal compression. It is important to reduce the transmission time of the information from the bio-signals [8]. Another task of the numeric processor is to integrate the signal acquisition and processing and send it to the information users. One of the most important parameter of the numeric processor is its capability to perform in real-time.

5. A communication channel must be used to send the information to its user. A proper and efficient data communication protocol is thus necessary. This channel must work in real-time, must provide an optimization of the information (data, in its written form) and must create the possibility of the use of secure information. It is also important to consider the utility of mobile EEG recording, processing and interpretation systems (wireless communication procedures) [9],[11].

3. Development of smart EEG sensor network elements

From the point of view of the electronic components (structure) an electrode used in a noninvasive recording procedure (electrode positioned on scalp) can be classified in the following categories:

a) Passive recording electrode: It lacks active electronic components. It is a passive element in contact with the scalp, sending signals to the conditioning electronics usually placed at a distance from the recording position.

b) Active recording electrode: It contains in its structure some of the recorded signal conditioning electronics

c) Intelligent sensor: Next to the incorporated analog and digital conditioning circuits of the recorded bio-signals, there is a signal processing unit based on a micro-controller of small or medium complexity. This processor provides the intelligence of the measuring technique.

d) Independent nod of recording: It contains the components described under point c.), plus an incorporated wireless communication subsystem of the acquired data based on our own communication protocol also incorporate in the firmware.

e) Intelligent recording module: It contains the components described under point d.), plus a circuit and protocol used in an auto-test and auto-scaling procedure of the module and a subsystem to modify the basic technical parameters (amplification coefficient, frequency band, poles of the filters, sampling frequency, etc.).

In the following some achievements are shown for modules belonging under the b.) to e.) descriptions, as a result of the NSRG group activity.

Fig. 2 is a block diagram of the concepts under b.) description of an active recording electrode. It has incorporated the analog signal conditioning electronics of the recorded signal and the analog-digital convertor sub-system.

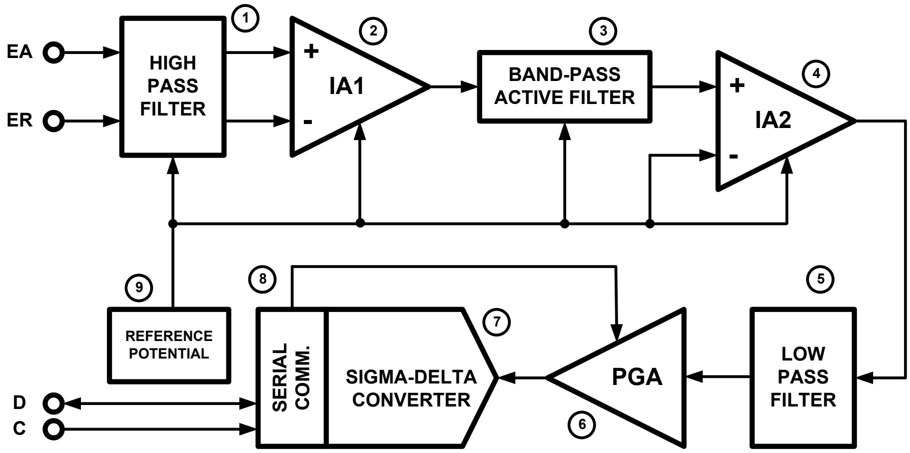

Fig. 2. Active recording electrode for EEG signal recording

The active recording electrode contains nine functional modules. The recorded bio-signal at the input of the circuit (EA, EB) is amplified by a high-pass filter (1) followed by an instrumental differential amplifier (2) as the next processing component. The elements (3) and (4) are another structure of active band-pass filter followed by a differential instrumental amplifier. The band pass filtered signal is applied to the positive input of the amplifier. To the negative input of this amplifier (4) a reference potential is connected, generated by the module (9). The output of this amplifier is connected to the input of a low-pass filter (5). The input of a programmable gain amplifier (6) is the output of the low-pass filter (5). The output of the programmable gain amplifier is the input of an analog-digital, Sigma-Delta converter. The output of this converter is the output of the active recording electrode using a serial data communication. The output signal is used in programming the amplifier with programmable gain. The module (9) is generating the reference potential for the analog conditioning of the bio-signal.

Fig. 3 is a block diagram of the concepts under c.) description of an intelligent sensor. The basic difference to active recording electrode is the module CPU (10). This electrode type contains 11 main modules.

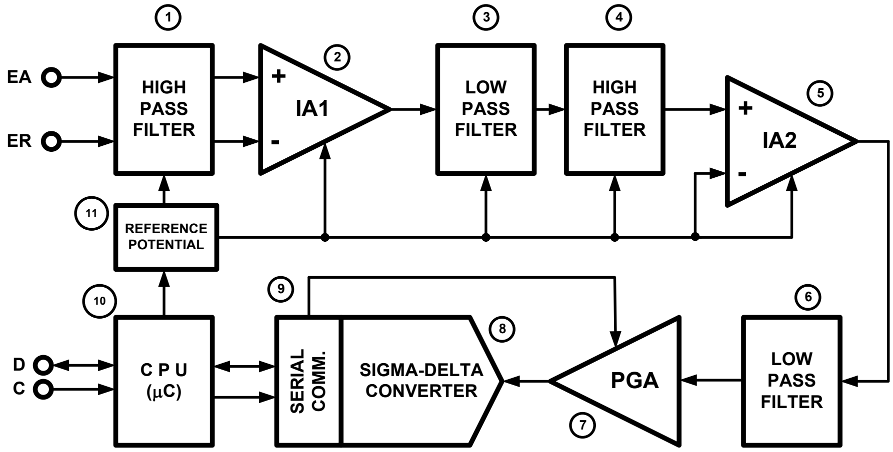

Fig. 3. Intelligent sensor for EEG recording

The modules chain from (1) to (9) differ from the structure of Fig. 2 in realizing the active band-pass filter (3) from active recording electrode bloc structure with a low-pass (3) and a sequential high-pass (4) filter (see Fig. 3). The output signals of the converter (8) are at the input of the CPU - central processing unit. This CPU is programming the PGA. This central processing unit also generates the reference potential (11) necessary for the analog conditioning channel. The CPU has a serial communication with a higher logical level to send the processed data. It is also the source of internal control, synchronization and command signals.

Fig. 4 is a block diagram of the concepts under d.) description of an independent nod of recording.

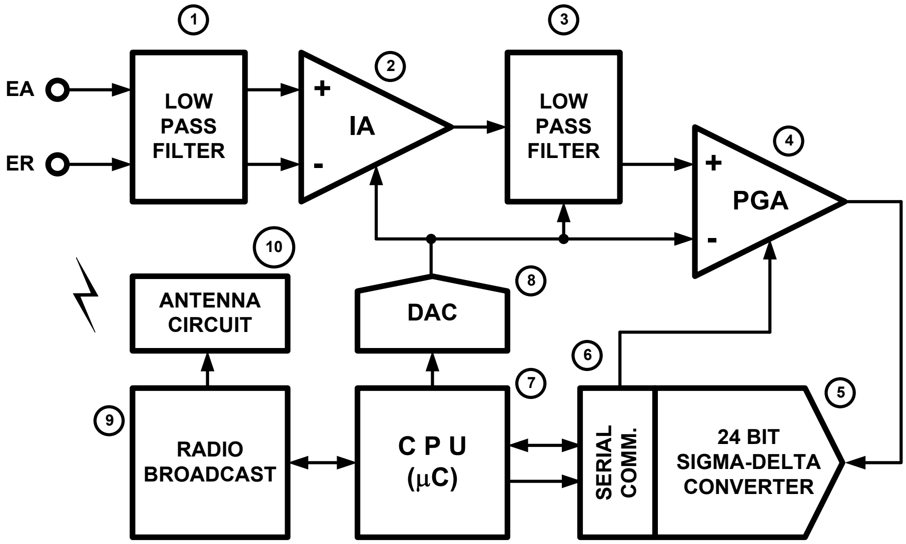

Fig. 4. Independent, intelligent nod to measure EEG signals

It contains the analog conditioner circuit of the recorded biosignal, an analog-digital convertor, a central processing unit and a wireless data transmission module. Each of these modules are incorporated in the electrode capsule. This type of intelligent electrode has 10 functional modules. The module (3) is a low-pass filter. The output of this filter is at the positive input of a programmable gain amplifier (4). To the negative input of this amplifier, is connected a reference potential provided by a digital-analog converter (8). The output of the programmable amplifier (4) is the input of an analog-digital Sigma-Delta convertor (5). The output of this converter is for the input of CPU module (7) interconnected with two channels. Based on these signals the reference potential can be provided to the programmable amplifier (4). The CPU has a serial communication with the radio transmission module (9). Through a wireless protocol, using a antenna circuit (10), the data and control, synchronization and command signals are transmitted to a higher logical level.

The diagram of 14 functional module blocks on Fig. 5 is presenting an e.) type of intelligent EEG signal recording module. It contains an analog signal conditioning module, an analog-digital conversion, a central processing unit realized with a micro-controller and a wireless data transmission module. An auto-test and an auto-calibration module are included, incorporated in the electrodes module.

The input signal is used at the input of a low-pass filter (1). Its output is the input of an instrumental differential amplifier (2). The output of this amplifier gets through a band-pass active filter (5). The output of the active filter is applied to the input of an electronic switch (6). The instrumental amplifier (2) has a feedback reaction (4) realized with an integrator circuit based on an operational amplifier. The common mode signal generated by the instrumental amplifier is used at the negative input of an operational amplifier (3) generating the reactive DRL signal. On the second input of the switch (6) the recorded signal is connected (EA1). The output of this switch is the input of a programmable gain amplifier (7). The output of this is one of the inputs to a Sigma-Delta analog-digital converter (9).

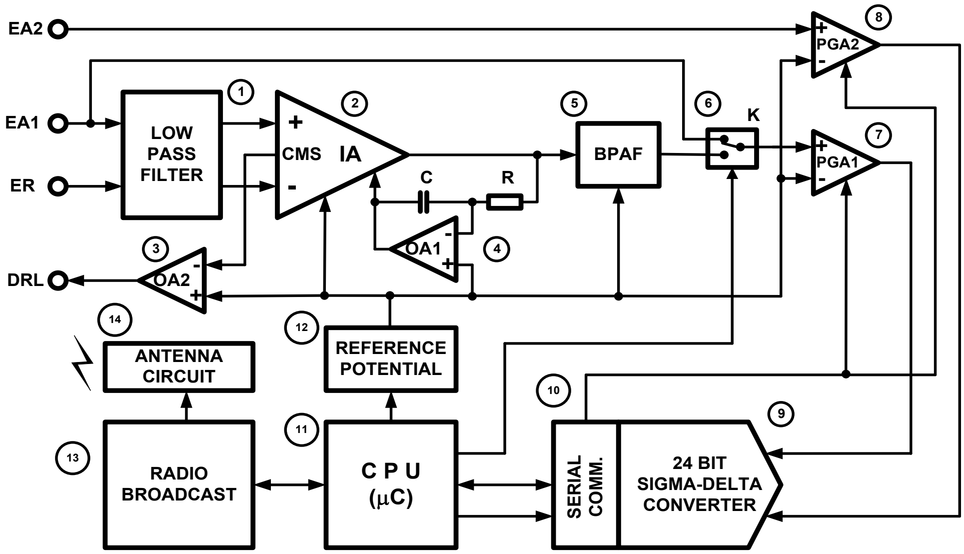

Fig. 5. Intelligent module of EEG signal recording.

The signal recorded by an auxiliary electrode (EA2) is connected to the input of another differential amplifier with programmable gain (8) and its output is the second input to the analog-digital converter (9). The dates from the output of the converter are forwarded on two serial transmission channels to the central processing unit CPU (11). The setting of the two programmable gain amplifiers (7) (8) is achieved this way. The CPU is controlling the reference potential (12). This reference potential is providing the analog conditioning of the recorded bio-signal. It is also applied to the negative input of the two programmable amplifiers and also to the positive input of the (3) module. The CPU is communicating on a serial way with the radio transmission module (13), in connection with the antenna circuit (14). This is the way to transfer data, control, command and synchronize signals. In the same time, CPU is controlling the electronic switch the analog-digital converter and it realizes the auto-test and auto-calibration protocols.

4. Conclusions

The basic solutions by the NSRG group researchers in EEG bio-signals recording project are the following: Strong rejection of the 50Hz noise of the power supply and of the common mode noise signals. The high impedance cables, another significant source of noise, were also eliminated. The saturation of the amplifiers due to the artifact signals at their input was corrected. The noise generated by analog channels was significantly reduced similarly to the noise generated by the quantification procedure. It was possible to maintain the high level and symmetric value impedance of the differential amplifiers of bio-signals. The wireless communication is also a very important realization. For experiments with sampling rate of 2000 sps, we achieved: CMRR 123dB and global input noise 0.9μVpp.

These procedures have other advantages, such as:

- the possibility of calibrating the offsets of the inputs, the calibration of the voltage amplification, and the possibility to measure the impedance of skin-electrode contact.
- the possibility to utilize the different modules in different applications in case there are necessary specific values for potential amplifications with a low number of passive components
- an easy possibility to interface the electrodes with other digital equipments
- an easy way to integrate and miniaturize making it usable in portable recording systems
- the possibility to integrate such a bio-signal recording module into a BCI (Brain Computer Interface) dedicate system.

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