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COST EFFECTIVE FLEXIBLE MODULAR SYSTEM FOR ACQUISITION AND PROCESSING OF BIOLOGICAL SIGNALS BASED ON ADVANCED SIGNAL PROCESSING

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Abstract: Measurement of signals from biological objects usually requires complex and expensive system. This paper presents a simple, cost effective, computer controlled modular systems consisting of self developed modules and modules from a few vendors and own software developed in LabVIEW. The system enables multichannel data acquisition with sampling frequency a few kHz with nearly unlimited lengths, triggering and pretriggering records. The records are stored in signal database and processed by software in PC using various advanced digital signal processing methods for recovering distorted signal. The system was developed and has been used for biological experiments on rats focused on evoked potentials.

Keywords: DAQ, biological signal, LabVIEW, digital signal processing, evoked potential, biological signal, waveform recovering.

1. INTRODUCTION

Studies of physiological processes in live biological objects require also to measure electrical potentials and currents of excitable tissue. Each living cell maintains some electrical potential on its membrane, called membrane potential. This potential can vary during cellular activity; these changes are induced by currents flowing through the cell membrane. These biological potentials and currents can be measured. The most common signals recorded from biological objects in experiments as well as in clinical practice are electrical signals generated by activity of the heart (electrocardiography, ECG), the muscle (electromyography, EMG), and by the brain (electroencephalography, EEG). Depending on the study, the recorded signals can be spontaneous (ECG), or evoked by some kind of stimulus. The later signals are called evoked potentials (EPs), and they are on the main focus of our paper. Simple definition of EP is that it is response to certain stimulus. EPs are used to study integrity and function of different pathways in the body, such as visual, auditory, motor and somatosensory pathways. According to the type of studied pathways, the stimuli can have different modalities; they can be electrical, sound, visual, etc. [2]. The special type of EPs are the event related potentials, which are the responses of brain to internal or external stimuli as a direct manifestation of thinking or perception. They could be prospectively used for communication of fully paralyzed people with external world. Experimental system for the most of EPs is required to generate or activate a stimulus, which is also the trigger event for acquiring response, with following processing and archiving.

Evoked potentials are used also for monitoring spinal cord function. This technique can detect acute changes of the spinal cord functions after different kinds of injury.

Requirements on convenient data acquisition system are:

- Sensing of very small electric potentials of micro and milivolts order that are usually deteriorated by noise and other disturbances.
- Low frequency measurements with maximal frequency of spectral components in order of hundreds Hz.
- Triggered acquisition by digital or analogue triggers derived from stimuli of measured object, and, optionally, generation of stimuli on trigger outputs.
- Processing of acquired signals and saving them in a database for later offline processing.

Professional systems are rather expensive, often also because of fulfilling various safety conditions required for experiments on human beings. These safety requirements are not needed for experiments on laboratory animals such as rats, etc. This was a challenge for the authors to design and develop a simple modular measuring system based on common, general purpose components, and advanced digital signal processing software, which can decrease hardware requirements. It would enable to perform experiments with laboratory rats at very low costs.

The important novelty in this work is application of chosen methods of advanced signal processing on acquired signals from EPs electrodes, which enable better recovering of biological signal, which are heavily deteriorated by noise and other distortions.

2. EXPERIMENTAL SETUP

The scheme of our experimental setup is shown in Fig. 1. The setup consists of electrodes implanted into the animal, stimulator, preamplifier, digitizing board and software processing acquired signal in PC.

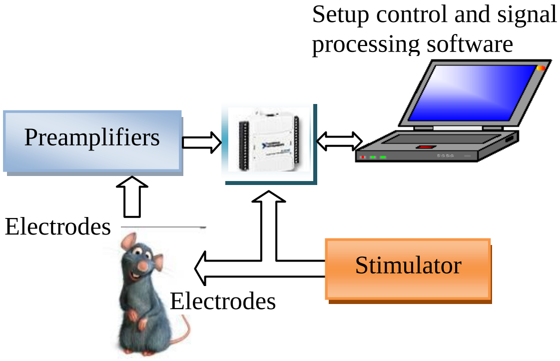

Fig. 1. Principal experimental setup.

The type of electrodes depends on the type of recorded signal. Strong signals (ECG, EMG, etc.) can be recorded by surface electrodes, such as clips, buttons, or adhesive electrodes. The most usual type of electrode for more focused recordings from deeper structures is simple needle electrode. To record from brain or spinal cord, the silver balls can be placed on the surface of recorder structure, or they can be implanted into the bone overlaying the structure. Experiments frequently require fabrication of special electrodes, such as multichannel electrodes, hook or cuff electrodes for peripheral nerve recording, intrathecal electrodes for continuous spinal cord recording, various chronic implantable electrodes, etc. [3]. Example of special fabricated electrodes for long lasting spinal cord recording is on the Fig. 2.

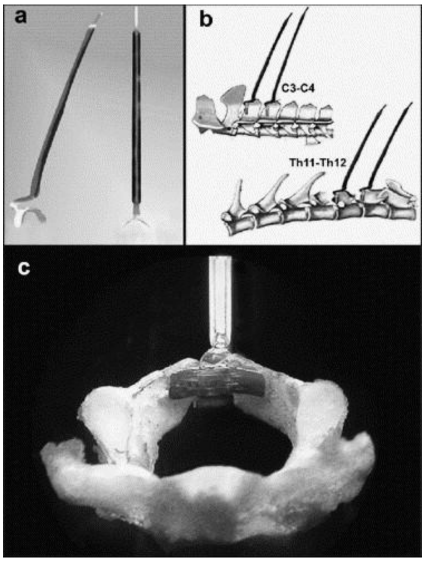

Fig. 2. Picture showing special type of electrodes for long lasting spinal cord recording. (a) Overall appearance of electrode shape . (b) Schematic drawing depicting localization of two pairs of electrodes. (c) Detailed picture of electrode placement - uninsulated part was precisely adjusted to fit below the arch of vertebra

These particular electrodes were used for repeated stimulation and recording of spinal cord evoked potentials (SCEPs) in the rat for the period of 4 weeks without any problems [1].

Stimulator should be electrically isolated from the recording circuits, to minimize size of stimulation artifact, which is disturbing signal caused by passive spread of stimulation current through the volume conductor of animal's body. In our case it is battery operated constant voltage stimulator DS2 produced by Digitimer (GB).

Signals acquired from electrodes are amplified by preamplifier and amplifier developed and realized by authors. The preamplifier is basically differential amplifier with very high input resistance in order of hundreds of gigaohms; realized by FET transistors, because recorded signal is very small and weak, and can be easily shunted down. The preamplifier should be small, in order to be placed as close to recording site as possible with short connecting wires, to minimize electromagnetic induction in the wires. The main role of preamplifier isn't to amplify signal, it is to convert high input resistance to low output resistance, to prevent induction of disturbing currents by surrounding EMG fields in wires and input circuits of connected amplifier. Preamplified signal is fed to the amplifier, which amplifies signal in orders of hundreds or thousands times. The amplifier is usually equipped with basic high pass (HP) and low pass (LP) analog filters.

Amplified signals are digitized by low cost multifunction data acquisition board USB 6009 by National instruments, connected to PC over USB. Although it is very simple board, their basic parameters (max. sampling frequency 40kHz, resolution 13 bits) are satisfied for given needs. The main disadvantage of the boards – missing hardware analogue triggering on stimulus has been overcome by software triggering technique based on continual signal acquisition with processing in real time.

The control and signal processing software was developed in LabVIEW. LabVIEW as software developing tools was chosen because of simple and effective graphical programming technique. The main tasks of the software are:

- Continual data acquisition with real-time software triggering. The software triggering had to be implemented because low cost DAQ cards do not have any analogue hardware triggering. Software triggering uses continual multichannel sampling into FIFO buffer with continual reading sub-blocks of data. Two subsequent sub-block are processed together. When triggering condition is fulfilled, software cuts a portion of samples with required number of pre-triggered and post-triggered samples into a subset and shifts the subset for further processing. If the trigger condition is not met, the oldest sub-block is cancelled and a new one is added to processed data.
- Real-time data preprocessing with suppression of noise, disturbances and other deteriorations,
- Presentation and storing recorded data into file database,
- Off-line reading and presenting data from database with additional advanced signal processing and analysis to estimate required parameters.

The real setup is shown in Fig. 3. Except the above-mentioned components, the setup is extended by temperature control system assuring the constant temperature of experimental animal. Optionally, the setup can be also supplemented by timing stimulus control unit for triggering repetitive stimulus for rate dependent measurements.

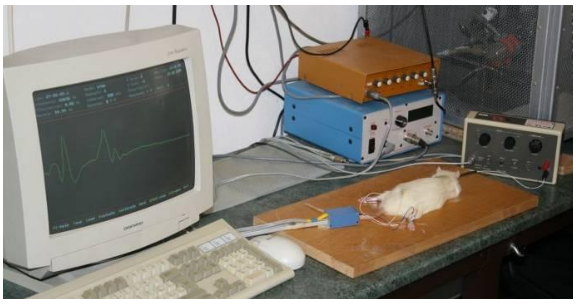

Fig. 3. Real view of the experimental setup.

3. EXPERIMENTAL RESULTS

The developed recording and data analyzing setup can be used for almost all types of recordings mentioned earlier. Data presented in this paper were acquired during recording of motor evoked potentials (MEPs). Recording of MEPs is used to monitor function of motor pathway, complete, or its part. Motor pathways control all movements in the body, they convey signals from the brain towards to executive organs (effectors), therefore they are also called descending pathways. Motor pathway originates in primary motoneurons in motor cortex in the brain. Motoneurons send signals via their long extension fibers called axons down through spinal cord to secondary motoneurons, which are connected directly to effectors. In our study we recorded whole motor pathway, it means, we stimulated beginning of the pathway in motor cortex. Stimulating electrodes were two needle electrodes inserted to the skull bone over motor cortex area. The response was recorded from the other end of pathway, from the muscle; in our case it was calf muscle (m. gastrocnemius). Recording was done in bipolar (differential) way to minimize contribution of random noise induced in the body and wires. Recording electrodes were again needles inserted into the muscle with reference electrode inserted into the skin on opposite side of body.

Signal characterizing response of animal under test (AUT) is in the form of unipolar or bipolar short time wave with a delay from stimulus. Many of short time wave parameters are needed from biological point of view, e.g., delay, duration, shape, amplitudes, rising and falling times, etc. If the stimulus is high, the response is also high in comparing to additional disturbances (see example in Fig. 4). The presence is simply detectable but reading parameters from noisy and disturbed waveform is rather uncertain.

The common method how to improve readability of examined signals used by the most of experimenters in biology has been an averaging of repeated measurements. Such averaging requires the exact repeatability of experiments what is hardly possible for biological objects.

If stimulus is small and/or noise and other disturbances are reasonable, the signal is hardly recognizable and required parameters cannot be read (example in Fig. 5).

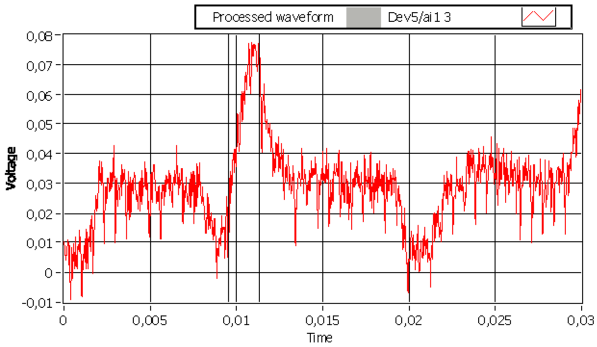

Fig. 4. Example of recorded signal from experiment with a relatively good readability.

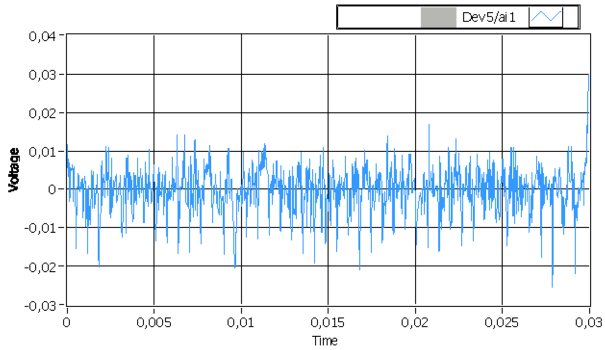

Fig. 5. Example of recorded signal from experiment with no readability, seemingly contaning no signal.

Therefore we decided to examine applying the advance digital signal processing for improving signal quality and readability even for unique measurement. The goal was to improve each single measurement so that it could be good enough for accurate reading of required parameters without need of repeating the experiment. We have developed software that offers to experimenter the following tools:

1. Nonlinear median filtration with additional liner digital IIR filtering. All parameter of both filters, e.g., left and right ranks of median filter, structure, order, cut-off frequencies, etc. of IIR filter are adjustable.
2. Approximation of whole record or a chosen part (time segment) by polynomial of arbitrary order.
3. Moving averages FIR filters with adjustable characteristics (Spencer or Henderson with adjustable number of terms)

All methods are equipped by indication of power of residuum, which can help to experimenter to find the maximal improvements. On the other hand, experiments show that the processing residuum is not the only, optimal, and best methods characterizing quality and level of signal improvement. Therefore the final decision on optimal recovering in each case is not automated and it remains always on experimenter.

To identify the presence and position of response from AUT in time as well as for detecting possible source of disturbances, optional additional supporting tools are offered:

1. Fourier power spectrum for detecting periodical deterministic sources of distortion, e.g., power distribution, computer, etc., that could be suppressed by

improving hardware, especially grounding and shielding of electronics in test setup.

2. Join time and frequency analysis in form of spectrogram to detect and identify signal segments of interest.

Processing response if signal is well over disturbances and noise is simple and whole processing is focused only on further improvement of signal readability. Example in Fig. 6 shows improvement achieved by application of combination of median filter + IIR filter on recorded signal from Fig. 4 (Fig. 6a), and alternatively by polynomial approximation of order 19 (Fig. 6b.) and FIR filter with moving averages (Henderson 23 terms, Fig. 6c.).

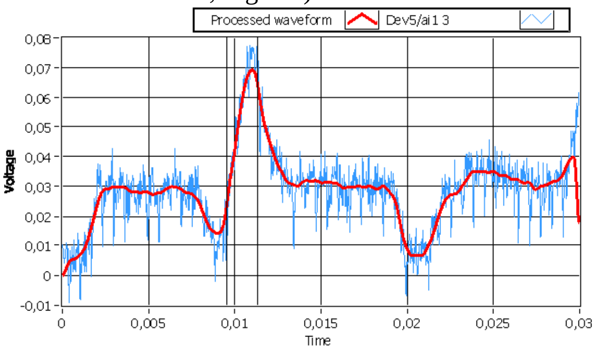

Fig. 6a. Recorded signal (from Fig. 4.) and result after processing by median filter + IIR Bessel low pass filter of 2nd order with cut frequency 800Hz.

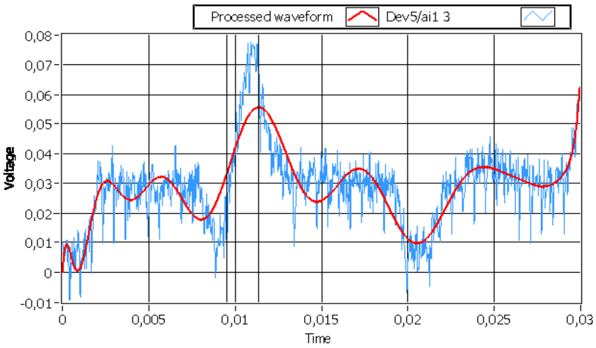

Fig. 6b. Recorded signal (from Fig. 4.) and result after aproximation by polynomial of order 19.

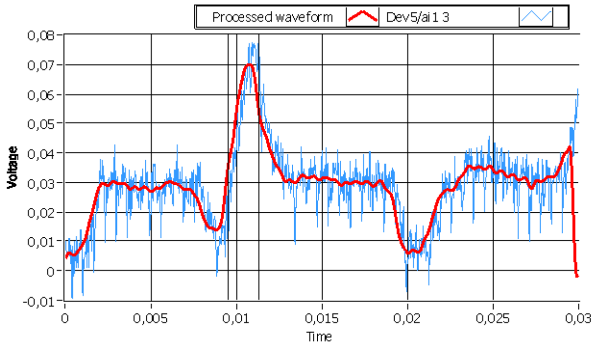

Fig. 6c. Recorded signal (from Fig. 4.) and result after FIR filtering by moving average (Henderson 23 terms).

Comparing figures 6a – 6c we can conclude that the best recovering of biological signal of EP was achieved by combination of median and IIR filter. Recovering by moving averaging gives also good result but a little shifted in time. This shift must be taken in account at measuring delay between stimulus and response. The worst results were achieved by polynomial aproximation because of complexity of the signal in long time. On the other hand, the polynomial approximation gives very good results if we approximate only a short period of signal in time segment of interest (Fig. 7.).

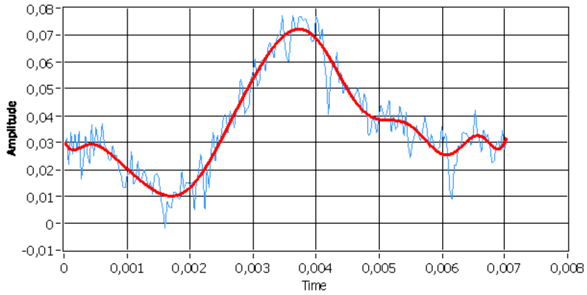

Fig. 7. Polynomial approximation (order 16) of time segment of interest from record shown in Fig. 4.

Seemingly different situation is for extremely disturbed and noisy signal as example in Fig. 5. For such signal we are using first examination by joint time frequency analysis. Spectrogram achieved by short time FFT can indicate presence of a reasonable signal in such record. In Fig.8 the spectrogram of signal from Fig. 5 is shown. It is seen that in the time interval around 10 ms a signal is hidden in noise with spectrum concentrated in low frequencies what indicates a possible presence of a deterministic signal in expected time and frequency region.

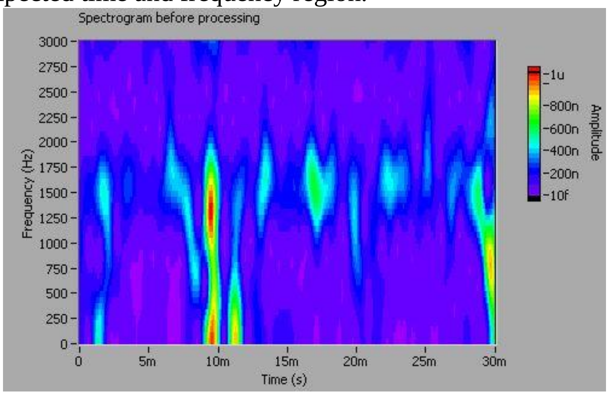

Fig. 8. Spectrogram achieved by short time FFT from signal shown in Fig. 5

Applying filtration by median filter and Bessel IIR filter we can recover the hidden waveform as it is shown in Fig. 9.

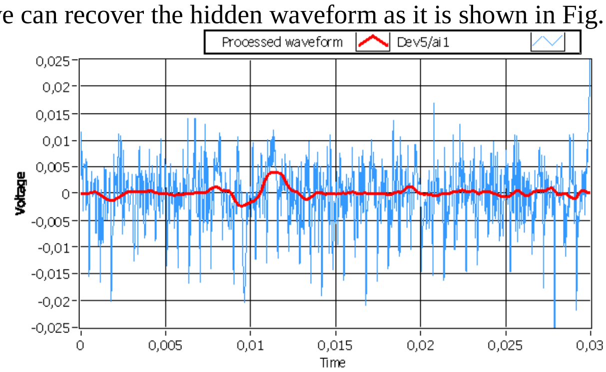

Fig. 9. Waveform recovered by median filter + Bessel IIR filter from noisy signal in Fig. 5.

4. CONCLUSIONS

The paper presents a cost effective modular system for acquiring and processing biological signals for experiments performed on rats. The main advantage of the system is cost effectiveness and modularity using combination of common ready to use modules and self developed hardware and software. Various advanced digital signal processing methods implemented in software gives to user very powerful tool to process signal acquired from AUT within biological experiments focused on EP even if the signal is deeply hidden in noise and disturbances.

6. ACKNOWLEDGEMENTS

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