BIOCYBERNETICS AND BIOMEDICAL ENGINEERING 35 (2015) 240–246

Available online at www.sciencedirect.com

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journal homepage: www.elsevier.com/locate/bbe

Original Research Article

Verification of the functionality of device for monitoring human tremor

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ARTICLE INFO

Article history:
Received 1 October 2014
Received in revised form
16 February 2015
Accepted 23 February 2015
Available online 4 March 2015

Keywords:
Tremor measurement
Multi-channel MMG
Mechanomyography
Parkinson's disease
Deep brain stimulation

ABSTRACT

Tremor accompanying the Parkinson's disease is perceived as one of its most disturbing symptoms. Among available treatments there is a deep brain stimulation, which effectively reduces unwanted oscillations of patient's muscles. Nevertheless, setting parameters of the stimulation is a highly empirical process and the final outcome depends primarily on the experience of involved medical personnel. We present a device which is meant to provide a clinician with feedback based on the measurable parameters of tremor, monitored in many points of the body simultaneously. Functionality of the device was verified at a basic level. During the verification, the vibrations were recorded: (1) in a relaxed arm, (2) during voluntary contraction of muscles and (3) after being damped by tissues (in this case the vibrations were introduced from an external generator). Moreover, a method of selecting optimal place for mounting vibration probes is presented.

1. Introduction

One of the most disturbing symptoms of the Parkinson's disease (PD) is the occurrence of a tremor, defined as unintentional, rhythmic, oscillatory muscle movements involving one or more parts of the human body [1–3]. The possible treatments of parkinsonian tremor are: drug therapy, physical training and surgical intervention. Most common form of the last mentioned is a deep brain stimulation (DBS). The DBS uses electrodes implanted in the patient's brain to stimulate its structures with sequences of electric pulses, what has been proven to significantly reduce tremor [4]. This treatment is also applied to, e.g., essential tremor and dystonia.

After implantation of the DBS electrodes, parameters of the stimulation (such as amplitude, frequency and pulse width of the stimulus [5]) have to be set individually for each patient. Medical personnel, when configuring the stimulator, usually rely on their own visual judgement or on the verbal information from the patient to qualify changes in the tremor resulting from the system settings. In such conditions tuning the device is a highly empirical process, consuming additional time, generating costs and reducing the patient's comfort [5].

This paper presents a system that provides the clinician with feedback based on the measurable parameters of tremor,

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http://dx.doi.org/10.1016/j.bbe.2015.02.002

which can be monitored in many points of the body simultaneously.

2. System structure

The proposed system is a modification of a previously made device for multipoint measurements of the magnetic field [6] (IMiIB, Warsaw University of Technology, Poland). This preceding system was developed to provide means of assessing an occupational exposure of medical personnel working with a magnetic resonance imaging apparatus. The measuring system itself is modular and portable, dimensions of the main data acquisition module are 89/61/20 mm (this module can collect data from up to five signal processing modules), and each specialized signal processing module has dimensions of 40/40/20 mm.

Because of the modularity of the field-measuring system, it was possible to enhance its capabilities through introduction of a new sensing element. A vibration sensor was developed together with a dedicated signal processing module (which can be fitted with up to three sensing probes), while the other parts of the system (parts responsible for acquiring data, processing it and storing results in a non-volatile memory, or streaming them to a computer) remained unchanged.

The presented system is monitoring human tremor through recording the mechanical activity of muscles. This kind of measurement is called a mechanomyography (MMG). It has been applied in many fields to examine the muscle function, including both clinical and experimental usage [7–10]. It is based on an observation that the muscle activity leads to mechanical deformation of the surrounding tissues, and this deformation propagates to the surface of the skin. The MMG signal can be measured there with, e.g., accelerometer, microphone, piezoelectric contact sensor or laser displacement sensor. When choosing an appropriate sensor, one should take into consideration that greater part of the power of measured signal is contained below 100 Hz. In case of contact sensors, the second important factor is the mass of a sensor, which should be small enough to not disturb muscle vibrations. Researchers seek new types of sensors, which could potentially improve the quality of measured signal. Specialized sensors are, e.g., a differential piezoelectric sensor probe [11], or a coupled microphone–accelerometer probe [12], both capable of rejecting artefacts and improving signal-to-noise ratio. Other innovative sensor conveys the pressure signal of the MMG form the skin to a piezoresistive element through liquid in order to avoid attenuation of the signal on the interface between the skin and the probe [13].

The piezoelectric transducer was selected as the sensing element for the following reasons: (1) it is a generating sensor (there is no need to deliver any auxiliary energy, like in a capacitive microphone or accelerometer), (2) it is available in versions with a relatively large active area, i.e., area sensitive to the vibrations (so these can be gathered from larger skin area, while measurements made with accelerometers or microphones are more selective), and (3) it is a displacement transducer (the signal does not have to be integrated to achieve skin displacement, like in the acceleration sensors). The assembly of a vibration probe used in the system is shown in Fig. 1. The probe consists of a disc-shaped piezoelectric plate

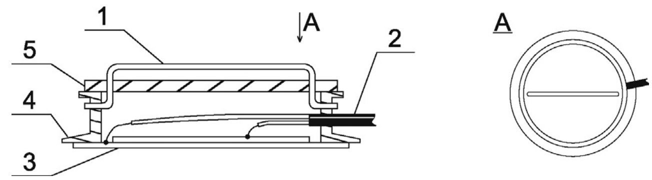

Fig. 1 – Assembly of the vibration probe: 1 – strap holder, 2 – two-core shielded signal cable, 3 – disc-shaped piezoelectric transducer, 4 – enclosure of the probe, 5 – lid; A – view from the top.

(3) glued to the sensor's plastic enclosure (4) around its circumference. The probe is mounted on the patient with a strap, which is placed between the strap holder (1) and the lid (5) of the enclosure. The largest diameter of the probe, measured at the external rim of (4), is 34 mm.

The signal generated by the piezo-element is amplified (with a gain of 2) and filtered with a low pass filter (2nd order Butterworth filter, attenuation of −3 dB @ 200 Hz). In the next stage, it is sampled with an analogue-to-digital converter (2 ksps, 10 b of resolution, successive approximating converter in a megaAVR family microcontroller) and digitally filtered with a finite impulse response low-pass filter to limit its band to 250 Hz. After filtering, the signal can be downsampled to 500 sps. Because of the capacitive character of the piezo-element, it is inherently high-pass filtering the signal with a RC filter consisting of its capacitance and parallel connection of the filter internal resistance and the resistance of the sensor load, which in this set-up is input of the signal conditioning chain. Theoretically derived lower cutoff frequency for the presented system is near 0.7 Hz.

Similar multi-channel MMG systems were used for, e.g., recognizing patterns of a forearm muscle activity (6 silicone-embedded microphone probes) [14], analyzing effect of a bulk movement (i.e., deformation of soft tissues surrounding measurement points) on the recorded muscular signals (5 single-axis accelerometer probes) [15], analyzing two-dimensional distribution of surface MMG signal (12 dual-axis accelerometer probes arranged in a 3×4 matrix [16,17]; 15 single-axis accelerometer probes arranged in a 3×5 matrix [18,19]), investigating the effect of sensor position along the muscle fibres on the MMG signal features (up to 8 single-axis accelerometer probes) [20], determining the propagation direction of oscillations in the examined muscle during voluntary contraction (15 single-axis accelerometer probes arranged in a 3×5 matrix) [21]. An example of a specialized commercial MMG system is the Biopac MP150 acquisition system fitted with accelerometric transducers TSD250/251 (BIOPAC Systems, Inc., CA, USA). This system can acquire up to 16 channels of MMG data in frequency band 20–200 Hz. When compared to the aforementioned solutions, our device has an advantage of combining the following characteristics: (1) it can collect data from up to 15 MMG probes, (2) it has a smaller size (all modules can be comfortably mounted on the examined patient) and is self-contained, no additional hardware (e.g., data acquisition card, external power supply, external data memory) is required to perform measurements, (3) it can be battery operated. In view of these aspects, it is possible to use it as a Holter monitor to