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Hardware-software complex for tensotremometric measurements in psychophysiological research

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Abstract

Introduction. One of the methods of assessing human psychoemotional reactions (PER) is measuring motor system activity. Traditionally, to register involuntary components of PER methods of measuring physiological tremor are used. This paper presents comparative analysis of different methods for tremor registration and also presents a description of a new pen-shaped device outfitted with tensometric sensors to assess severity of stress PER. **Methods**. The device includes tensometric sensors connected to analog-digital conversion device and microcontroller in order to translate the signal to administrator's terminal. The signal contains tensotremorometric data from three fingers, corrected according to maximum voluntary contraction (MVC) of the subject. Said signal is then divided into overlapping segments which are then filtered for the frequency of physiological tremor and analyzed using Epps-Singleton criteria. **Results**. A plan of study that allows to assess severity of stress reaction using presented device is tested. It is shown that if a stressor is introduced, then changes of the background tensotremorogram coincides with the moment of stressor introduction. A prototype for software-hardware complex for assessing PER based on tensotremometry registration and analysis is introduced. **Discussion**. Hypotheses regarding the specifics of connection between tensotremorogram changes and stressor characteristics are formulated. Further developments of technology are discussed.

Keywords

psychoemotional reactions (PER), stress, involuntary movements, vegetative neural system, physiological tremor, tensotremorometry, sliding window, Epps-Singleton criteria, force-sensitive resistor, maximum voluntary contraction

For citation

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Introduction

One of the classic criteria of stress-induced psychoemotional reaction (PER) is tremor (Alexandrov, Uplisova, Stepanov, Ivanova, 2017). Physiological normal (muscular) tremor is defined as oscillations of forces, created by coordinated work of different neuromotor units.

The main characteristics studied when assessing tremor are frequency and amplitude. Based on the literature, tremor characteristics allow to diagnose current psychophysiological state of a person in range of 8-16 Hz (Alexandrov, 2018; Dick, Nozdrachev, 2019; Kruchinin, Lebedev, Kholmogorova, 2013; Aleksanyan, Bureneva, & Safyannikov, 2018; Carignan, Daneault, & Duval, 2012; Young, 1933).

Currently the main methods used to measure tremor are electromyography, accelerometry, tensotremometry and video (Govorova, Popova, Tappakhov, 2019). Choice of the method is defined by the goals of the research, experimental procedure, restrictions of the workspace and data analysis technology available.

Main task of accelerometry is measuring tremor amplitude based on data about acceleration and coordinate changes using information from rotational speed sensors (Bobylev, Bolotin, Voronov, Kruchinin, 2012; Ishlinsky, 2018). From biomechanical perspective, accelerometry is a kinematic method. While it is pretty handy, it has some important restrictions: imprecision of the gyroscope, dependence on the ADC precision and quality of the amplifier and difficulties registration when finger amplitude is very small (Elble & McNames, 2016). The fact that accelerometer measures absolute acceleration (combination of accelerations forced upon it) restricts usage of this method when dynamic changes of hand positions are required. Another significant drawback of accelerometry is lack of ability to differentiate between postural, physiological and other kinds of tremor.

Electromyography (EMG) mostly enables gaining important data and has a number of advantages, being cheap, non-invasive and safe, but also having a stable signal due to stable mount (Meygal, Rissanen, Zaripova, Miroshnichenko, Karyalinen, 2015). In most cases EMG uses surface mount. This restricts the data, because pair of surface electrodes is able to gather data only about activity of close laying motor units tangentially to the muscle. However, in cases where complex mathematical analysis is needed, EMG appears worse than other methods due to unavoidable low-frequency filtration of signal by the skin (Gygi & Moschytz, 1997).

Videoregistration (Pintea et al, 2019; Williams et al, 2020) is a handy contactless method that needs a complex mathematical apparatus to analyze (often including artificial neural networks) and lacks the ability to analyze high-frequency or low-amplitude tremor due to technical limitations of recording camera. IF the need to increase precision arises, high resulting price of a stand makes videoregistration prohibitively expensive to use.

As an alternative to said methods there is tensotremorometry (TTM). It allows to evade unwanted "physiological" filtration, is non-invasive, safe and allows to register tremor of any frequency or amplitude desired. The "gold standard" of TTM is a load cell, which works on the idea of tensoresistors changing their resistance when deformed. A load cell consists of one or more tensoresistors mounted on a metal plate that is elastically deformed under the force. The main drawback of load cells is inability to change the sensitivity, because most of the time precision of a tensoresistor is a fixed value (Ohm/N) and doesn't change based on applied force. This property lays base for a wide use of load cells in scales of varying purpose but it disables the ability to use said cells while researching tremor. This is because change in amplitude of tremor may be tenth, hundredth or even thousandth part of general pressure, and sensors that can reliably gather data that precise are very expensive and largely unavailable.

Sensors based on capacitive (Denner, 1999) or inductive (Pedersen, 2006) schemes have high precision on small and extremely small deltas but are largely unusable when applied forces are high. Those sensors may have limited use when measuring resting tremor, but using those in conditions of movement activity appears hard or even impossible.

In order to find technical (software-hardware) solution that allows to lift those restrictions from the TTM method, an experimental method was created. It is based on registration of tremor data using TTM with active movement of the hand. Past research is mostly limited to measuring "average" forces or is related to pathological tremor (Baur, Fürholzer, Jasper, Marquardt, & Hermsdörfer 2009; Lin et al., 2019).

Analyzing tremorogram during movement activity requires more complex hardware that not only has required resolution to measure small differences, but also filter movement activity, including smallest of the movements. This is unachievable by accelerometry, videoregistration and electromyography and most common method of TTM using load cells doesn't have the required resolution.

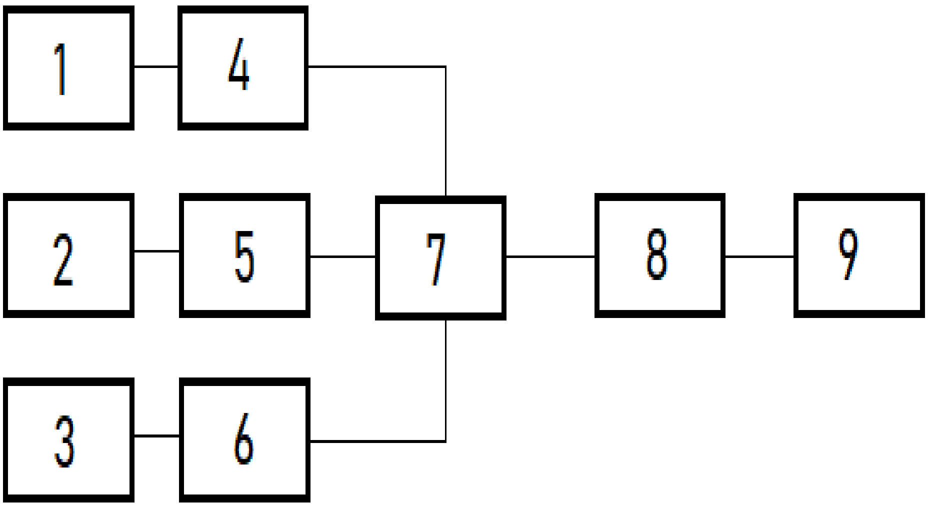
This study presents sample of hardware-software complex (HSC) that contains statistic and hardware improvements that allow to measure finger tremor when holding pen using TTM. Pilot studies are presented that illustrate the potential of improving stress reactions diagnosis using TTM methods with suggested improvements.

Methods

Suggested methodic relies on the new type of force sensors that allows to measure small differences in tremor in wide range of movement forces. The sensors are built upon force-sensitive resistors that have high resolution in certain range of forces and much lower in other ranges (Baker & Sanchez, 2006). Setting the high-resolution range in accordance with individual characteristics of a participant allows to gather measurements of tremor with high sensitivity while negating the influence of other forces.

Schematics for the device are presented on Figure 1.

Figure 1
Schematics for the device



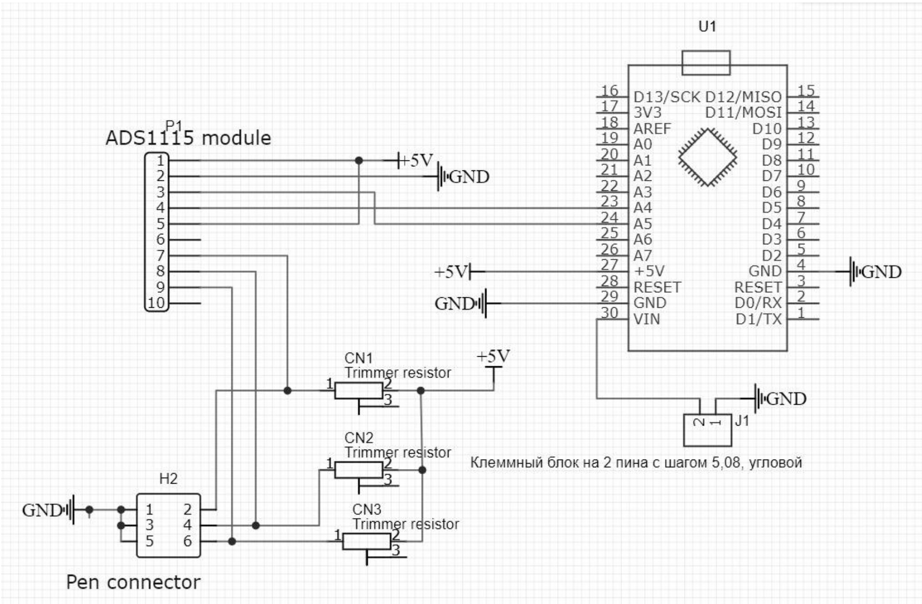
Note. *1, 2, 3 – FSR-based force sensors, 4, 5, 6 – voltage dividers, 7 – ADC module, 8 – microcontroller, 9 – network link to administrator terminal.*

When creating sample device, most common activities involving small hand movements were analyzed. Assuming that using pen and paper is quite common in the everyday life and using pen requires three fingers, pen-shaped form for the device was chosen (Figure 2). An additional description of the device is provided in the article (Belinsky, Devishvili, Chernorizov, Lobin, 2023). Sample device has outer module in the shape of a pen, including digital pen compatible with Wacom tablets. This enables the potential ability to combine TTM data from the pen with handwriting analysis from the tablet. Module has three tensometric sensors attached under the fingertips while using the tripod grip. Tripod grip is a method of handling pen based on the middle finger with thumb and index finger controlling the pen (Donica, Massengill, & Gooden, 2018).

Figure 2
Device appearance

Measurements, preparation and sending data to the administrator terminal are handled by the main module. Main module contains ADC adapter, ATMega328PB-based microcontroller and network microscheme in the form of USB-UART adapter. Electrical schematics are presented on figure 3.

Figure 3
Electrical schematics for the main module



Note. *U1 – microcontroller, P1 – ADC module, H2 – contacts for the pen module, CN1-3 – trimmer resistor*

Since tremor changes can occur on relatively high frequencies, according to Shannon-Nyquist theorem, sampling frequency was chosen higher than 120Hz in order to fully measure all meaningful ranges of tremor frequency (5-60Hz). Sample device allows to gather data from three force sensors in parallel and independently from each other, however, further development might include more data gathering points.

Changes in pressure force created by tremor were compensated by using sensors based on force-sensitive resistors (Baker & Sanchez, 2006). Connecting said sensors on one leg of voltage divider gives non-linear, but well-approximated as linear changes on voltage on other leg, assuming ranges are relatively small, which is the case with tremor.

In order to compensate for individual differences in pen handling manner for each test subject a 100k Ohm trimmer resistor was used. This allowed for a calibrating session with each participant before main study. Too low (less than half of measurement range) or too high (significantly more than half of measurement range) MVC leads to losing precision. In order to calibrate participant was asked to take the pen with the tripod grip and then hardware was adjusted so MVC of the participant correlated with 2.7 V on the voltage divider leg (~55% of the measuring scale for 0-5V ADC). Empirically this is the best value for getting high precision out of the device, but math required to find out the precise best value is still in development.

Since each of tremor frequencies gives information about a particular source of motor reaction, in order to analyze data, it is needed to get the precise frequency range. To achieve this, 6-th order bidirectional Butterworth filter was used.

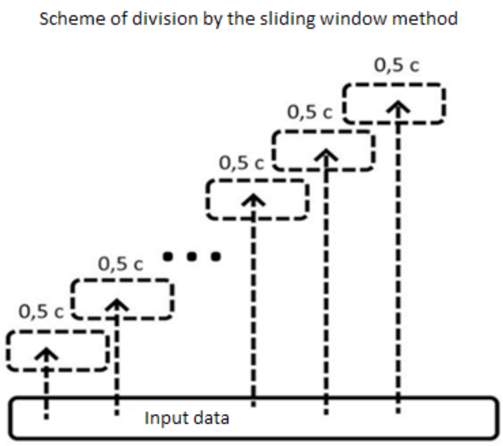
While analyzing the recording, sliding window method was used. This method divides recording into overlapping parts, which are then independently analyzed. Schema of the method is presented on figure 4. This method allows to find reaction time on tensotremorogram and overlapping windows allows to find part that contains the reaction the fullest (Fumarola, Ciampi, Appice, & Malerba, 2009).

For statistical analysis the Epps-Singleton criteria was used. Main advantages of the criteria are ability to be used with discrete data and different size data. This is achieved by using characteristic function instead of distribution function. Furthermore, the statistical power of this criteria is much higher than that of Kolmogorov-Smirnov criteria (Goerg & Kaiser, 2009).

In order to test the methodic an experiment was conducted. Participants were asked to handle the pen module with tripod grip while resting, and then randomly were presented with loud stressing sound (105 dB) lasting 1 second. This schema is largely analogous to experimental research of TTM where electric shock was used (Christou, Jakobi, Critchlow, Fleshner, & Enoka, 2004).

The experiment included 10 participants, 7 men and 3 women (average age 25 +/- 4.2 years). Each participant was given the instruction and then was given test series of one test with stimuli and one control test without stimuli. Then each participant was asked to partake in test series of six random tests – three with stressors and three control tests. Data was controlled for quality of gathering and artifacts. Main goal of the experiment was to determine whether proposed HSC allows to find the moment of the human reaction to stimuli using TTM.

Figure 4
Sliding window method schema



Results

Figures 5 and 6 present the recording with characteristic differences in TTM data with stressor stimuli and without one.

Figure 5
Resting tensotremorogram

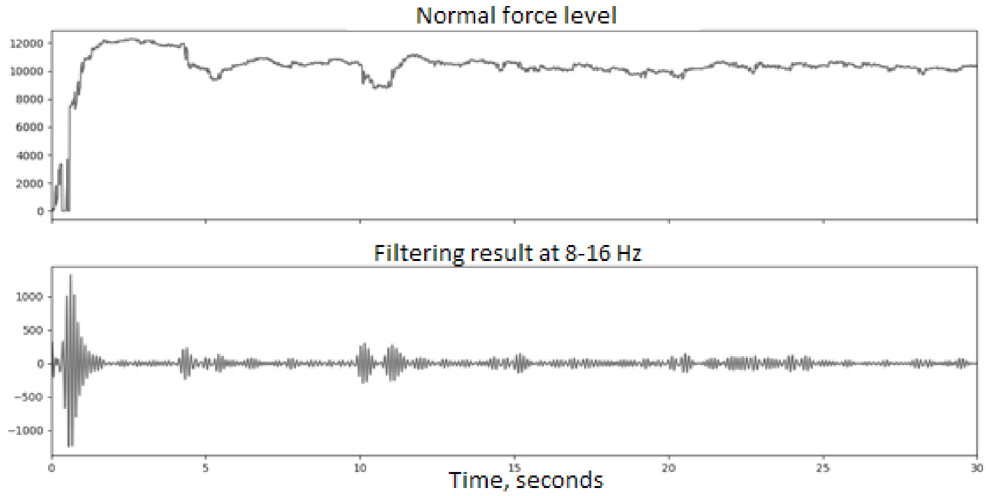


Figure 6
Tremorogram with stimuli, stimulus presented on t = 15s.

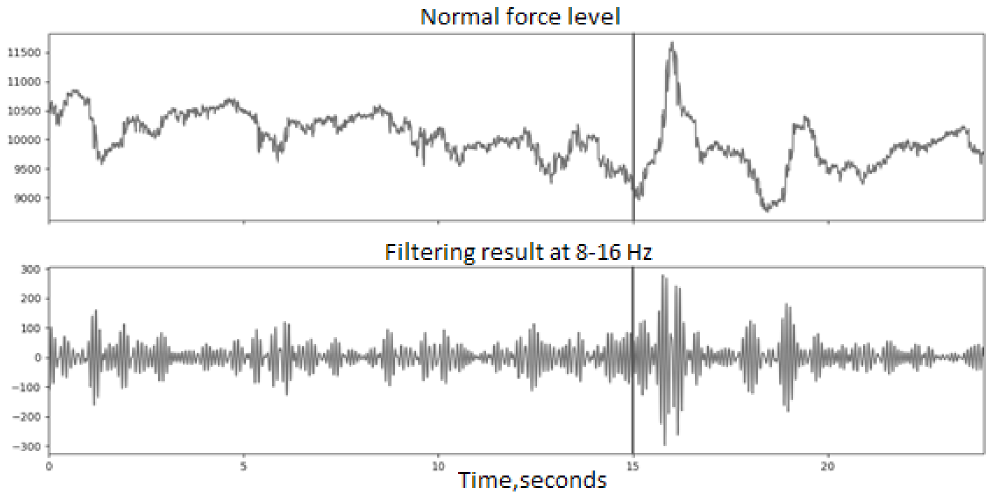


Figure 6 demonstrates the characteristic peak on 16th second, linked to the moment of giving emotionally significant stimulus on 15th second. Big splash on the start of figure 5 is due to participant taking more comfortable grip with the pen while on recording.

Table 1
Statistical analysis of tensotremorogram

Sound stimuli given			No stimuli		
Epps-Singleton criteria	p - value*	Δ, % MVC	Epps-Singleton criteria	p - value*	Δ, % MVC
40,25	0,0043	10,83	26,42	0,003	3,11

***Note**: "*" marks p-value significant on the level of p <0,05.*

Experimental results are presented on table 1. Data analysis shows that stimulus moment was the same as the moment of difference in tensotremorograms for each finger. Presenting sound stimuli gave us value of 40,25 with p=0.0043 on the Epps-Singleton criteria. Resting conditions gave us value of 26.42 with p=0.003 on the Epps-Singleton criteria. This difference marks statistically significant differences in samples, which proves the hypothesis that stimulus has interfered. At the same time, difference between minimal and maximal amplitude of tremor on the "stress" recording is 10.83% MVC which is significantly higher than at "rest" recording (3.11% MVC) which proves the hypothesis of link between tremor and stimulus.

Discussion

Results of present study are proving that the proposed method can find the moment of the stressor on the recording of TTM. Such moment is marked by a characteristic "splash" on the tensotremorogram which signifies the rapid increase in pressure force. On the experiment with the sample size of ten statistically significant differences of TTM data when presenting sound stimuli were found. Our results correspond with the work of Christou et al (2004) about the increase in tremor amplitude in 1-2 Hz range when researching young healthy participants. In the same time, Blakemore, Shoorangiz & Anderson (2018) found no significant differences in amplitude-frequency data of tensotremorographic measurements while showing emotionally significant images.

Previous studies were based on classic load cell force sensors (Kruchinin et al., 2013; Safyannikov, Bureneva, Zhirnova, 2018; Blakemore et al., 2018; Christou et al., 2004; Ferenčík, Jaščur, Bundzel, & Cavallo, 2020).

Present study proposes the methodic of better precision while measuring tremor under static load using force sensitive resistor type of force sensors in conjunction with mathematical apparatus for preparing data after digitizing. Such information opens the possibility of improving methods of stress diagnostics for cases with high physical stress in circumstances of static or mostly static load. Furthermore, proposed improvement of mathematical apparatus for analyzing tremor under dynamic load allows to measure stress while writing or doing other tasks requiring a lot of small hand and finger movement. This was previously little explored due to complexity of the methods used.

Proposed improvement of data gathering methods based on tensometric sensors with no frequency limitation allows to gather data on frequencies in range of 0.1 to 120 Hz. This paper uses 8-16 Hz range as the most common for the physiological tremor. Proposed method allows to have resolution about $1/100^{th}$ of a gram in designated force range but lacks the resolution outside designated range. This makes it more applicable for measuring tremor in grip tasks, allowing to calibrate the device for the designated range to be the same as force changes range.

That said, main scenarios for the proposed methodic lay in fields where use of other methods is significantly limited. Mostly this is the case of dynamical activity where high precision for gathering tremor force data is required, but fingers and hand are constantly changing acceleration. At the same time, the methodic lacks the ability to measure tremor of other body parts and limbs, and loses in comparison to others when the hands are free, so its scope of use is rather limited.

Sample experiment results suggest that inducing stress with a stimulus forms a reaction in form of change in tremor characteristics which can then be measured and analyzed. However, kinds and power of stimuli that can be found using TTM and specifics of the device that could find the reaction for the specific type of stimuli still requires further research.

Conclusion

A methodic and software for analysis TTM data is developed. Sample device is pen-shaped with external data analysis module and connects to the researcher's terminal with USB cable. Methodic uses tensotremorometric sensor of the new type, which significantly expand ability to measure tremor characteristics in many ranges of frequencies. Calibration by using trimmer resistors is available, and also the pen module can be swapped for another module should those be developed too.

The methodic allows to analyze individual specifics of tremor automatically using sliding window method and Epps-Singleton criteria. Proposed methodic can be a replacement for the accelerometry method when its applications are limited and expand the instrumental abilities of psychologists in different spheres of theory and practice: research of movement sphere in normal and pathologic situations, diagnosis and monitoring for stress, lie detection.

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Author Contributions

Artyom Viktorovich Belinsky – development of the design of the experiment, preparation of the text of the article, conducting the experiment.

Vazha Mikhailovich Devishvili – study and device conception, correction of article text and experiment design

Alexander Mikhaylovich Chernorizov – preparation and revision of the text of the article.

Mikhail Alexandrovich Lobin – development of technical and program solution, data analysis.

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Conflict of Interest Information

The authors have no conflicts of interest to declare.