JOURNAL OF PHYSICS AND TECHNOLOGY

Volume 6 (2025) Number 1, pp. 33-38

METHOD FOR MEASURING MUSCLE TREMOR IN RESEARCHING THE HUMAN – OPERATOR CONDITION

Emil Vasilev and Zoya Hubenova

Institute for Space Research and Technologies - Bulgarian Academy of Sciences, Acad. Georgy Bonchev str., bl. 1, 1113 Sofia, Bulgaria

Corresponding author: evasilev@space.bas.bg; zhubenova@space.bas.bg

Keywords:
Muscle tremor
Accelerometer
Psychoemotional state

Abstract:
A method for non-invasive measurement of muscle tremor and its use as a source of information in researching the psycho-emotional state (PES) of the human operator in a complex system is presented.

Submitted on:
18.12.2024

Accepted on:
04.08.2025

1. INTRODUCTION

In the analysis of complex technical systems, such as large-scale transport, energy, aviation and other complexes, a number of problems related to people and human factors occur. According to statistics, more than 75 % (in aviation more than 90 %) of the accidents of this kind of systems occur due to human error. This places high demands on highly-skilled operators and in most cases (especially in the defence complex) also on their stable psycho-emotional state (PES).

Developments are currently underway to create diagnostic systems designed to continuously monitor a person’s condition [1]. Limitations in the applicability of the equipment are related to the narrowed capabilities of the biometric methods implemented in them, but recently new technologies have started being developed and existing ones - updated. The type of function performed by a person as an element of the system is one of attributes used to classify biometric systems, and by this attribute they are divided into medical and ergative. Medical systems include systems for instrumental diagnosis and treatment of diseases using physical factors and technical means to influence the human body, systems for information support of the healing process - clinical information systems for documentation and storage of patient data, systems in telemedicine, automated workplaces of the doctor-specialist.

In the framework of medical biometric diagnostic systems, a description of the functional systems in the human body that determine the state of the organism, the means of registration of physiological information and diagnosis of the condition is formed. Through the study of these systems, the requirements for the sensors of physiological parameters, the structure of technical means, algorithms for processing biosignals and obtaining diagnostic information are determined [2].

The main difficulties on the way to creating the necessary biometric system are related to the specificity of the information to be recorded. On one hand, these are poorly correlated parameters, and on the other hand, their values are multimodal and variable. In essence - the problems solved by the algorithms are similar to image recognition problems. The results of the work carried out in this direction may have practical relevance not only for biometrics, but also for other fields - radar, radio navigation, etc.

Biometric methods are known to diagnose the functional state of a person, such as electrocardiography - (ECG); electroencephalography - (EEG); oculography; measurement of the skin-galvanic response (SGR), measurement of changes in pulse, blood pressure, etc.

In this paper, we discuss the feasibility of using muscle tremor as a primary source of biometric information by applying an acceleration sensor to convert muscle oscillations into electrical signals.

2. THEORETICAL JUSTIFICATION

A person's psychoemotional state (PES) plays an important role throughout his or her life, determining his or her behavior in different life situations as well as his or her abilities to cope with the task at hand. Developing methods to measure PES is an urgent task in psychology in terms of addressing such fundamental problems as assessing mental stability, studying emotional intelligence and mechanisms of mental self-organization. High demands on the operator in complex technical systems imply their sustainable PES. In many cases it depends not only on the volitional qualities of a person, but also on the intensity of external influences - noise, vibrations, stressful situations, etc.

Tremor is the medical term for shaking and other rapid, somewhat rhythmic, involuntary contractions and relaxations of a group of muscles. Tremor is the most common of all involuntary movements and can be registered in the trunk, arms, legs, head, face, vocal cords. In some people, tremor may be a symptom of neurological disease, but physiological tremor normally occurs in healthy people. It is low frequency and hardly noticeable [3].

In the considered method, changes in the characteristics of motor activity in this case muscle tremor are used as a source of biometric information. The main reason for the occurrence of these changes in muscle tremor is pointed out as the well-defined excess of human motor abilities and the limited computational resources of the brain [4].

It is well known in engineering that in real time there are no problems to solve problems whose dimensionality matches the dimensionality of the computing machine. Our brain consists of neurons in a three-dimensional space having multiple inputs and a single output. According to the modern view of physiologists, it cannot be a three-dimensional computing machine, i.e. - a machine that is capable of processing a three-dimensional image in one cycle.

The approximate size of the movement control problem can be estimated from the number of muscles used in certain actions. For example, more than 50 muscles are involved during writing, with about 10 having the most important influence. It turns out that when writing with a pen one solves in real time a multidimensional control problem. A model corresponding to such a situation is shown in **Fig. 1**, where n = 10;11.

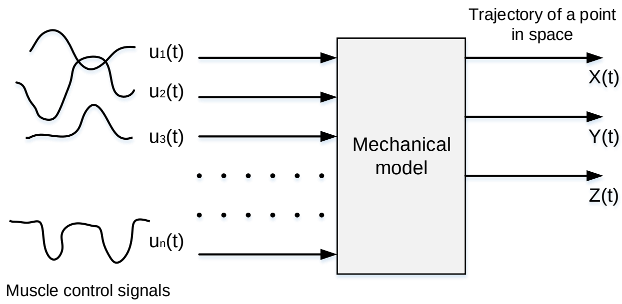

Fig. 1 A multidimensional model of mechanical control of a material point in space.

During speech, 44 muscles of the chest, 9 muscles of the abdomen and abdominal cavity, 28 muscles of the face and jaws, 12 muscles of the tongue, 9 muscles of the pharynx, 6 muscles of the soft palate and muscles of the larynx are involved. Approximately 120 muscles are involved, of which, under the 20 % hypothesis, the group of muscles with the greatest influence yields a 24-dimensional control task. The most difficult problem to solve in speech production is that control signals must be generated as quickly as possible. When the muscles of the speech-forming tract are controlled, a high-frequency signal is generated (pitch ranges from 60 to 600 Hz) that can be compared with the softer control modes of the fingers of the hand, which have significantly lower frequencies of control signals. For exam-ple, in the signature, the frequency spectrum is from 0.1 to 10 Hz.

The fact that the dynamic tasks we solve in everyday life have a dimensionality much larger than the dimensionality of our computing machine (brain) shows our inability to perform complex actions that are new to us quickly and accurately. Through computation we cannot perform complex movements. To accomplish them, we must search for and select successful solutions to complex dynamic problems, and then memorize them through practice and repetition. Thus, solving complex dynamic control problems is very labor-intensive, usually using only one path. Once an individual has developed their gait, handwriting and voice character over years, it is very difficult to change them again. A person uses the skills developed for the rest of his life, which are programs of overall muscle control. The transfer of the task of control to an automatic subconscious level is always difficult, but it involves a considerable increase in the accuracy and speed of movements, the emancipation of consciousness, and the emergence of strictly individual characteristics of complex movements representing his individual handwriting.

Subconscious movements are stable if a higher conscious level does not intervene. With the intervention of a higher-level of consciousness, the "subroutine control" is interrupted until a decision is made. This situation is illustrated in **Fig. 2**, which shows two coordinates of the vibration of the signature writer's pen, who ponders for a moment the correctness of the configuration he is reproducing. The discontinuity of the motion control subroutine corresponds to the horizontal stretch that exists in both processes.

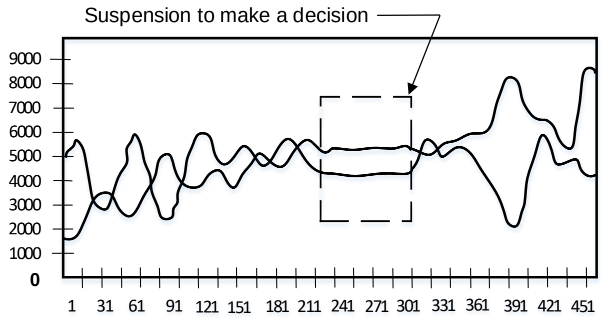

Fig. 2 Stopping to make a decision.

The cut-off parameters for the management program depend on the PES of the person. The complexity of controlling muscle movement in a similar way leads to the fact that a change in the emotional state causes a change in the system of control signals at the subconscious level, which is reflected in the values of the external parameters of the process. These can be recorded and used to determine PES.

It is clear from the above that changes are individual. That is, for a correct diagnosis, it is necessary to have preliminary data on the relevant parameters of the research subject in a normal, calm state. The principle of measurement consists in the initial registration of the biometric signal with the help of a sensor, after which the signal is amplified, filtered and passed to a primary processing procedure. Further, through a data acquisition unit, which in this case is an analog-to-digital converter (ADC), it enters a computer where the information parameters are calculated using mathematical analysis methods [5]. For the tremor signal they are as follows:

$\mathbf{f_{cp}}$ is the average frequency of the signal spectrum;

I is the oscillation intensity, defined as the sum of the harmonics per modulus of the tremor signal spectrum.

Either an acceleration sensor or a seismic sensor can be used as the Tremor Channel sensor, the former having higher sensitivity [6]. The signal from the acceleration sensor must be amplified and filtered and fed to the data acquisition unit. A block diagram of this channel is shown in **Fig. 3**.

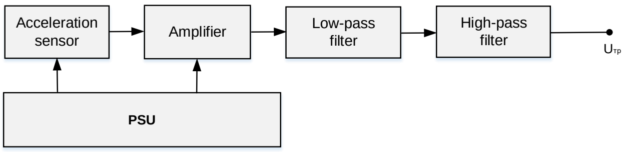

Fig. 3 Tremor channel block diagram.

The useful channel signal is in the range of 0 to 20 Hz [7]. Its constant component not only carries no information but, on the contrary, has a parasitic character. In this case, it is necessary to transmit signals in the frequency band from 0 (without including the constant component) to 20 Hz, choosing the lower limit of 0.5 Hz. Filtering is performed by a band-pass filter, which is in practice implemented as a low-pass and a high-pass filter in series. It is possible to use the accelerometer ADXL345, which is small in size, thin, has a low power consumption, having three axes of readout with high resolution (13 bits) and a range up to +/-16 g. Output data is formatted as 16 bit numbers made up of two parts of 8 bits. Both SPI (3 or 4 wires) and I2C communication interfaces are used. The sensor also has a 32-level, first-in-first-out (FIFO) type buffer that can be used to store the readings so as to reduce calls from to the host processor. This allows relatively accurate measurement of jitter.

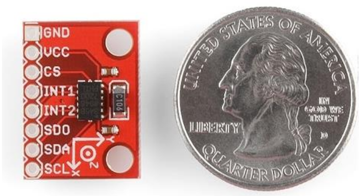

Fig. 4 An accelerometer ADXL345.

Details of the sensor as well as all the basic parameters are given in [8]. On the **Analog Devices** website [9] there are available Arduino (C/C++) and

Circuit Python (Python 3) libraries, **Fig. 4** shows a general view of the sensor compared in size to a coin.

3. PROPOSED RESEARCH METHODOLOGY

To fully test the described measurement system, in order to experimentally confirm its capabilities, it is necessary to conduct a human study in different states and to repeat the diagnostic sessions. The described procedure is associated with a number of difficulties, mainly consisting in the fact that the apriori objective assessment of the research condition requires the use of specialized medical equipment as well as a team of experts. In the framework of the proposed study, this is very difficult and in some cases impossible. For this reason, the task of testing the system undergoes some simplification and is reduced to investigating the capabilities of the system to register a change in the human condition. As it is known from [10] factors such as stress, fatigue, nicotine, alcohol and others, in most cases lead to changes in the functional state of a person, regardless of what state he was in before. Therefore, conducting an experiment according to the “measurement - influencing factor – measurement” scheme will allow to evaluate the ability of the system to fix the change in the state of the person under study.

The use of a stressor is suggested as an influencing factor, the assumption being that it will induce a change in the person’s state quickly enough. The experiment proceeds as follows: a group of volunteers undergoes preliminary psychological tests (MMPI and Cattel) to assess their personality. Then, the measurement of tremor signal parameters is conducted for each, and under the same conditions, measurements are made with other equipment to give verified data for comparison: oculograph, skin-galvanic response (SGR) meter, electrocardiograph (ECG). The measurements are synchronized by providing a synchronizing signal common to all sensors. The biometric information is multimodal and variable. In this respect, the registration of only one signal would not allow a complete description of the PES of the person, therefore it is necessary to use biometric techniques that provide additional information about the condition, with complex measurements to make a reliable decision.

4. EXPERIMENTAL SETUP

The management of unmanned aerial systems (UAS) is a complex and dynamic activity requiring technical skills, integration of various mental resources such as memory, attention and decision making, as well as adaptability and stress resilience. On the other hand, this activity is associated with a number of challenges that can easily disrupt effective and safe human performance during flight. The increased risk of human error when piloting drones requires a thorough investigation of the physiological and cognitive state of the pilot-operator during a mission with its capabilities and limitations, tolerance to workload, resistance to stress and fatigue - factors that affect the performance of flight tasks. On the other hand, the study and understanding of personality characteristics allows to optimize individual and team performance and enables to manage risk by identifying individuals with personality traits conducive to safe and effective unmanned aerial vehicle (UAV) control. In this regard, both physiological parameters and personality characteristics of operators should be considered when examining the human operator.

a)

b)

Fig. 4 a) General view of the C-Star simulator in the “Laboratory for Selection, Training and Control of UAV Operators”; b) operator screen.

a) b) c)

Fig. 5 Available equipment: a) Pupil Labs Core binocular mobile oculograph; b) Pupil Labs Core mobile oculograph; c) EEG system EMOTIV

The experimental work with the contingent of volunteers is carried out in the existing "Laboratory for Selection, Training and Control of UAV Operators" at IKIT-BAS, where non-invasive physiological and psychological methods are used to study the human operator of UAVs in a complex high-tech working environment in crisis situations [11, 12]. Participants performed a familiar flight exercise "Controlling a UAV along a set trajectory" on a **C-Star** simulator **(by SimLat company)** (**Fig. 5).** At some point in the flight, the instructor introduces a stressor, e.g. expressed by a sudden change in flight conditions (occurrence of strong crosswind, fog, engine failure, etc.). In this case, the recorded biosensor readings shall be compared with the readings taken before the flight. Further analysis of the results obtained from the tremor sensor, as well as the use of the data from the additional instrumentation, would facilitate the decision whether and to what extent the proposed sensor for measuring muscle tremor can be used in measuring and determining the functional state of the HR in a complex real-time technical system.

5. CONCLUSION

Particularly important characteristics of man-machine systems are their reliability and efficiency. Reliability of the human operator in the "operator-UAV" systems is determined not only by the psychophysiological resistance to extreme loads, but also by the mental capabilities of the human to compensate for the various distortions in the information processes when interacting with the technique. The development of these systems requires the extension of research on the processes of perception, processing, storage of information by man, decision-making mechanisms (in different situations), the influence of psychological factors on the efficiency and reliability of these systems.

The diagnostic methodologies used are non-invasive and would allow real-time diagnosis. The registration of the operator's PES variation is a good informative indicator of the transition from incapacitation to incapacitation of the PE.

The proposed multi-modal diagnostic system, allows the combined use of non-invasive physiological and psychological methods to investigate the HR of BAS in a complex high-tech work environment.

Such a PES assessment system can be used in the educational process, in sports, for professional recruitment and other industries.

REFERENCES

[1] Moore, J. (2004). Biomedical technology and devices. Handbook, Edited by J. Moore, CRC Press LLC, 750 p.

[2] Grimnes, S. (2000). Bioimpedance and bioelectricity basics. London: Academic Press, p. 265.

[3] Young, I. C. (1933). A study of tremor in normal subjects. Journal of Experimental Psychology, 16 (5), pp. 644-656.

[4] Akulov, S. A. & Fedotov, A. A. (2014). Fundamentals of Biotechnical Systems Theory. PHYSMATLIT, Moscow, p. 259.

[5] Wasserman, P. (1992). Neural Computing: Theory and Practice. First Edition by (Author), Van Nostrand Reinhold, NY, United States.

[6] Lupandin, V. I. (2009). Mathematical Methods in Psychology, Ural Publishing House, p. 196.

[7] Ageev, I., Shishkin, G. & Eskin, S. (2007). Superheat radiation of man. International Conference “Cosmos and Biosphere”, Sudak, Ukraine, 2007, pp. 228-230.

[8] ADXL345 accelerometer;

https://www.robotev.com/product_info.php?products_id=372

[9] http://www.analog.com

[10] Bodrov, V. & Orlov, V. (2000). Psychology and Reliability: Man in Technical Control Systems, RAS.

[11] Hubenova, Z. & Metodiev, K. (2023). C-STAR simulator teaching experience. South Florida Journal of Development, Miami, 4 (6), pp. 2348-2358.

[12] Aleksandrova, D., Aleksiev, L., Ivanova, D., Hubenova, Z. & Metodiev, K. (2023). A Research on Visual Control of Flight Information Among Unmanned Aerial Vehicles Operators Via an Oculographic Method (Eye Tracking). 25th Congress of Balkan Military Medical Committee, Albena, Bulgaria.