MEASUREMENTS AND PERCEPTION IN MAN/MACHINE SYSTEMS

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Introduction and statement of problem

The report deals with a possibility to objectively determine (using purely instrumental methods) human sensor system parameters which influence his adaptability to natural and technogenic environment.

First qualitative studies of the human sensor sphere started more than a century ago. Probable, it was caused by the development of instrumental methods of natural objects. It was necessary to understand what was objective in the phenomena registered and what was inherent to human perception. In the course of these studies H.Helmholtz, E.G.Weber and G.T.Fechner grounded a possibility to introduce qualitative psycho-physical sensor scales, thus having made a principle break in the area which lies at the joint of psychology, physiology and physics.

The suggested psycho-physical methods of constructing qualitative sensor scales are based on a discovered human ability to give a stable qualitative comparison of different stimuli, acting upon a person, and on the application of these statistic estimations of testees subjective replies concerning quantitative relation between perceived stimuli. Long-year consequent studies resulted in a generalized Weber-Fechner law which is empirically proved for practically all modalities (types) of perception; according to this law quantitative degree of perception and stimuli are in power dependence [1]:

$$I(p) = I_0 \bullet (p/p_0)^{\alpha} \qquad (1),$$

where I and I_0 are subjective estimates of perception under the effect of p *and* p_0 stimuli, respectively, and α is parameter, different for various perception modalities (types).

A new rise of interest was associated with ergonomic problems, i.e. with the study of human interaction with different complex technical systems. The situation drastically changed with the appearance of man/computer systems, including computer- or microprocessor-controlled limb, auditory or ocular protheses. These has emerged a challenge of designing new human-computer interfaces that required a match of qualitative sensor data, used by a living organism for control, and quantitative data, used to control technogenic systems [2].

A new method of sensor scale introduction was suggested by us as an attempt to solve this problem [3-6]. This method is based on a very simple fact: a man when interacting with the environment uses his perceptions in the regime of feedback to control his functions (e.g. moving function). Hence, studying a relationship between instrumentally measured error in fulfilling a control task by a testee with the stimulus intensity, one may expect to get quantitative characteristics of perception.

The present report describes the results of experimental work on the investigation of muscle and audio analyzer sensor scales.

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Muscle analyzer
Scale of load perception

A muscle analyzer was studied when a testee was fulfilling a task to hold a load with his biceps [3, 4, 7]. To this end, the testee sat on a chair very straight and bend his arm at the elbow at right angle trying to keep loads of different weight which were fixed on a bracelet on his wrist. To guarantee the situation when the load is kept in equilibrium only due to the tension of a biceps only (without participation of other muscles, especially a triceps) electric activity of both muscles was controlled. Then, an accelerometer fixed on the same bracelet, registered spontaneous vibrations of the forearm (i.e. tremor) which were associated with an error of load keeping in the state of equilibrium. The registration was considered correct when the electric activity of the antagonist muscle (i.e. triceps) was small when compared to that of a biceps. Besides, to additionally confirm the fact that only a biceps is active, the spectrum of the loaded forearm tremor was controlled.

According to theoretical and experimental data obtained during previous experiments the frequency of extremum (approximately 2 Hz) in this spectrum does not depend on the mass of the load held if only a biceps is active [3, 4]. After that we studied the dependence of the extreme spectral component amplitude on the mass of the load held. The loads held were 1.0, 1.4, 2.0, 2.8, 4.0, 5.6 and 8.0 kg.

As it was theoretically shown in [3], this link is described by the function $a(p)$ which is derived from the function $I(p)$ where p in this case is load mass. Hence $a(p)$ should also be a power function with exponent of power being $(\alpha - 1)$.

Simultaneously in these experiments we reproduced a classical psycho-physical experiment for the same values of the held loads.

Experimental estimates obtained in a group of 13 trainees aged from 19 to 49 showed that the index of the function $I(p)$ lies within the interval 1.2 ± 0.1, that gives the estimate of the power exponent $a(p)$ 0.2 ± 0.1, i.e. in the interval from 0.1 up to 3. Power function index $a(p)$, determined based on the studies of tremor, lies within the interval of 0.35 ± 0.13, i.e. the interval from 0.22 to 0.48. It is evident that the intervals are overlapping and, as a result, the data obtained using psycho-physical and instrumental methods are not contradictory.

Acoustic analyzer
Perception of pitch and level of music tones

The following technique was used to qualitatively estimate a sound pitch by an acoustic analyzer. A testee was given a task to reproduce a musical sound of this or that pitch. A reproduced sound was registered by a microphone and via an analog-digital converter was put into computer memory. Then, using a specialized "SpectraLab" program, a time dependence of a momentary frequency of the registered sound signal was studied.

As a testee can "sing" only a vowel, several vividly expressed components – formants – were observed, while wide-band noise components were practically absent. It allowed to carry out reliable observation of formant frequency fluctuations in time. Fluctuations of the first formant were studied. Then, the dependence of these fluctuations on the frequency of the reproduced musical tone was investigated.

Test experiments were staged in a group of 4 trained singers of Nizhny Novgorod municipal chamber theatre. The testees were given 3 tasks each. Each task was to reproduce a series of 24 sounds. In the first series it was necessary to exactly reproduce a certain tone (played by the piano), in the second one - to sing it one octave lower and in the third series – one octave higher. The series were chosen specially for the pitch of the reproduced signal to lie within the audioband of the testee's voice. Sounds of 4 pitches were randomly included into each series. Thus, a sound of every given pitch was reproduced by a testee singer 6 times in each series.

The results of the investigation showed as follows:

1. Really, the frequency of the sounds reproduced by the singer fluctuates in time.
2. However, the deviation of its time mean value from that required by the task is statistically invalid, and a reliable interval is the smallest when tones are reproduced without any octave shift. This result proves that a control over the frequency of the reproduced signal is realized using a feedback. Finite operating speed and finite sensitivity of the control circuit lead to fluctuations.
3. The dependence of the frequency band of the main spectral component of tone sounds, reproduced by the voice, on the frequency of the reproduced tones is best approximated by the power function (correlation coefficient R lies within the interval of 0.89-0.91). For all three series an exponential index of the approximation curve lies within the interval of 0.89-0.94.

It means that instrumental studies confirm, that sound frequency perception is in agreement with Weber–Fechner exponential law and the exponential index of this dependence lies within the interval of 1.89-1.94. It was rather interesting that the data obtained for each singer were so similar that we managed to plot them on one graph and to construct a general approximation (See Fig.1).

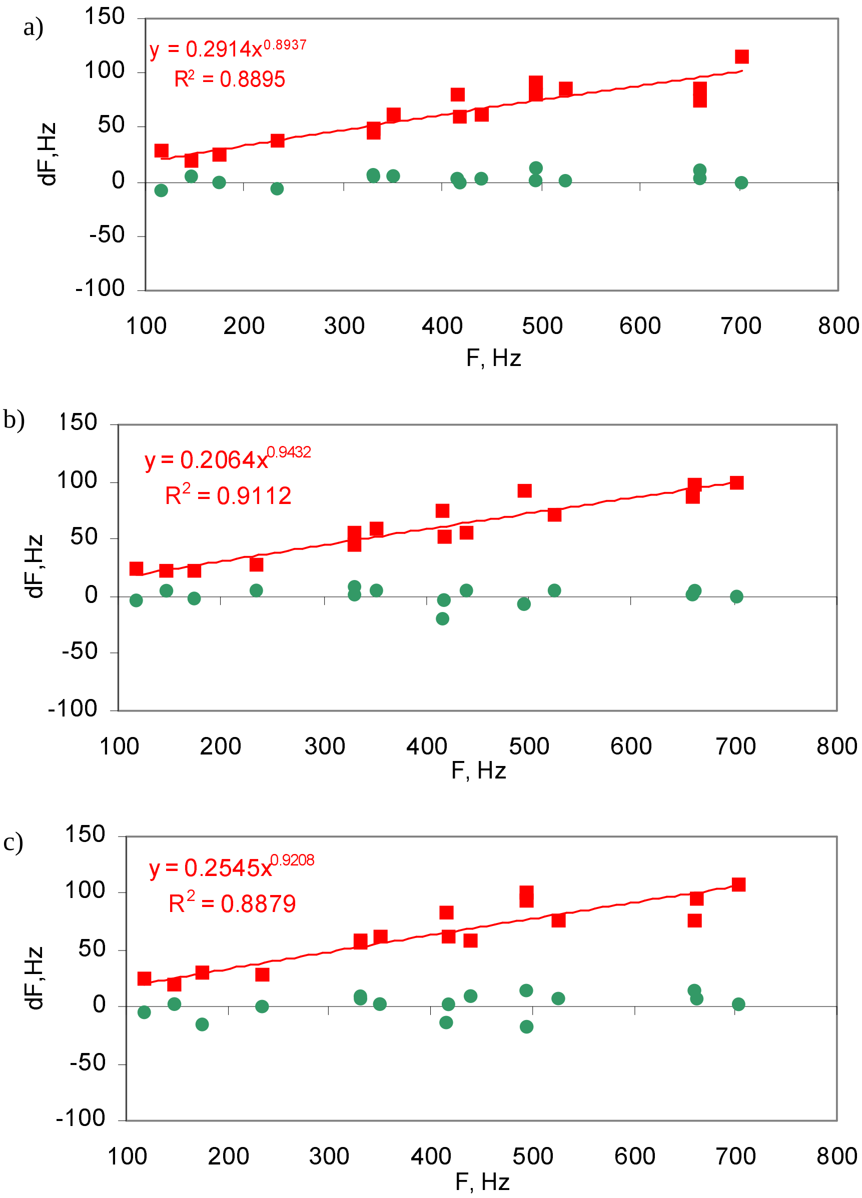

Fig.1. The dependence of the frequency band of the main spectral component of tone sounds, reproduced by the voice:

a) during reproducing by the singer of the sounds pitch;

b) during reproducing by the singer of the sound by one octave lower;

c) during reproducing by the singer of the sound by one octave higher

It seems that such (power) dependence of perception on the stimulus can be interpreted as some stability of a relative error, occurring when the acting physical stimulus is felt within the range of adequate loads. Probably, such interpretation is more simple and reasonable from the physical point of view.

A drawback of the technique suggested can be attributed to the fact that vocal range of singers rarely overlaps even 2 octaves. Thus, for each concrete trainee it is possible to estimate sound perception in the frequency range, which is much narrower than that within which this very man hears.

A similar technique was suggested to qualitatively estimate magnitude of sounds using an auditory analyzer. A testee was given a task to reproduce a musical tone of this or that pitch. The reproduced sound was registered by a microphone and via an analog-digital converter was put into computer memory. Then, using a specialized “SpectraLab” program the amplitude of the registered sound signal and its fluctuations in time were measured. After that the dependence of fluctuation values on the magnitude of the reproduced tone were studied.

The test group comprised 3 trained singers from Nizhny Novgorod municipal chamber theatre. Using special earphones, which allowed to hear both the record and ambient noises, the testees were offered the sounds of different magnitude whose pitch corresponded to their vocal range. The amplitudes of these sounds had one of the 7 values which were logarithmically linear distributed. The weakest sound was 8 times different from the loudest one and neighboring-in-magnitude sounds were different in amplitudes by $\sqrt{2}$ times. During the test testees themselves chose individual maximum magnitude of the test signal.

The task was to sing three series of sounds. In the first series it was necessary to reproduce the magnitude of the sound offered, in the second one-to sing twice as loud while in the third series the sound reproduced should be twice as low as a control one.

It turned out that none of the testees managed to cope with the problem. They could graduate their voice in magnitude and control it so that the magnitude of the reproduced sound, registered by a microphone, monotonously depended on the magnitude of the sound offered. However, none of them could overlap the required octuple range. The difference between the lowest and the loudest sounds was not greater than a triple one. We cannot eliminate a possibility that such discrepancy can be explained by the fact that a man can hear himself not only via the air, but also thanks to sound conductivity via bones.

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