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ABOUT THE ACCURACY OF VIBRAIMAGE TECHNOLOGY

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Abstract: *This theoretical and experimental study identified the most significant errors of the vibraimage technology. The experimental studies of vibraimage errors, including the study of random, systematic, methodological and instrumental errors, have been carried out. Developed and researched methods for assessing the accuracy of the psychophysiological parameters measurements of the subject using the vibraimage technology. The average resulting error of the vibraimage measurements within ± 6,1% was shown.*

Keywords: *vibraimage, psychophysiology, error, accuracy, measurement.*

Accuracy of measurement is studied by the science of metrology. Each country has adopted its own metrological standards, which differ relatively little among themselves. Modern metrology is focused on the measurement of physical quantities. A physical quantity is one of the properties of a physical object (physical system, phenomenon, or process) that is qualitatively common to many physical objects, which can be quantified [Metrology, 1999; JCGM 200, 2008]. Measurement accuracy is one of the measurement characteristics that reflects the proximity to zero of the measurement result error [Novitski, 1975, Guide 99, 2007]. Thus, it is correct to speak about accuracy only for measurement, the very question about the accuracy of technology sounds not quite correct. This is about the same as asking "what is the accuracy of Ohm's law or Fourier transform?" [99, 2007]. At the same time, the question "what accuracy does the vibraimage technology have?" is asked by almost every user, so I prefer to leave the scientifically incorrect title of this article, since it should be most closely and clearly understood by users of vibraimage systems. The measurement process is always a comparison with a measure [Novitski, 1975]. However, standardized measures (standards) for measuring the psychophysiological state (PPS) do not currently exist, which makes the question of the accuracy of the vibraimage technology even more difficult. In addition, it is not entirely correct to speak about the accuracy of the whole technology, since the vibraimage includes measuring more than a hundred different parameters, which are measured with different errors [GOST 34400.1, 2017; JCGM 100, 2008]. Despite these uncertainties, we will try to understand the accuracy of the vibraimage technology in this article.

From the above definition of measurement accuracy, it follows that accuracy is determined by various measurement errors. For a part of the technical applications of the vibraimage technology, the accuracy of measurements of the vibrations of mechanical objects depends on the errors in determining the parameters of the mechanical displacements of physical objects. However, most of the accuracy issues are not related to technical applications, but to the use of vibraimage technology, associated with the determination of the parameters of PPS or other characteristics of a person's personality. It should be noted that modern science basically avoids the term "measurement" in determining the characteristics of a person's personality. Most researchers talk about "assessment" [Wilhelm, 2006], "detection" [Gunavan et al., 2018] or "recognition" [Chavan, Kulkarni, 2012] when it comes to human emotions, behavior, abilities or PPS, although the term measurement is also used in psychology [Maus, 2009] and psychophysiology [Meiselman, 2016]. There are certain reasons for this, since most psychological research is focused on the qualitative assessment of personality characteristics, while measurement requires a transition to the quantitative properties of an object. However, most psychophysiological technologies that use the measurement of human physiological parameters to determine personality parameters measure physical quantities (electrical signal for EEG, ECG, GSR, mechanical displacement parameters for vibraimage), which means that it is permissible to speak about the measurement of personality parameters.

The aim of this study was to explore and determine the basic errors of the vibraimage technology during the direct conversion of measurand quantity [Novitsky, 1975].

Errors affecting to the accuracy of PPS parameters measurement by vibraimage technology

Consider the main types of errors [Novitski, 1975], affecting the accuracy of the result of the vibraimage technology, and try to evaluate them.

The instrumental error of the vibraimage technology (the error of measuring instruments) includes the errors of measuring the mechanical movements of a human head or any mechanical object. The error parameters for determining the mechanical displacements (frequency, amplitude) depend on the accuracy of measuring instruments and measurement conditions. They are mainly determined by the parameters of the used television camera (dynamic range, temporal noise, contrast), which, in turn, depends on the brightness of an object and processor parameters (performance). Most of these technical parameters are included in the calculation of the quality indicator during measurements [VibraMed, 2019]. When the quality indicator is close to 100%, the error of measuring instruments usually does not exceed ±5%, which can be checked by measuring the motion parameters of a test mechanical object having known motion parameters, for example, a fixed frequency of motion. Also to test the errors of mechanical displacements, test software objects were created and used for moving with a given discrete frequency of 1, 2, 4, 5, 6, and 10 Hz [Akimov et al., 2019; Vibraimage PRO, 2019]. The law of distribution of the mechanical displacements error is close to normal with a quality indicator of 100%. The main ways to reduce instrumental error are the use of recommended equipment, compliance with the recommended measurement conditions and control over the measurement quality indicator, which is implemented in most programs.

Additional (complimentary) error in the measurement of human PPS is associated with the instability of the measured psychophysiological parameters themselves. Human physiological parameters change over time due to natural causes, as well as under the influence of various external factors and stimuli. All programs vibraimage can be divided into two groups according to the principle of analysis of the PPS person. The first group of programs is intended for direct measurement of a quasi-stationary PPS without external stimuli. From the point of view of measurement theory, these are direct-conversion measuring devices. These include the programs VibraMed [VibraMed, 2019] and VibraMid [VibraMid, 2019], respectively, the Micro and Macro modes in Vibraimage PRO version [Vibraimage PRO, 2019]. The second group of programs [VibraMI, 2019; VibraPA, 2019] is intended for comparative measurement of changes in PPS under the influence of presented stimuli. According to the theory of measurement, these are measuring devices of a balanced transformation [Novitski, 1975]. If emotional instability is a problem and an additional error for the programs of the first group, then for the parameters of the second group, the emotional instability of the subject leads to an increase in the measured PPS differential and a decrease in this error [Minkin, Nikolaenko, 2017]. Studies show significant instability of most physiological parameters [Minkin, Myasnikova, 2018] and the possibility of their changing within 10–20% even during short testing from one to seven minutes The error of instability of the measured value directly affects the resulting error, especially for the programs of the first group. The most effective method of reducing this error and other random errors is averaging the results. The average median value is more resistant to significant outliers, so this estimate is used in the VibraMed program to determine the measured value of the parameter during the measurement time. The error in the instability of the PPS has a random distribution law, if there is no one-sided trend of changing the PPS during the measurement. It was experimentally established [Minkin, Myasnikova, 2018] that 1 minute is enough for the absence of a one-sided trend in changing the PPS, but a decrease in the testing time can lead to a significant increase in the error due to the instability of the PPS.

The methodological error (error of method) of the vibraimage technology is determined, first of all, by the correctness of the proposed model for converting the mechanical parameters of moving a human head into psychophysiological or personal parameters of a person. The transformation models were investigated during the development of the vibraimage technology [Minkin, Shtam, 2000; Minkin, 2018; VibraStat, 2019] and are based on previous studies in the physiology of activity [Darvin, 1872; Sechenov, 1965; Pavlov, 1927; Bernstein, 1967; Lorenz, 1966]. Currently, the evaluation of the accuracy of modeling the parameters of the PPS is of considerable complexity, because there are no alternative generally accepted and standardized methods for measuring the PPS. However, the openness and reproducibility of methods for determining PPS parameters by vibraimage technology for all researchers allows you to quickly adjust the developed methods. For example, for multiple intelligence, the Gardner-Minkin-Nikolaenko model [Gardner, 1983; Minkin, Nikolaenko, 2017] was adjusted after collecting statistics for more than 500 subjects [Minkin et al., 2019]. Despite the seemingly complete uncertainty of the methodological error, it can also be assessed, knowing the other measurement errors, the total measurement error and the known laws of the distribution of measurement errors.

Method and Participants

In this study, the accuracy of the vibraimage technology was assessed by two experiments.

In the first experiment, 100 measurements of one person's PPS were performed using the VibraMed10 program [VibraMed10, 2019] installed on an HP EliteBook 840G2 computer with an i7-5600 CPU 2.60 GHz processor with an externally connected MS LifeCam Cinema webcam.

Measurements were taken on January 30, 2019, for 2 hours from 11.00 to 13.00. The program settings of VibraMed10 are set to Micro by default, the resolution of the webcam is set to 640 × 480 elements. The subject was located at a distance of 40–50 cm from the camera, the size of the head of the subject in the image was approximately 200 elements. The illuminance of the subject was uniform, stable, and was 600 lux during testing. The LifeCam Cinema camera was located opposite the subject's face.

In the second experiment, 50 measurements of the same person's PPS were performed using the VibraMA program [VibraMA, 2019] installed on a Samsung Galaxy S8 mobile phone with a Snapdragon 835 processor with an integrated main camera. The measurements were carried out on February 4, 2019, for 2 hours from 11.00 to 13.00 hours. The settings of the VibraMA program are set by default, the resolution of the camera is 800 × 480 elements. The subject was located at a distance of 40–50 cm from the camera, the size of the head of the subject in the image was approximately 200 elements. The illuminance of the subject was uniform, stable, and was 600 lux during testing.

Measurement results

Consider the results of computer-based testing of the PPSs (Table 1), choosing the measurement standard deviation (MSD) for the basic error estimate [Novitski, 1975] (experimental standard deviation) [JCGM 100, 2008], especially since it coincides with the standard deviation (SD), which is automatically determined by the VibraMed10 program for each main parameter of the vibraimage (T1–T10).

Table 1

The results of 100 measurements of PPS parameters T1–T10 and I-E, divided into group 1 (first 50 measurements), group 2 (subsequent 50 measurements) and combined into one group. M — the average value of the parameters, б avg — the average value of the standard deviation in the group of measurements (SD), б(M) — measurement standard deviation (MSD)

PPS Parameter	M1 avg %	б1 avg %	б1(M) %	M2 avg %	б2 avg %	б2(M) %	M avg %	б avg %	б(M) %
T1	33,21	4,24	3,98	32,06	3,95	2,94	32,63	4,09	3,55
T2	31,24	3,76	3,28	29,28	3,69	2,43	30,26	3,72	3,05
T3	26,30	9,74	6,66	20,83	10,07	3,07	23,57	9,91	5,86

Table 1 *(end)*

PPS Parameter	M1 avg %	Ϭ1 avg %	Ϭ1(M) %	M2 avg %	Ϭ2 avg %	Ϭ2(M) %	M avg %	Ϭ avg %	Ϭ(M) %
T4	30,69	4,05	3,60	27,82	3,86	1,56	29,25	3,95	3,12
T5	62,31	7,87	6,22	65,87	7,67	5,84	64,09	7,77	6,29
T6	72,21	2,01	1,91	70,75	2,14	1,34	71,48	2,08	1,81
T7	18,42	2,83	2,51	18,74	2,94	2,49	18,58	2,89	2,51
T8	67,28	4,28	3,49	68,32	4,17	3,12	67,80	4,23	3,35
T9	14,37	3,85	2,47	15,92	4,65	1,53	15,14	4,25	2,20
T10	38,45	14,23	11,29	46,46	18,35	10,67	42,46	16,29	11,69
E	28,81	2,46	3,14	28,35	2,75	3,05	28,58	2,61	3,05
I	47,95	6,10	5,67	51,66	5,47	5,14	49,81	5,79	5,14
dP	–0,02	0,00	0,09	–0,01	0,00	0,09	–0,01	0,00	0,09

The data in Table 1 shows that the spread of the MSD between different parameters is from 1.34 for the parameter T6 of group 2 to 11.29 for the parameter T10 in group 1. The average value of the MSD over 100 measurements of the parameters T1–T10 was 4.34%. At the same time, the spread of the MSD for the same parameters between groups 1 and 2 is significantly less than the spread of the parameters of the MSD in each group.

Consider the similar comparative results of computer and telephone testing of the PPS (table 2), choosing measurements standard deviation (MSD) error as the basic error estimate.

Table 2

The results of 150 PPS measurements of the parameters T1–T10 and I-E, divided into group 1 (50 mobile measurements), group 2 (100 computer measurements) and combined into one group. M is the average value of the parameters, M is the average value of the parameters, Ϭ avg is the average value of the standard deviation of the measurement group, Ϭ(M) is the measurement standard deviation (MSD)

PPS Parameter	M1 avg %	Ϭ1 avg %	Ϭ1(M) %	M2 avg %	Ϭ2 avg %	Ϭ2(M) %	M avg %	Ϭ avg %	Ϭ(M) %
T1	49,00	3,54	5,04	32,63	4,09	3,55	38,09	3,91	8,74
T2	23,67	1,92	2,26	30,26	3,72	3,05	28,07	3,12	4,19
T3	21,59	7,97	3,75	23,57	9,91	5,86	22,91	9,26	5,33

Table 2 *(end)*

PPS Parameter	M1 avg %	б1 avg %	б1(M) %	M2 avg %	б2 avg %	б2(M) %	M avg %	б avg %	б(M) %
T4	31,43	2,85	1,72	29,25	3,95	3,12	29,98	3,59	2,92
T5	71,56	3,76	2,92	64,09	7,77	6,29	66,58	6,43	6,45
T6	75,76	4,38	4,91	71,48	2,08	1,81	72,91	2,85	3,78
T7	36,99	2,94	5,52	18,58	2,89	2,51	24,72	2,90	9,47
T8	73,62	3,28	2,06	67,80	4,23	3,35	69,74	3,91	4,06
T9	22,15	3,12	1,71	15,14	4,25	2,20	17,48	3,87	3,89
T10	31,15	6,56	8,18	42,46	16,29	11,69	38,69	13,05	11,91
E	48,65	2,35	10,46	28,58	2,61	3,05	35,27	2,52	10,39
I	41,29	2,67	6,46	49,81	5,79	5,14	46,97	4,75	6,48
dP	–0,01	0,00	0,08	–0,01	0,00	0,09	–0,01	0,00	0,08

The data in table 2 show that the spread of MSD between different parameters goes from 1.71 for the parameter T9 of group 1 to 11.69 for the parameter T10 in group 2. At the same time, the spread of MSD for the same parameters between groups 1 and 2 is significantly less than the variation of the parameters of the MSD, and the combination of groups 1 and 2 gives a large error (the average value of MSD = 6.1%), due to the addition of instrumental error.

For errors estimation is necessary to know the law of changing for the measured value [Novitski, 1975]. Most of the measured parameters T1–T10 are based on the calculation of the average frequency of the vibraimage (energy characteristic) and the standard deviation of the vibraimage frequency (information characteristic). Consider the distribution density of these values (fig. 1 and fig. 2) for computer and mobile measurement of the PPS.

The given distributions are far from the normal distribution law, which most likely indicates the presence of not only random error in measurements, but also the presence of systematic errors in the captured data.

Discussion of the measurement results

We will try to understand how accurately we can determine the measurement error for the experiment performed. The main advantage of estimating errors by the standard deviation of the measured value is that the total standard deviation includes the sum of all errors of the standard deviation [Novitski, 1975, Shanon, 1946], and this is true for any law of distribution of the measured value in the absence of a correlation between the analyzed errors.

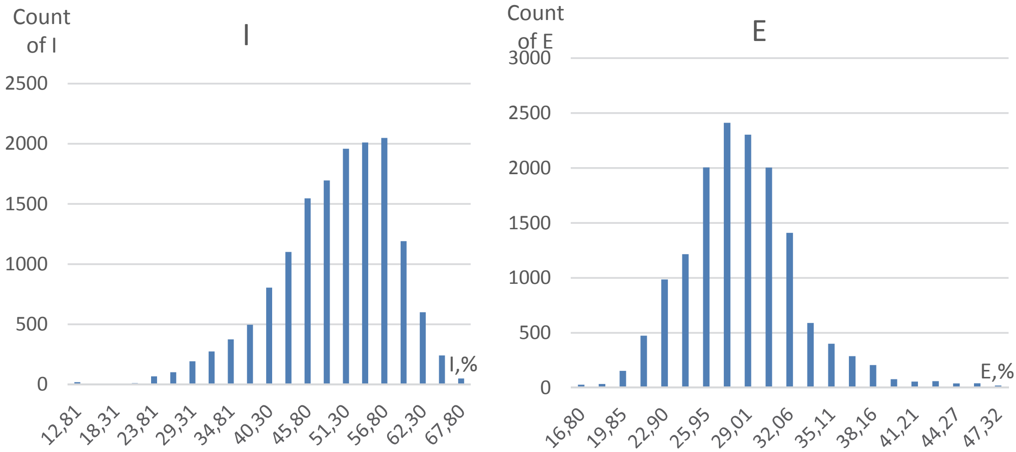

Fig. 1. Distribution of information and energy characteristics in computer measurements

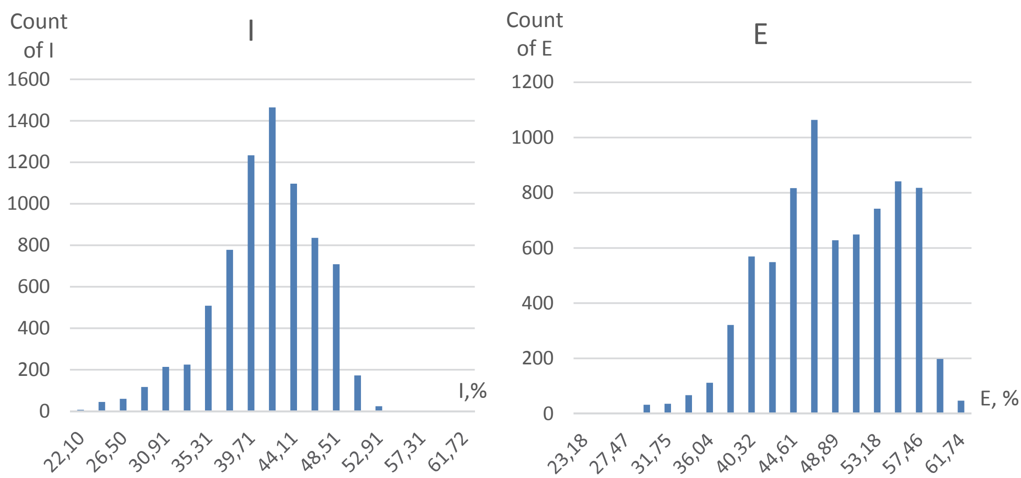

Fig. 2. Distribution of information and energy characteristics for mobile measurements

The existence of a correlation between the instrumental, additional, and methodological errors analyzed is difficult to predict; therefore, formulas 1 and 2 should be used to estimate the errors.

$$\sigma_\Sigma^2 = \sum_{i=1}^{n} \sigma_i^2. \quad (1)$$

From this follows that in the presence of three basic errors, each individual of them will be less than the total and is determined by the formula:

$$\sigma_1 = \sqrt{\sigma_\Sigma^2 - \sigma_2^2 - \sigma_3^2} \quad (2)$$

The number of measurements made for each measured value is approximately 150 counts for each PPS testing, and for 100 testings it is 15,000 samples, which makes it possible to estimate the accuracy of the measurements made with a confidence level not lower than 0.997. In the measurement theory, it is customary to estimate the limiting measurement error $\Delta = 2\sigma = \pm\sigma$ [Novitski, 1975].

Consider the results of table 2 comparative testing of PPSs on a mobile device (M1) and PC (M2) in the form of a histogram in figure 3, drawing attention to significant differences in the value of the measured mean values of the parameters M.

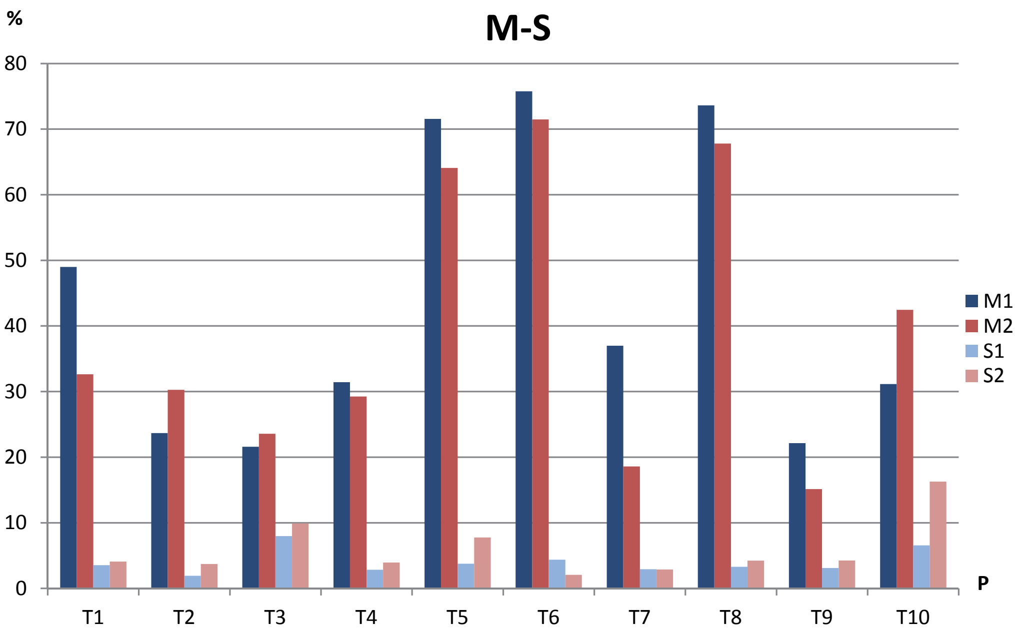

Fig. 3. The results of M and the standard deviation of 150 measurements of parameters T1–T10 PPS, divided into group 1 (50 mobile measurements) and group 2 (100 computer measurements). M is the average value of the measured parameters, S is the SD of the measured parameters

The given values of M show significant differences that exceed the measurement error of the parameters within each group, primarily for the parameters T1, T7 and T10, i. e. indicate a noticeable instrumental error. To understand the causes of this phenomenon, it is necessary to move away from the theory of measurements to the technology of vibraimage. The main difference in the compared groups is the differences in the photodetectors used in this experiment. The Samsung S8 mobile phone uses a low-noise CMOS matrix made using the backside technology, the main advantage of which is increased sensitivity and low level of own noise. The LifeCam Cinema webcam is equipped with conventional CMOS (frontside), the sensitivity of which is about 4 times lower than that of the backside [Lesser, 2015]. Vibraimage technology is based on the calculation of elements having a different signal level [Minkin, 2007, Akimov et al., 2019], so the threshold sensitivity of a photodetector is of primary importance when calculating the original vibraimage. For a contrast object, differences in the threshold sensitivity of photodetectors may not be as significant as in the analysis of a low-contrast human face. For a low-contrast object, its vibration image upon vibration is directly proportional to the threshold sensitivity of the photodetector, i. e. if a low-sensitivity photodetector with sensitivity S sees N changed elements, then a highly sensitive photodetector with 4 S sensitivity sees 4 N changed elements. Theoretically, such an increase in the number of elements does not have to affect the change in the average value, but judging by the experiment, the shape of the distributions (histogram of the frequency of vibrations) turns out to be different, the best camera sees more vibrations, and the average value of vibrations determined by the camera with high sensitivity and clarity is higher which is consistent with one of the basic principles of obtaining an ideal vibraimage [Minkin, 2008]. The ideal vibraimage was explained as vibraimage, in which ALL points with a changed signal are defined. Naturally, the best camera sees more points than the camera with the worst parameters. That is why the parameters T1 and T7, the calculation of which is based on the average value of the frequency of vibrations, are higher in the group of mobile measurements with the best camera. The reverse picture is observed for the parameter T10, which is associated with the determination of the variation of the period of the vibraimage image signal. The best in parameters (sensitivity, clarity) camera is more stable and more accurately measures the value of the vibraimage signal, therefore the parameter T10 defined on the mobile device shows a smaller value. The remaining parameters of the vibraimage characterize the spatial and temporal characteristics of the vibrations, they turn out to be not so sensitive to the total number of identified vibration points. For example, parameter T3 characterizes the ratio of high and low vibration frequencies. This ratio is stable and does not depend on the total number of elements of the vibraimage. As for the methodological error of the parameters of the vibraimage, it is rather difficult to evaluate it at the present time, since there are no other generally accepted methods and standards for determining the psychophysiological parameters and the psychophysiological state of a person. Existing methods for assessing psychophysiological parameters provide only qualitative characteristics [Chavan, 2015], and measurement methods do not provide any accuracy indicators [Mauss, 2009; Meiselman, 2016]. The standard for assessing the accuracy of psychological data [Standard, 2014] is based only on the processing of a person's conscious reaction and does not include psycho-physiological responses; therefore, the accuracy declared in it has not practical relation to the actual behavior and measurement of the human psychophysiological parameters.

The vibraimage technology, according to the developers reports, is the first open technology of psychophysiological detection, calculating ANY psychophysiological parameters using open algorithms [Minkin, 2000; Minkin, 2018; VibraStat, 2019, Minkin, 2019]. This approach allows customers to adjust algorithms for measuring PPS and minimize the methodological errors after the set of statistical results.

Conclusions

This study is practically the first comprehensive research and analysis of direct-conversion vibraimage systems errors. Separate studies of vibraimage errors were carried out earlier, although they were not identified as independent works. For example, [Minkin, 2017] analyzed the noise of various chambers (similarly to the analysis of instrumental error), and [Minkin, Nikolaenko, 2017] investigated the stability of the measured parameters in comparative testing (similarly to the analysis of the errors of the balanced conversion method in metrology).

The main objectives of this work were metrological examination of vibraimage technology, finding ways to improve accuracy for developers and developing proposals for reducing errors for users. The conducted research allows drawing the following conclusions:

1. The average value of the marginal error of measurements of psycho-physiological parameters was ±6.1% (without instrumental error ±4.3%). This value is a rather low value for measurement errors of psycho-physiological parameters compared to data from analogs [Shmelev, 2010; Kosti, 2017], the resulting error (20–50)%, which considers good results, indicates a highly informative vestibular-emotional reflex [Minkin, Nikolaenko, 2008] as an indicator of the PPS.

2. The instrumental error can make a significant contribution to the errors of vibraimage. The parameters of a television camera (sensitivity, clarity, dynamic range, temporal noise) have a significant impact on the result, for individual parameters the instrumental error can reach ±4%. However, when collecting statistics and obtaining verified dependencies of the PPS on the factor under study on one hardware, the instrumental error has only a minimal effect on the result. Therefore, users of vibraimage systems should collect their own statistics on specific hardware and use it when determining the parameters of the PPS, this allows to significantly reduce the instrumental error.

3. The systematic error is mainly determined by the additional error associated with the one-sided trend from changing the PPS under the influence of external factors (time, incentives); it is not eliminated by averaging the measurement results used in each test. However, the one-sided trend of changes in psycho-physiological parameters in the quasi-stationary state of the subject does not exceed ± 3% per hour and rarely can be long in time. At the same time, the free oscillations of the PPS parameters in a short time (within a minute) significantly exceed the slow trend and can be up to ± 10% for individual PPS parameters (the anxiety parameter in table 2), which does not allow for significantly reducing the measurement time without loss of accuracy.

Studies have shown that currently the technology of vibraimage has minimal errors in measuring the parameters of the PPS in comparison with the known analogues [Polonnikov, 2013; Gunavan, 2018]. At the same time, there are significant resources to improve the accuracy in measuring individual parameters of the PPS, these reserves relate to the refinement of both hardware and software vibraimage.

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