XIX IMEKO World Congress
Fundamental and Applied Metrology
September 6−11, 2009, Lisbon, Portugal

MULTIPARAMETRIC MEASUREMENTS OF EMOTIONS

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Abstract − A concept of the model intended for measuring emotions is grounded. The efficiency of evolutionary analysis when forming the model of measuring the emotions which are contained in acoustic and visual impacts is demonstrated. The possibility to develop a corresponding measurement instrument is shown.

Keywords: measurement of emotions, acoustic impacts, visual impacts.

1. INTRODUCTION

An emotion is the sense that arises in an individual in the course of perceiving the reality-life. The emotions motivate, organize and direct perception, thought, and actions [1]. To present day, a unified and consistent theory of emotions has not been formed.

Evolution of arts, human sciences and some branches of industry requires the development of measurement methods and measuring instruments, which can provide identification and quantity evaluation of the emotions connected with perception and interpretation of acoustic and visual impacts. Such stimuli carrying an emotional content are specific sound signals, music, speech intonations, advertisements, TV-programs, shows, etc.

A demand to develop decisions allowing to optimize an original acoustical or visual impact for getting a maximum expression at a minimum cost, arises.

Using the results of panel tests (self-report responses to verbal questions to assess participants' current feeling) or of biophysical tests for predicting an expected response to a new acoustical or visual impact can result in gross errors.

The emotions accompanying the human perception of acoustical or visual impact can be evaluated with the help of reliable measurements of a set of parameters characterizing this impact.

Measurement is here defined in accordance with [2], in the wide sense, as a process of empirical, objective assignment of symbols (names) to attributes of acoustic and visual impacts, in such a way as to represent them, or to describe them.

Psychologists and physiologists have not developed the consistent model linking the emotions with the stimulus parameters and enabling to realize objective measurements. The problem complexity is redoubled by the fact that there are no unambiguous indices of emotional state and there is no any generally accepted classification of emotions. Many authors divide the emotions into pair indices: happiness - sadness, pleasure – disgust, and so on. Combination of various types of emotions reflects their variety.

In order that the measurement results will not significantly depend on subjective features of an experimenter, it is necessary to provide their metrological traceability, i.e. the results should be related to a reference.

In a common case, this requirement can be interpreted as the need to have:

- - established measurement model and an appropriate equation linking a required quantity, Z, with each of parameters x_i, measured, where $1 < i \le n$, n is the number of different parameters;
- capability to relate each of the parameters measured with a reference established for this parameter. The reference can be a definition of a measurement unit through its practical realization, or a measurement procedure, or a measurement standard [3].

2. GROUND FOR THE MODAL OF MEASURING THE EMOTIONS

The authors suggested a measurement model [4, 5] which is based on the hypothesis evolved below.

Needs of living organism to have sensor systems appeared in the process of evolution in connection with the need to perceive signals stimulating readiness for action. These signals were the signals warned about approaching natural disasters, enemies, as well as “food” or a male (female) animals.

The term “signal” means here a change in the environment, which is registered within a short period of time. For living creatures which appeared on the Earth in the ocean, the system providing the sense of touch became the most important sensor system [6]. This system is responsible for the ability to perceive medium density changes (oscillations) in the infrasonic frequency range, as well as in the lower part of the audio range (hereinafter, all this frequency range will be referred to as the IF one). Since sound is the process of transferring the energy of mechanical oscillations of particles in an elastic medium, then it is possible to make a conclusion that the prototype of the auditory system originated at the earliest stages of life formation.

When reptiles left water and settled on land, where the density of a medium surrounding a large part of their bodies was significantly less, their sensitivity to IF oscillations giving signals of danger, sharply decreased.

The necessity for reptiles to keep the ability to respond

ISBN 978-963-88410-0-1

to IF signals, resulted in emerging an additional sensor system, i.e. the system of hearing (auditory system) [7]. This system contributed to extending the range of oscillations being perceived to the zone that is characteristic for a medium of lower density and higher mobility (air). At the same time, the auditory system provided the possibility to detect IF oscillations in the oscillations of the sound frequency (SF) range.

The mechanism of IF oscillation recognition can be explained by the hypothesis of the authors, that in the "ear-brain" system, the memorization and non-linear conversion of the SF oscillations is realized. After non-linear conversion, IF oscillations which are the signals- stimuli [5] are detected (revealed).

Response to the important signals-stimuli is determined, obviously, by identifying the closeness of their frequencies to the frequencies of biorhythms. For a human, the IF oscillations are also emotionally important. They can cause panic; a long stay in silence stimulates depression. Evidently, the reception of signals confirming that the environmental processes take place in a regular way, contributes to emotional harmonization of behaviour.

The advent of a homo sapience and further development of human society are connected with a more noticeable differentiation of dangers and a more developed palette of emotional reactions. A Cro-Magnon man (unlike the Neanderthal man) survived because he managed to enrich the IF oscillations he used, having put into them an emotionally rich logical content along with comparatively simple emotions: he learned the art of speech [8].

An IF oscillation characterized by a specific amplitude and frequency, is the signal-stimulus defining an elementary emotional response. This response is the emotional stress that prepares some action and has a minimum content. It causes the sense of fear, aggression, or happiness depending on the signal-stimulus parameters and additional information, previous and expected.

Enrichment of emotional information takes place due to formation of emotional images on the basis of small ensembles of signals-stimuli and then on the basis of combining such ensembles. Concept of such a kind resembles a speech with a limited number of sounds, incommensurably wider set of words and practically unlimited possibility to transfer substantial logical information. Other sensor systems of living organisms appeared afterwards, but they developed, evidently, in the same way.

As we think, the emotions arising due to perception of visual stimuli are basically formed by the way of combining sets of stimuli too. An eye successively selects variations of a light flow, forming signals-stimuli and their ensembles. A significant part of these ensembles, as in case of their formation for auditory impacts, was caused by the necessity to identify vitally important events, i.e. fire or thunderstorm. However, the visual perception originating is a significantly later progress of evolution than the auditory perception one. Moreover, for human and developed mammals, many ensembles of signals-stimuli continue their formation with participation of logical thinking. They are associated with the generalization of the concepts of objects giving rise to danger, forthcoming pleasure, and so on.

Thus, in accordance with the hypothesis put forward by the authors, any auditory or visual stimulus carrying emotional information for a man, is converted in the system "ear-brain" or "eye-brain" into a succession of signals-stimuli, the perception and recognition of which in an associated sequence give rise to emotions.

Each of the signals-stimuli can be characterized by a number of parameters which can be measured. The mechanism of emotion formation can be simulated in the form of a "black box" that performs functions of the "ear-brain" or "eye-brain" system.

The emotion measurement equation can be written as:

$$Z=f\,[Y_1(x_1, x_i \ldots x_n), Y_2(x_1, x_i \ldots x_n), \ldots, Y_m(x_1, x_i \ldots x_n)],$$

where $Y_1, Y_2, \ldots Y_m$ are the signals-stimuli and m is the number of various signals-stimuli generating the whole set of emotions examined, $x = x\,(t)$, t is time. The time interval between the first and last stimuli does not exceed the value of T, which characterizes the system lag.

In determining the relation between signal-stimulus parameters and emotion, statistically stable estimates of emotional colour of musical fragments and visual images can be applied. In spite of the fact that the existing emotion classifications made by different authors are ambiguous, it is possible to separate the reactions which differ in quality, for example, "happiness" and "sadness", as well as the reactions which differ in quantity, in particularly, "light sadness" and "grief".

3. EMOTIONAL IMAGES ON THE BASIS OF THE SEQUENCE OF SIGNAL-STIMULI

Harmonic tonal music permits for a researcher to get some analogue of the Rozetta stone that made it possible to decode hieroglyphic written text on the basis of the text duplicated using a known language. In such music, sequences of the tonal chords of relative tonalities (over steps I-IV-V) form the simplest images carrying emotions, e.g. meditativeness, grief, detachment (aloofness), or happiness. It is essential that the emotional colouring of such an image is statistically stable for a definite key and tonality in case of the classical way of performance [9]. (Modulations as well as change of timbre, tempo, and articulation change the spectrum of IF oscillations, and, accordingly, influence on emotional colour.)

The above hypothesis was tested for harmonic tonal music. A calculation analysis of the spectrum of combinational components generated due to the interaction of SF oscillation combinations corresponding to tonic triads in the non-linear converter, has confirmed the following.

- In this spectrum the IF combinational oscillations (the signals-stimuli) are formed.
- Parameters of the IF combinational oscillations, i.e. frequency and level, depend on a tonic.
- The major key is characterized by IF oscillations of a higher level as compared to the minor key.
- The lower part of a sound scale both in the major key and in the minor key forms powerful IF components, and the higher part of the sound scale does not practically form any IF components. As a result, in the lower part of the sound

scale, music acquires a “major” hint, and in the higher part it has a “minor” hint.

- For the ancient Pythagorean scale (characterized by a higher expressiveness), the difference between various tonalities with regard to IF components is significantly greater than for the equally tempered one.
- A melody can form IF oscillations only in the non-linear system having memory (lag effect).

Identification of the emotions caused by signals-stimuli and their ensembles should be based on statistically reliable estimates of emotional reaction of listeners.

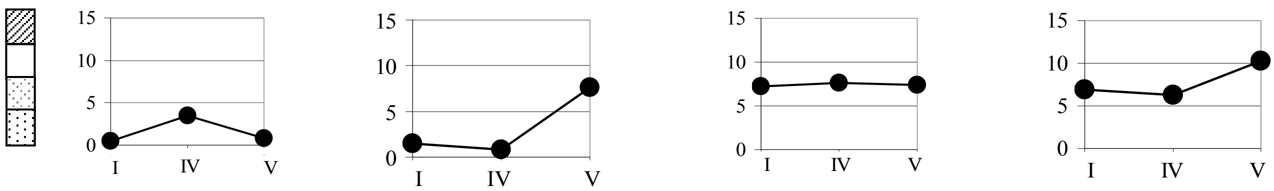
In the scientific literature, we could not find experimental data which would give an opportunity to define the emotional content of signals-stimuli.

To identify the emotions produced by the simplest ensembles of signals-stimuli, the estimates of the emotional response of listeners to fragments of musical compositions written in definite tonalities of harmonic tonal music were used. They were obtained on the basis of a durable experience of an art-therapeutist [9].

Fig. 1 illustrates the formation of the simplest emotional images on the basis of a sequence of chords of relative tonalities, calculated for a small octave. In Fig 1, a), b), c), and d) relate to the major tonalities, while e), f), g), and h) relate to the minor ones; value of order "p" determines a degree of non-linearity of the conversion function, required for forming an IF combination component. Usually, the component level quickly falls with the rise of the p value.

It is interesting that the character and location of the presented functions in the space of biorhythms, permit to judge about the emotional colouring of an image without addressing to a name of a corresponding musical composition. Correlation between the impression from graphical representations of emotional images displayed in Fig. 1 and emotional reaction to appropriate musical fragments, apparently, takes place due to the analogy between the models of perception of acoustic and visual impacts.

According to the results of an analysis, the equation of conversion for the measurement model can be expressed by polynomial of the 9th power.

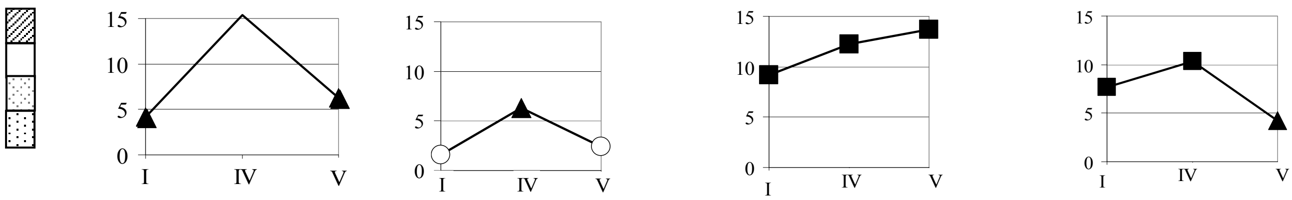


a) Fis-dur, “meditativeness”

b) As-dur, “great energy and more joyful mood”

c) H-dur, “energy, triumph with a transfer to calm and harmony”

d) A-dur, “happiness”



e) as-mol, “detachment" (aloofness)"

f) h-mol, “detachment, transfer from mournful insensibility to tragic mood”

g) e-mol, “bright sorrow, dreaminess”

h) cis-mol, “fantasy, dream, transfer from a day-dream to detachment and grief"

Fig.1. Formation of the simplest emotional images on the basis of a sequence of chords of relative tonalities in a small octave (a dependence between frequency, f, Hz and a step number)

the zone of delta-rhythms; the zone of theta-rhythms; the zone of alpha-rhythms; the zone of beta- rhythms

● p=4; ▲ p=5; ■ p=6; ○ p=9

Last decades, a special audio guidance technology (Hemi-Sync**)**, which was developed and patented by Mr. R. Monroe, is under discussion [10]. This technology is based upon the binaural effect that works by sending different sounds (tones) to each ear through stereo headphones. The two hemispheres of the brain then act in unison to “hear” a third signal – the difference between the two tones. This is not an actual sound, but an electrical signal that can only be perceived within the brain by both brain hemispheres working together. The effect of the technology is explained by stimulating of the brain, which is realized if the binaural beat frequency is close to the frequency of the biorhythms.

The influence of acoustic beats on the condition of a listener goes with the hypothesis given above. However, to explain the formation of IF oscillations which, according to [4, 5], cause emotions, by the binaural beats only is impossible. Such a concept would contradict the fact that music excites the listeners who have one defective ear.

Moreover, it is known that two hemispheres of the brain can process information both in parallel and independently. At the same time, the interaction of the hemispheres is not continuous and voluntary.

4. INFLUENCE OF THE FREQUENCY OF SIGNAL-STIMULUS ON THE FORMATION OF EMOTIONAL IMAGE

Further specification of the measuring model requires for revealing relationships between signals-stimuli and emotions. One of the available fields of investigation is the sphere where the spectrum of the simplest emotional images arising as a result of acoustic signals, has bright and clear emotional colour. Therefore, at the new stage of research an emphasis was made on the analysis of ethnic and ancient religious music with a preliminary given emotional mood.

With that end in view, at the D.I. Mendeleyev Institute for Metrology, software "Music 1.0" has been developed. It was designated for analyzing sound files of wav-format.

Software includes a virtual four-pole network, the conversion function of which is described by a polynomial of the power "*k*" ($k \leq 11$). Polynomial coefficients, measurement time and delay time are given by a user. The measurement time should be less that a half of input signal duration. Software enables to calculate the spectrum of input and output data by executing the Fourier-transform. The latter provides convenient visualization of frequency decomposition of a complicated stationary signal into the simplest oscillatory functions. A frequency range of the spectrum being analyzed at the four-pole network output, can be adjusted within a wide range.

(For subsequent researches, taking into account the non-stationary character of data, another version is being developed which is based on some other kind of conversion.

With the help of the above version of the program, there was made an analysis of the fragments of African ethnic music with specific titles “Festival” (Fig. 2),“Fear” (Fig. 3), and “Nightmare” (Fig. 4), performed on drums. The figures show the IF spectra (up to 16 Hz) at the pole network output after the non-linear conversion.

Taking into account that the spectrum of the drum sound lies in the band of low frequencies, the conversion function, for a greater obviousness, has been assumed as the quadratic one (k=2). Measurement time was set about 4 c.

The mechanism of measurement of emotions is shown, usinig the examples given below.

Fig. 2 – 4 show the difference of the IF oscillation spectra and a small number of maximums (signal-stimuli) in these spectra which determine an expected emotional response of listeners. To reveal the emotional content of such images, it is necessary to analyze the relationship between the frequencies of IF maximums and the biorhythms frequencies. In particular, a minimum frequency of a signal-stimulus for the fragment “Festival” is near 4Hz, which corresponds to the field of the theta-rhythm; for the “Fear” sounding it decreased approximately to 2.8 Hz, passing into the zone of the delta -rhythm; for the fragment “Nightmare” it fell down and became less than 2Hz. The “Festival” is characterized by comparatively low level of maximums in the band of the 2nd and 3rd harmonics of the signal-stimuli (the field of alpha- rhythm). At the same time, these maximums are smooth. The spectra formed by the "Fear" and especially by the "Nightmare" contain the increased number of maximums, which are sharper than in the previous case.

Representatively, that for the "Fear":

- in the band of the 2nd harmonic of the signal-stimulus (the zone of theta – rhythm) the maximum is blurred,
- in the band of the 3rd and 4th harmonics (the zone of alpha – rhythm) the maximums are higher than the 1st one.
- even in the band of the 5th harmonic (the zone of beta – rhythm) the value of the maximum and the square under it are close the those for the 1st one.

The "Nightmare" forms noticeable maximums near the 2nd and 3rd harmonics (the zone of delta – rhythm), some picks (including the highest one near 7 Hz) in the zone of theta – rhythm, and significant maximums in the zones of alpha - and beta – rhythms.

The relationship between activated biorhythms of the brain and an wakeful man's condition is shown in Table 1.

The information given is in a good correspondence with the data of the IF spectrum analysis. The analysis shows that the frequency of a signal stimulus defines a basic emotion.

With appearance of a signal-stimulus in the zone of delta- rhythm, a troublesome mood arises. The less the frequency of the signal-stimuli, the more is the level of expected danger. Combination of a signal-stimulus and additional components of the frequency spectrum forms an emotional image. Stress mobilizes attention and muscular activity; significant increase of the level of the alpha - rhythm and, to a lesser extent, of the beta—rhythm ("Fear") testifies about it.

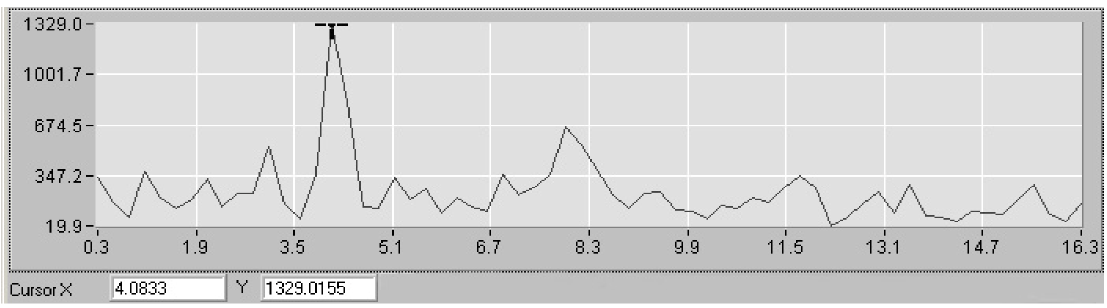


Fig. 2. "Festival". Spectrum of the IF oscillations after non-linear conversion
(x-is frequency, Hz, y is the level of spectrum component, conventional units)

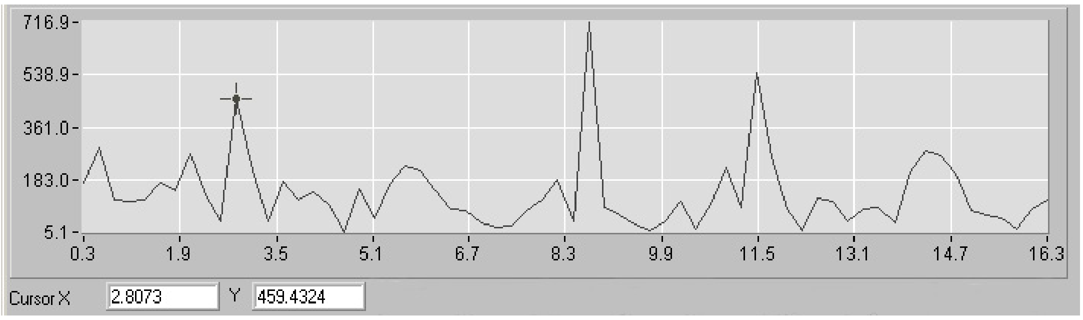


Fig. 3."Fear". Spectrum of the IF oscillations after non-linear conversion
(x-is frequency, Hz, y is level of spectrum component, conventional units)

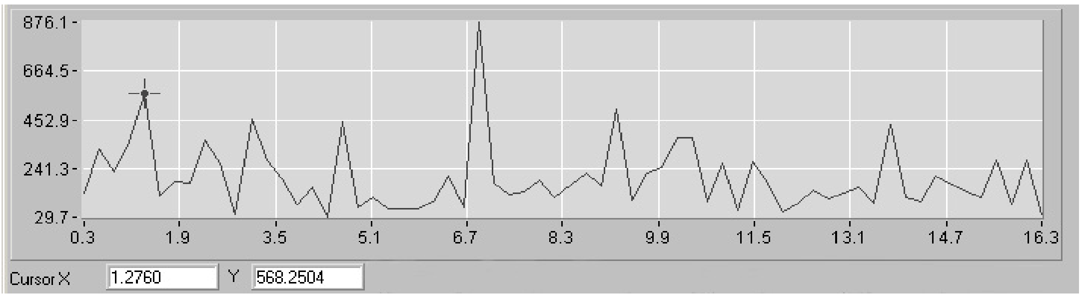


Fig. 4 "Nightmare". Spectrum of the IF oscillations after non-linear conversion
(x-is frequency, Hz, y is the level of spectrum component, conventional units)

Table 1. An wakeful man's condition and activated biorhythms of the brain

Biorhythm	Frequency range, Hz	Man's condition
Delta-rhythm	0.5 – 3.5	Interest of a man in something, special kind of stress, increase of production of hormones, which contribute to physical reconditioning
Theta-rhythm	4.0 – 7.5	Appearance of bright images, recollections, and unexpected associations
Alpha-rhythm	8.0 – 11.5	Improvement in sensibility, sharp increase of muscular activity
Beta-rhythm	12.0 – 29.5	Intensive attention, mental exertion, emotional excitement

The uncertainty of the source of anxiety together with the increased danger ("Nightmare") enhances the search of recollections and associations which could form the activity program. The increase in the level of the oscillations in the zone of the theta -rhythm pointed to this opportunity. The maximums in the zone of the alpha- and beta-rhythms are smooth, cover the lesser square and have the lower level. This shows that the program of activity for a subject has not been defined.

The emotion related to the "Festival" reflects the recollections about progress and give hope (by associations) for future victories. Such a feeling is stimulated by the signal with the frequency of the theta-rhythm. At the same time, the level of attention to the environmental condition and mobilization of muscular activity are at the usual (background) level.

The examples given proves an opportunity to decode emotional content of music fragments which originate practically simultaneous signals consisting of oscillations with several frequencies in IF range.

Moreover, decoding of the mood being formed by each signal-stimulus enables to develop the above estimates of the emotional content of the simplest images caused by the sequence of tonic triads of relative tonalities. Examples are given in Table 2.

The above said proves that a special device can be developed, which will objectively evaluate the expected emotion reaction to music. It appears that later the instrument for corresponding evaluation of visual stimulus will be developed also.

The scale of such a device is multiparametric. Each emotional image should be defined on the basis of several parameters of IF oscillations, measured during adjacent time intervals. The method of its building is illustrated by the above examples. It should be emphasized, that the main simplest emotional images for acoustical impacts depend on the biological background which is objective. Therefore, the emotional response to this signals-stimuli and images for people with healthy psychic will have a comparatively sharp distribution curve.

The possibility to apply the same approach to decoding fragments from African ethnic music and harmonic tonal music is not random.

Table 2 Examples of emotional content of the simplest images

Tonality	Mood according to [9]	Mood according to the results of biorhythm analyses
Fis-dur	meditativeness	Recollections and associations with a background of deep grief
As-dur	great energy and more joyful mood	Rise of bright hope after increasing tragedy
H-dur	energy, exultation (triumph) with a transfer to calm (rest) and harmony	A number of pleasant recollections and associations
A-dur	happiness	Bright associations accompanied by a wish to intensify muscular activity
as-mol	detachment	Cloud recollections (the level of IF components is low, but this level is the highest one for the minor)
h-mol	detachment, transfer from mournful insensibility to tragic mood	Feeling of tragedy after cloud recollections (the level of IF components is the lowest)
e-mol	bright sorrow, dreaminess	The mood agrees with the interpretation of [9]
cis-mol	fantasy, dream, transfer from a day-dream to detachment and grief"	The mood agrees with the interpretation of [9]

The type A evaluation of measurement uncertainty, first of all, depends on the state of health and mood of the testees. The psychic of listeners (spectators) is also under the influence of external influence quantities, such as colour and illuminance in the room, unwanted sounds, etc.

To decrease this uncertainty, it is useful to carry out a preliminary emotional adjustment, i.e. to prepare the testees for experiments, to relieve their internal stress, etc. [11]. In essence, a musical overtures serves the same purpose.

Stable deviation of emotional reaction of a person to the signals-stimuli from the typical one can serve as an indicator of some mental troubles. Reaction to more complicated acoustic and, particularly, visual impacts was formed at comparatively late stages of evolution and depends, to a greater degree, on cultural traditions of the testees.

The type B evaluation of measurement uncertainty is determined, mainly, by deficiency of available concepts concerning the role of the brain biorhythms. For them even frequency zones are evaluated as different in various publications. Obviously, if the IF oscillations are in the boundary zones, the uncertainty of emotional reaction increases.

5 CONCLUSIONS

The approach suggested gives grounds to conclude that the emotions which are contained in musical and visual impacts can be measured. This corresponds to the conditions of the measurability, which have been proposed in [12].

The procedure of identification and quantitative evaluation of emotions corresponding to an expected perception of acoustical and visual impacts can be performed with the help of measuring instruments on the basis of the approach suggested.

Such a procedure complies with the "widely defined concept of measurement" and is maximum close to the concept of "strongly defined measurement" [2].

REFERENCES

[1] C.E. Izard, *The Psychology of Emotions, Plenum Press,* New York and London.

[2] L. Finkelstein, "Problems of widely-defined measurement", *Proceedings of the 12th IMEKO TC1 & TC7 Joint Symposium on Man Science & Measurement*, Annecy, France, pp.23-29, Sept. 2008.

[3] *International Vocabulary of Metrology — Basic and General Concepts and Associated Terms (VIM*), JCGM, 2008.

[4] K. Sapozhnikova, R Taymanov, "About a measuring model of emotional perception of music", *Proceedings of the XVII IMEKO World Congress*, pp. 2049-2053, Dubrovnik, Croatia, June 2003.

[5] K. Sapozhnikova, R Taymanov, "Measurement of the emotions in music fragments", *Proceedings of the 12th IMEKO TC1 & TC7 Joint Symposium on Man Science & Measurement*, Annecy, France, pp.75-70, Sept. 2008.

[6] S.V. Savelyev, *Origination of the Brain*, VEDI, Moscow, 2005.

[7] Muller J, Tsuji LA, "Impedance-matching hearing in paleozoic reptiles: evidence of advanced sensory perception at an early stage of amniote evolution", PLoS ONE 2(9): e889, 2007, doi:10.1371/journal.pone.0000889.

[8] V.R. Dolnik, *Indocile Child of Biosphere*. St.Petersburg, Chero-na-Neve Press, 2003.

[9] V. Elkin, *Curative (medical) magic of music. Harmony of colour and sound in therapy of a disease,* Respeks, St.Petersburg, 2000.

[10] http://www.monroeinstitute.org/hemi-sync/

[11] K. Sapozhnikova, R. Taymanov, and V. Elkin, "The procedure of measurements for discovering regularities of relationships between music and color", *Proceedings of the 2nd International Symposium on Measurements, Analysis and Modelling of Human Functions,* pp. 391-395, Genova, Italy, June 2004.

[12] G.B Rossi, "Measurability", *Measurement: Journal of the International Measurement Confederation,* nº 40 (6), pp. 545-562, 2007.