Development of Wearable Devices for Measurement of Multiple Physiological Variables and Evaluation of Emotions by Fingerprints and Population Hypotheses

Martin Malčík, Miroslava Miklošíková and Tomáš Zemčík
Department of Social Sciences, VSB-Technical University of Ostrava, 17. Listopadu 15, Ostrava, Czech Republic

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Abstract: We live in an age in which technology provides us with constant access to virtual online services. Consumption and production of an immense amount of instant data, which is becoming the basic raw material autonomously processed by artificial intelligence algorithms, open up brave new possibilities and levels of research and its application in many traditional scientific disciplines. Biometrics is one of the disciplines experiencing an unexpected renaissance, owing to the wide availability of cheap sensory technologies connected to the network. We find great untapped potential, especially in devices that allow measuring the body's physiological responses to emotional stimuli, such as heart rate (HR) and electrodermal activity (EDA), also known as galvanic skin response (GSR). Many readily available and professional wearable devices provide digital recordings of these variables. However, each of these technologies suffers from multiple shortcomings. These shortcomings stand in the way of the mass popularization of the technology, which enables, among other things, real-time monitoring and digital recording of the body's physiological reactions to emotional stimuli. In other words, creating big data that can be used for digital, automated reconstruction of certain aspects of emotionality. In our research, we have identified three main social areas where these technologies are of interest: laboratories, professionals working with the human psyche-body-emotionality, and regular users of biofeedback devices such as wearable devices (WD). Each of these groups has specific requirements in terms of the hardware implementation of the technology, and software and measurement methodology open to users. In our emotion laboratory, we have developed a series of comprehensive solutions, Sensetio, based on a thorough analysis of the needs of all three groups of users of biofeedback technologies. We intend to obtain standardized big data sets for further thorough scientific analysis.

1 INTRODUCTION

Every emotion experienced is accompanied by physiological reactions of the organism. These include, for example, changes in facial expressions, behaviour, perception and also the reactions of the autonomic nervous system (ANS). These changes in ANS activity are most frequently measured in the field of biometrics by physiological records of heart rate, respiration or sweat gland activity, etc. In the field of biometrics of emotions, there has been over a century-long debate whether ANS changes initiated by specific stimuli connected with specific emotions or more generally witch a specific emotional category, can be used to retroactively reconstruct the category of that emotion. Whether we can recognize an emotion category by simply measuring the ANS response.

The most used model of emotion categories contains five basic emotions: happiness, sadness, disgust, anger and fear. However, there is still no scientific consensus on whether it is possible to determine – from the record of an ANS activity – the experienced emotion; that is, whether there is a typical model of an ANS record for individual emotion categories. Therefore, it would be ground-breaking to be able to read from the recording of a biometric pattern with a high degree of probability that it is specifically about happiness when experiencing the emotion of happiness. The record of the ANS structure typical of happiness could thus be

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distinguished, for example, from the pattern typical of fear. Ideally, it would be possible to determine the quality, ambivalence or source of this particular emotion category. However, this is very complicated and so far no one today can say with certainty that it is even possible with the deployment of the latest technological solutions and sufficient source data. Therefore, the scientific community is opinion-divided and is still seeking an adequate theoretical model combining physiologically measurable variables with objectively or subjectively experienced states. (Cacioppo, 2004).

The reason is that every unique emotion episode evoked by a specific stimulus turns out to be full of artefacts, errors, variations and singularities in real measurements. The recording of an ANS activity is not identical for one person at two different times in response to the same situation (stimulus). Naturally, the variations in the ANS records between different test subjects are even greater. There have also been other age-old disputes about the nature and origin of these recorded variations of ANS on the same stimulus. There are two basic hypotheses. One assumes that these variations are inert and a functional part of emotions. The second hypothesis attributes the origin of variations to events that are epiphenomenal with respect to emotions – that their source can be, for example, the method used, the environment, hidden cognitive mechanisms or the technology itself. (Siegel, et al., 2018).

Two Paradigms in Biometrics of Emotions.

The first is the classic theory of emotions or the Appraisal Theory of Emotion, which argues that emotions are formed as the subject evaluates and assesses the stimuli acting on him. (Moors, 2017) The classical view of emotions states that specific emotions experienced within emotion categories share characteristic patterns, just as each person has their unique fingerprints by which we can identify them. Therefore, this paradigm is often based on a hypothesis known as the emotion fingerprints. This hypothesis assumes that a thorough analysis can recognize in the measurements of an ANS activity an emotion fingerprint and at the same time that different categories of emotions have different but typical fingerprints.

It is clear that the feeling of happiness can be evoked by a different stimulus every time: meeting a loved one, performing a favourite pastime, ingesting a substance that changes the state of consciousness or simply observing happy people. We can reasonably assume that these different situations will evoke significant variations in the ANS record and the fingerprint of happiness. Therefore, within the hypothesis of emotion fingerprints, a certain degree of variation from one emotion instance to another is allowed. However, it is important that the pattern is always similar enough to identify an emotion category (such as happiness) and distinguish it from other emotion categories (such as sadness). Thus, within the emotion fingerprint hypothesis, it is assumed that each of the emotion categories has its own unique ANS fingerprint.

The fingerprint hypothesis is based on a tradition that assumes an emotion essence. This supposed emotion essence was to evolve during the species evolution as an adaptive mechanism. This is an essential view and can be found already in Darwin's The Expression of the Emotions in Man and Animals (Darwin, 1964). The essence in each emotion category is still the same. Therefore, if a person cries with happiness, is happy because their child was born, happy from movement and exercise, from touching a loved one, or feels happiness due to a substance that changes the state of consciousness, the same pattern is activated within the ANS that triggers and regulates the emotional category of happiness. The essentialist approach assumes that a certain area of ANS is responsible for a particular emotional category and is identical across individuals, physiology, age, or cultures – it is universally human. It is a kind of analogy to "the organ of happiness, fear, disgust, sadness and anger." And it is the activity in this area that leaves a typical pattern in biofeedback measurement, which we can record, recognize and predict.

This hypothesis has its undeniable pros and cons. Attempts to trace generally shared patterns in ANS measurements have repeatedly failed – but they are the basic precondition for the emotion fingerprint hypothesis. (Barrett, 2006) From the point of view of this hypothesis, this is interpreted as evidence that there are random errors across different emotional categories that significantly distort ANS measurements. However, these errors are assumed to be epiphenomenal with respect to emotions, and thus do not disprove the assumptions of this hypothesis. These epiphenomena can be based not only on individual physiological properties of the organism and the nervous system, statistical fluctuations or individual regulatory emotion mechanisms but also on the imaging methods used or the physical-technological properties of measuring devices. Therefore, it can be assumed that it should be possible to eliminate, filter or mitigate their impact using an appropriate methodology and technology. However, this has not yet been confirmed in repeated experimental findings. This view is therefore problematic and practically led to the fact that the fingerprint hypothesis has never been generally accepted and scientifically confirmed. (Sterling, 2012).

Among the population models based on constructivist hypotheses, we can include socio-constructivist, psychological-constructivist or neuro-constructive and rational-constructive theories and their numerous combinations. These constructivist theories that establish the population hypothesis can again be traced back to Darwin's idea (Darwin, On the Origin of Species, 1923) that all biological categories, such as species, genus (including the notion of "life" at the beginning of this classification), are mere conceptual categories. These are basically created by the human mind precisely for the purpose of mental classification. The real content of these categories are heterogeneous, unique and essentially non-repeatable individuals.

If we transfer this idea to pattern recognition in measuring ANS response when measuring emotional responses, we find that the variations in ANS patterns are not completely random but contain an internal meaning and structure. The mentioned structure is a consequence of the functions of behavioural interactions with the environment, which differ from situation to situation, and the situations themselves are uninterchangeable. However, many structural similarities can be statistically traced and described – although they are merely probabilistic concepts, they tell enough about their nature and reality. Therefore, it is possible to follow them according to the principles of causal probability. The patterns of these variations begin to overlap densely with a sufficient amount of analysed data from the records at certain points. The values of the measurements thus form clusters around certain values– populations begin to form, which we can already easily delimit and statistically formulate. Then we can determine with a certain (and frequently very high) degree of probability that the measured value is in the range of the population where the measurements of a certain emotion category most regularly overlap, even though that value is essentially singular and unrepeatable. The uncertainty arising from variations in measurements between different stimuli in different situations outside the emotion categories is therefore not a mistake, they are the essence of the emotional response. (Clark-Polner, Johnson, & Barrett, 2017).

The first part of the article describes the methodological starting points that are used in the analysis of emotional states of an individual during the experience of various life situations. Based on these starting points, technological and hardware devices called Sensetio were developed. These make it possible to measure, evaluate and analyse signals from the measurement of human physiological variables with the possibility of evaluating the intensity and quality of experienced emotions.

2 MATERIALS AND METHODS

2.1 The Sensetio Method

The Sensetio method is a unique psychodiagnostic method based on an exact measurement of the physiological manifestation of currently experienced emotions, namely the measurement of skin conductivity and heart rate variability (Miklosikova, Malcik, 2019). The method is based on the realisation that the intensity of physiological expression of emotions changes under the influence of stress, fear and anxiety, which allows obtaining objective data about the psychological state of an individual (Boucsein, 2012). Measurement can also be done by recording the emotional activation of a student throughout their self-presentation, while a specialist measuring physiological values notes down critical moments into the system – the so-called nodal points – a description of specific situations during which the physiological values of the student changed significantly (Miklosikova, Malcik, 2017).

Several types of devices with corresponding software have been developed to measure the emotional arousal of the organism.

2.2 The Sensetio Devices

The Sensetio devices consist of the Sensetio Mouse, Sensetio Wristband and Sensetio software. The Sensetio software uses artificial intelligence algorithms for GSR curve analysis, the Sensetio Mouse has been patented by Patent No. 307554, and the Wireless Sensetio Wristband uses some of the Sensetio Mouse technologies.

By using the method, it is possible to record physiological changes in the organism during an emotional experience, namely skin conductivity and heart rate variability. This objective data is further supplemented by a structured diagnostic interview, which guides the measured person to gain insight into the experience, its causes and provides recommendations which should lead to coping with the problematic situation.

2.2.1 Biometric Sensetio Mouse

For actual measurements, the GSR mouse (patent pending) will be used, which uses a six-channel measurement system between four skin contact points (see Figure 1). The resulting GSR is then determined by a neural network that is taught to determine the actual GSR value by reference from the precision sensor. At the same time, the mouse measures skin temperature, heart (HR), and heart rate variability (HRV) is counted.

Figure 1: Prototype of the biometric mouse with GSR and HR sensor and palm skin temperature. The four black areas on the surface of the mouse are made of a conductive plastic and represent four electrodes for measuring GSR. These electrodes provide 6 signals, from which the resulting GSR value is calculated by a special algorithm. The temperature sensor is located in a small hole on the top of the mouse. The HR sensor is located in the black area on the left side of the mouse and the HR is thus read from the thumb of the right hand.

2.2.2 Bluetooth Sensor Sensetio Wristband

Wireless measurement is used wherever there is a need for certain motor freedom to perform diagnostic and performance activities (psychotherapeutic interview, coaching training, physical and mental exercise, etc.).

Wireless Bluetooth sensor (see Figure 2) is mounted on the wrist and two fingers. The signal transfer is transmitted via the Bluetooth interface to the PC or tablet where the results are evaluated and processed and their graphical display is presented both in the form of a continuous curve from the time during measurement and as a current and instant value. The prototype is displayed in the picture below.

Figure 2: Bluetooth GSR measuring system – a wristband with finger contacts (left picture), wristband with adhesive back contacts (right picture).

2.2.2 The Sensetio Software

a) Software for Continuous Measurement - Sensetio Pro.

For continuous measurement – e.g. psychotherapeutic interview, coaching training etc. – the Sensetio Pro software for continuous measurement is used, which allows to measure and evaluate GSR or HRV in real-time, to save data, and later analyse and possibly use it for measuring progress, outputs and other uses. Continuous measurement of your experiencing can be realized during activities that are uncomfortable or stressful for you, inducing fear or anxiety. Through such measurement, you will be able to see what is happening in your body and gradually control and change your experience through willpower. During the measurement, sound can be recorded synchronously and then see the respondent's organism react within the individual stimulating events. Several special algorithms have been developed for the analysis of peaks during measurement with the possibility of their evaluation in terms of assigning them to the experienced life situations.

Measurements can be saved for later analysis, and also for graphical outputs in reports, etc. To be able to set a specific measurement time, if necessary, Sensetio Pro includes a timer with a range of up to several hours.

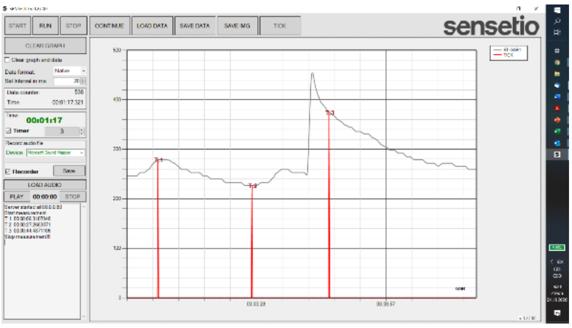

Figure 3: Sensetio Pro – GSR and HRV - mouse measurement system. Indices T1–T3 are identified significant events during the measuring. (Source: Authors).

From the point of view of measurement, GSR is an electrophysiological indicator that significantly indicates the properties of the nervous system and thus brain processes. It follows that we can use it to monitor excitation and inhibition processes, reactivity to various types of stimuli as well as the process of adaptation.

And this also results in its significant diagnostic value and conclusions for assessing the psychophysiological state of the respondent (experimental person) in various working or relaxation conditions.

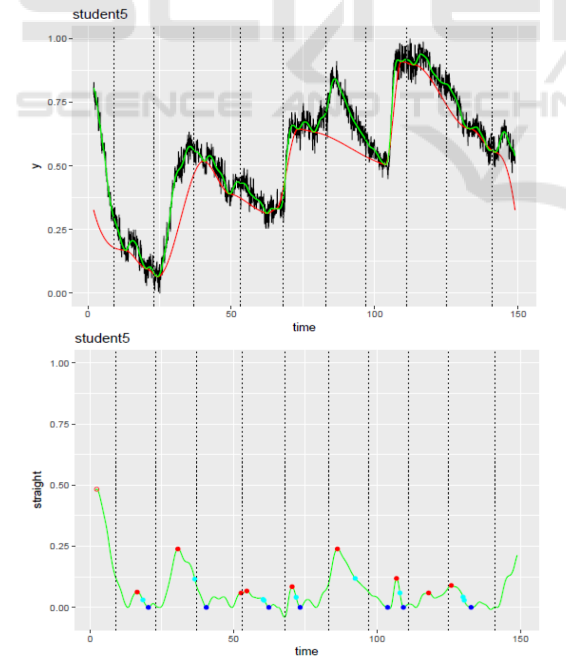

Figure 4: Sensetio Pro analyzer analyzes raw data, interleaves them with a baseline curve (graph above), converts raw data into filtered smoothed data, where peaks, false peaks, monotonic intervals, etc. are identified (graph below). (Source: Authors).

Several algorithms have been developed for the analysis of the measured signal, which diagnose peaks in the measurement with the possibility of their evaluation in terms of assignment to the experienced life situations (see Figure 4).

b) Stimuli-based SW – My Sensetio.

A specialised SW My Sensetio was made for the stimulated measurement; it triggers the stimulus in the form of image or audio medium, and at the same time measures the GSR with precisely defined time stamps, where the individual parts of the stimulus are shown to the respondent. The software is customised so that underlying guidance through the entire measurement can be inserted into it, including the introduction and description of the test with an adjustable timer or click and the possibility of selecting and providing the individual stimuli in the form of sentences and time pauses between them with a timer. The duration of the stimuli exposure is identical for everyone or can be set dynamically depending on the decrease of the respondent's emotional activity to the normal level. After each stimulus, the respondent slider is used to express the emotion experienced in terms of positivity and negativity and in what strength. Subsequently, a comparison of cognitive-emotional experience and the emotional power of the emotions measured as GSR is evaluated (see Figure 3).

The software, due to the different conductivity values of the skin of individual respondents, normalizes the resulting values on a scale of 0-1, compares similarities of the resulting curves, divide the respondents by the monotonicity to raising, decreasing and constant. It further measures the peaks of individual stimuli with respect to the previous time delay and selects a set number of them for further analysis. In the next phase, it can continue testing interactively by working with the highest selected peaks and focusing on the selected areas. The software also manages the initial calibration (the cube) to measure the truthfulness of responses. Furthermore, it compares the direction of the curves and the individual peaks with the likelihood of a false answer.

c) Sensetio Go Mobile Application.

This is an application that uses the biometric Sensetio Wristband to clearly record skin conductivity (GSR) values, which are closely related to the level of emotional response. The application works on Android and iOS. The connection with the wristband can be realized in the application directly via Bluetooth without unnecessary setting of the mobile phone. An important feature is where the user has the opportunity to upload their videos or photos and then measure their emotional response to them.

Each user can set individual measurement parameters, create several profiles, etc. It is also possible to choose the measurement time or preparation time before measurement. Based on the measured data, the application evaluates the emotional state of the user and then the user is offered exercises in the form of custom meditation exercises.

3 RESULTS AND DISCUSSION

An extensive meta-analysis of hundreds of empirical studies, 10 qualitative reviews, 4 meta-analyses and a handful of multi-variable classification analyses of patterns accumulated over the last 60 years, comes with findings relevant to the Sensetio project. (Siegel, et al., 2018) The content of the meta-analysis were studies that focused on whether emotion categories, from the point of view of ANS measurements, correspond more to hypotheses based on fingerprints or population models. The results revealed that there are repeated methodological errors, generating distortions and misleading interpretations that occur in many studies that deal with the measurement of emotions, especially those confirming the fingerprints hypothesis. These errors include unverified and unverifiable inductive methods, induction of low-intensity emotions, use of very simplified models of ANS functioning, incomplete characterization of ANS response activity, or poor synchronization of the induced ANS response with the presented stimulus. Sensetio copes with all these repeated methodological errors and reacts to them.

The meta-analysis also recommends the future direction of research to be focused mainly on the population hypothesis based on constructivist theories and abandoning the historical consensus of searching for emotion fingerprints. The authors believe that the field's future is rather in mapping heterogeneity and examining its conditions, states and probabilistic occurrences than in searching for stereotypes of patterns in ANS that evoke emotion categories. Thanks to technological progress, the present opens the possibility of monitoring and measuring with new biofeedback devices, like Sensetio solutions, which are becoming commonly available and widespread – all thanks to miniaturization, affordability, availability and a user-friendly interface. These devices are commonly used for biohacking, measuring the physiological responses of the body during sports or normal activities, in the field of virtual reality or the digital entertainment industry and others. This introduces new perspectives for the field, which allows observations to not always take place only in laboratory conditions but in the natural environment.

At the same time, the new biofeedback devices enable the collection of biometric big data with the prospect of a uniform data format. The big data in turn – thanks to advances in machine learning and artificial intelligence, which make it possible to analyse social and cultural influences – can be used to revolutionise the creation of "digital traces of real emotions" when measured in the natural environment.

Such measurements can help discover individual and specific traits of a particular unique personality in different emotion categories adequate for different contexts – in other words, idiographic models. Another potency is in finding users who are similar in these idiographic patterns. This will allow the creation of group probabilistic prediction models.

Another potential of the research lies in the search for connections between these probabilistic idiographic patterns with different linguistic and cultural contexts, as it has been confirmed that the experience of emotions is related to the specific language and cultural environment used. Furthermore, it is possible to look for new methodological approaches to refine the measurement and its predictions or the connection between the methodology used and the specific socio-cultural or idiographic context. (Siegel, et al., 2018).

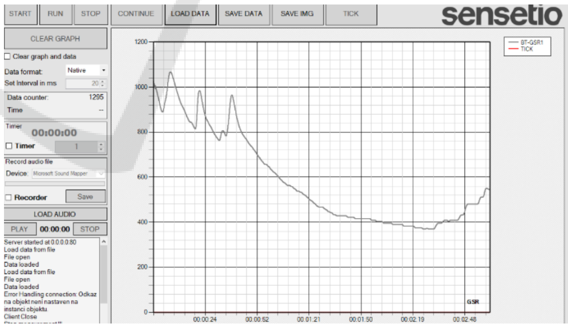

Figure 5: Wristband measurement during psychotherapeutic interview of respondent. We can see several peaks at the beginning of the interview. (Source: Authors).

These findings essentially correspond to our long-term research goals, we functionally include them in our implementations and we try to take them into account in our methodology. We also agree with other proposed application directions, we supplement them and add new ones. We have long been exploring the possibilities of using Sensetio solutions in therapies and mental trainings of various kinds (see Figure 5), in human-machine communication, in e-sports and traditional sports training, and as a safety “kill-switch” for operators in contact with mechanical robots or in the porn and sex equipment industry or in meditation practice.

4 CONCLUSIONS

The findings from the meta-analysis (Siegel, et al., 2018) and long-term scientific work of the emotion laboratory that is implementing the Sensetio solution can be applied in many fields where it is possible to use the predictive power of the digital trace of the measured emotion or where it is necessary to build idiographic algorithms simulating trends in individual or group emotionality. An example of such use may be in the field of persuasive technologies, which are morally and ethically questionable, however, and need to be applied consciously, conscientiously and in accordance with good morals, legislative trends and institutional developments so as not to undermine the fabric of social cohesion.

Ethically and legislatively no less controversial is the use of this knowledge to train communication algorithms, so-called chatbots. Thus far, this artificial intelligence can only rather clumsily assign a specific meaning to the syntax when talking to the user. This is largely because one sentence, spoken in different situations under the influence of different emotions, can have different and even incommensurable meanings. Assigning an emotional vector of the user to a syntactic sentence structure would lead to a breakthrough in human-machine communication. Generally speaking, it can be argued that development in this discipline can be useful in any field where we work with a digital record, model or algorithm representing a real user’s emotion.

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