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Applying Neurointerface for Provision of Information Security

Alexandr Alexandrovich Emelyanov[1], Elena Yurevna Avksentieva[2], Sergey Yurevich Avksentiev[3], Nikolai Nikolaevich Zhukov[4]
[1] Information Systems and Technologies department, Saint-Petersburg State University of Economics, Saint-Petersburg, Russia.
[2] Faculty of Software Engineering and Computer Engineering, ITMO University, Saint-Petersburg, Russia.
[3] Mining and Transport Machineries Department, St. Petersburg Mining University, Saint-Petersburg, Russia.
[4] Faculty of Software Engineering and Computer Engineering, ITMO University, Saint-Petersburg, Russia

ABSTRACT

The importance of this study is based on necessity to comply with modern requirements to methods and tools of authentication in various soft hardware and network complexes as well as in modules of information systems of wide scope. Existing methods of solution to this problem are analyzed, their positive and negative features are considered, application ranges are determined. Reasonability of BCI application is substantiated as the most accurate and multifactor method allowing to determine uniquely person who carries out identification and authentication. Neurophysiological performances of brain activity are estimated as recognition system. Analytical and statistical methods of processing and interpretation of distribution of wave patterns accepted by BCI are considered with subsequent formulation of mathematical model of identification and authentication procedures.

Key words: authentication, neurointerface, biometry.

1. INTRODUCTION

In the environment where digital tools of data processing and storage become de facto standard, the issue of private and commercial safety is highly urgent. Irrespective of way of living, scopes of activity, everybody needs to protect personal data [1, 2]. Similar situation can exist in various small, medium, and large-scale companies. The number of potential hazards, procedures of unauthorized access and information theft increases every day.

The most important components of any information system are units of identification, authentication, and authorization, which determine personality of customer accessing resources of information system, verify presented identification data and actual state of things, and then the customer receives access with certain authority level. Performance of the mentioned procedures is based on numerous methods starting from login/password and to scanning of various physiological and anatomic features. Each approach is characterized by certain advantages and disadvantages. For instance, the oldest method based on certain sequence of symbols (login and password) is, on the one hand, the simplest and the least expensive with respect to authentication, and on the one hand, the most vulnerable. Password compromise/theft can be carried out using maximum approaches: hardware, software, network, social. Similar situation exists in the case of RFID chips. Theft of locking cards, contactless duplication of identification/authentication data and other potential hazards minimize the advantage of simplicity because of possibilities obtained by intruder at minor consumptions of expenses and time for unauthorized access.

Somewhat better reliability is provided by biometric analysis. Peculiar features applied in this type of authentication systems are related with human organism, it is highly difficult to steal or to duplicate them. However, in these cases it is possible to imitate such features with high degree of confidence, and violator could obtain access to confidential personal data and/or information of commercial significance of a company [3]. The main approaches applied in conventional systems of biometric control are as follows:

1. Fingerprint scanning. Since the combination of visually determined epidermis features is highly individual (it is assumed that fingerprints are unique, exceptions are exceedingly rare), then unique identification of a user can be performed by any method of scanning of skin covering, analyzing the fingerprint, building a mathematical model which determines whether the specific fingerprint belongs to the specific person, verifying according to the existing (registered in database) model and arriving at the conclusion: whether this person is really the claimed one. These approaches are based on optical, capacitive, and thermal sensors. Since this technique is known for quite a long time, there exist known methods to falsify fingerprints and to obtain unauthorized access to various software and confidential data.

2. Recognition of voice patterns. This method is more efficient. It is based on extracting individual features of human voice. There are several anatomical features of vocal

tract generating amplitude and frequency pattern of speech sound signal, hence, it is possible to select certain parameters for model of user identification with high probability. This approach involves analysis of spectral and time features, such as average spectral blurring, normalized values of envelopes, coefficients of cross correlation, duration and pitch of reproduced phonemes and segments, their forms, etc. These features make it possible to determine speech features based on structural peculiarities of speech organs. In addition, cepstral features are taken into account (determining energy spectrum), such as mel-frequency cepstral coefficients, power parameters of frequency registration, and others. Basic issues of voice biometry are intensity, amplitude, basic frequency, jitter, shimmer, formant frequencies, radial basis kernel functions. Voice analysis by means of nonlinear dynamics (Lyapunov exponent, phase pattern, Poincare map, Kaplan-Yorke dimension, and others) makes it possible, using phase spatial models in combination with Takens's theorem, to build general mathematical model which accounts not only for static speech properties but also dynamic indices which vary depending on human psychoemotional state. At present this procedure of biometric identification is being improved, however, methods of falsification of voice patterns are also developed on the basis of soft hardware, taking into account individual features of vocal tract and facilitating user voice imitation with high degree of confidentiality.

3. Retina scanning. Since blood supply structure is very specific for each person, this can guarantee unique identification of the person. This method is comprised of projection of light beam in IR electromagnetic band and analysis of absorption pattern. Intensity of this process varies depending on retina segment determined by mutual position of blood vessels and different ratios of reflection/absorption coefficients. Similar approach is applied for iris scanning. Similar to retina scanning, IR radiation is used together with analysis of reflection/absorption pattern.

The described procedures are considered to be quite reliable, however, existence of basic vulnerability comprised of possibility of automatic recognition of biometric authentication under the control of violator leads to certain critical situations in information systems.

Nowadays biometry procedures with neurointerfaces (brain-computer interface, BCI) are developed as alternative. Operation principle of such devices is based on neural anatomical and neural physiological features of brain activity. Since single neurons interact by electrochemical signal transfer, it is possible to determine electric potential of both single neurons and brain areas. These data are recorded using electroencephalography. Several approaches can be applied: invasive, when the state is determined by direct connection to single neurons; semi-invasive, involving analysis of separate brain areas; and noninvasive: by means of sensors located on head skin in order to measure magnetoelectric potentials.
In general, the operation algorithm of neurointerfaces is as follows:

Figure 1: Flowchart of BCI operation

Electric activity generated by pulse neural oscillators is a superposition of interaction of numerous single neurons or a nonlinear model of signal combination. In order to describe oscillation wave patterns characterizing dynamic state of various brain segments, it would be reasonable to apply mechanisms of nonlinear dynamic systems. Successive variation of spatial wave distribution of electric potentials makes it possible to obtain certain dependences characterizing individual features of brain activity peculiar to a human in the frames of certain psychoemotional situations.

Application of noninvasive BCI makes it possible to estimate 3D pattern of neural network state in the form of electric activity, to highlight characteristic properties which could be used for formulation of mathematical model. Since brain comprised of interacting neurons is a classical variant of multichannel system, then the multidimensional spatial time pattern of superposition of electric potentials seems to be more significant in terms of its information importance.

Application of spectral, factor, coherent analyses, wavelet and Fourier transformations makes it possible to highlight interrelations, determining meaningful performances, characterizing certain psychophysiological states of a human. Formation of dynamic models describing interaction of neural oscillators can be used for experiments in virtualized environments when participants use tool of virtual and augmented reality, such as VR headset, tactile interfaces, etc., for detection of interrelation between audiovisual stimulus series and patterns of electrophysiological brain activity.

At present certain tasks of neurointerface support are efficiently implemented, such as control of external actuators with high degree of anthropomorphism (limb prostheses, exoskeletons), as well as interaction with industrial and game effectors. However, this segment of tasks is peculiar and includes only detection of α and γ motor neurons innervating extra/intrafusional fibers through which muscular system performs contractions and extensions, and in the case of robots, signals are converted and artificial actuators are activated.

Investigations related with analysis of intelligent activity by means of BCI are at present at initial stage, because there are no more or less adequate models describing human thinking not in terms of high level (psychics, intellect, etc.) but, instead, in terms of intraneural interactions.

Estimation of electric state of both single neurons and overall areas does not provide obvious presentation of brain cognitive functions implemented at current time.

General approach (operation algorithm) for BCI is as follows:
- detection of electric potential using electrodes installed by means of invasive, low-invasive, or noninvasive methods;

- signal amplification, since initial values of estimated parameters are too low for subsequent processing;

- separation of signal from noise. This is a classical problem, it is well studied, supported by numerous solutions and should not be described;

- analytical processing of prepared signals. Application of auto- and cross-correlation methods, spectral expansion, distribution mapping, other approaches;

- transfer to subsequent blocks for further analysis and/or adoption of solutions concerning control action on these or those effectors (manipulators).

An important aspect of processing of dynamic properties is that the pattern of electric excitation of separate brain segments varies in accordance with certain wave distribution, its ranges are characterized by the so-called rhythms. It is possible to highlight some wave subranges responsible for these or those aspects of brain activity functions and states:

- α waves. Frequency distribution is in the range from 8 to 13 Hz, signal amplitude is from 5 to 100 μmV. They characterize the activity state of corticothalamic circuit, the most expressed pattern takes place during sensor deprivation. In addition, this property correlates with psychoemotional state of excitation, aggression, anxiety, fear, agitation, and, as a consequence, with activation of vegetative nervous system;

- β waves. From 14 to 40 Hz, from 3 to 20 μV. They are related with somatic and motor cortical mechanisms. They characterize motor tonus and tactile simulation. In addition, they estimate the state of attention focusing, involvement of higher cognitive functions;

- γ waves. From 30 to 100 Hz, from 1 to 15 μV. They determine activity of frontal, temporal, and parietal lobes. Maximum expressiveness takes place during solution of complicated analytical problems.

The other ranges are secondary for the considered subject because they are the most significant for estimation of pathological processes (partial and generalized epileptic activity, other functional disturbances) in cerebral cortex, they do not bear information load for analytical model determining individual properties of pulse wave patterns.

Despite the fact that at present there are no tools (both soft- and hardware) for development of a system estimating higher psychic processes with high accuracy which would allow to accept semantic sequences of human thinking, it is possible on the basis of multidimensional analysis of dynamically varied performances to build models for personality identification by scanning using BCI by comparison wave distribution pattern with preliminary formed model.

2. LITERATURE REVIEW

Numerous works are devoted to the issues of identification, authentication, and authorization. Nowadays this problem is more and more related with artificial intelligence [4], [3], [5], machine training [6], [7]. In some works, the attention is paid to correct identification of person as the main problem for remote cooperation systems (in the frames of commercial and educational modules of information systems) [8], [9], [10], [1].

Application of biometric verification of personality for automated authentication was studied in numerous works [11], [12], however, most of them only highlight peculiar features of each approach.

It should be mentioned that at present only few works are devoted to studies of biometry based on BCI methods. Herewith, the described procedure can be applied for direct purposes and for interaction with artificial neural networks, virtual reality systems, and other modern fields.

3. METHODS

Various BCI application programs were used for statistical processing in this work.

4. RESULTS

A series of experiments were performed including all stages of the procedure: from scanning of electrophysiological brain activity to application of mathematical method for building and processing the resulted pattern of wave distribution. Discharges were detected by noninvasive BCI. Predictions of cumulative signal frequency distribution and cutting intermediate wave patterns were based on significant increase in pulse number in the time interval from 50 μs to 100 μs.

In initial conversion, the wave distribution pattern is as follows (raw data):

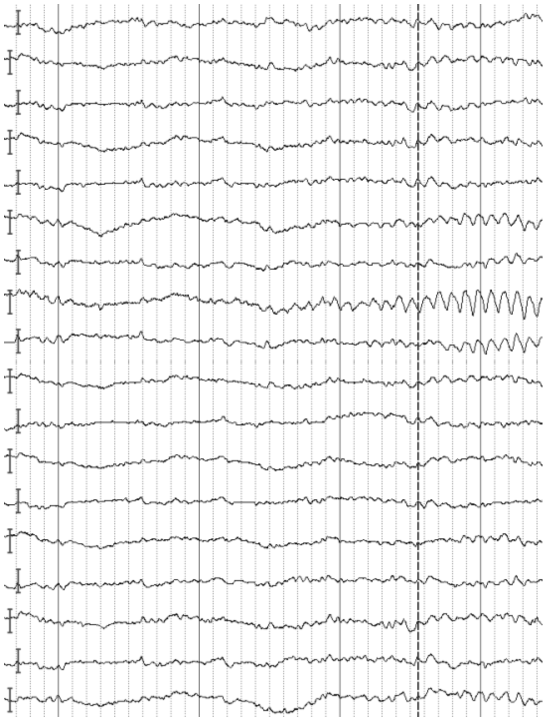

Figure 2: Wave distribution of activity patterns (raw data).

Application of independent component analysis (ICA) (PCA extension and factorial analysis) made it possible to expand the signal variation sequence into component superposition. This process is required to reveal noises (distortions, artifacts) in analog part of BCI A/D converter and, if required, to adjust sensor levels aiming at minimization of external electromagnetic interferences

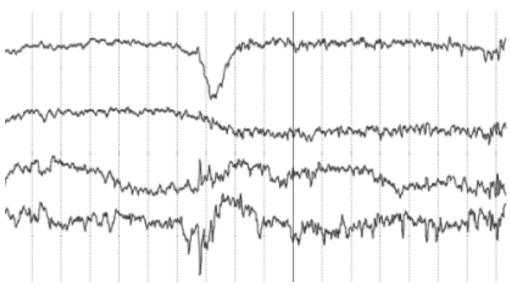

Figure 3: Segment of integral wave distribution after ICA.

Application of correlation analysis revealing interrelations between dynamic variations of wave patterns made it possible to estimate statistically valid links between several ranges of measurements. Normalization by amplitude and alignment with regard to average value provided the following results:

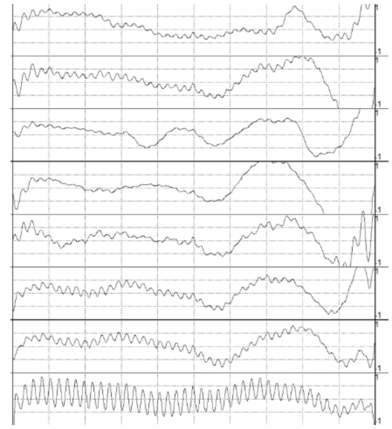

Figure 4: Distribution after correlation analysis.

Analysis of coherence revealing involvement of various brain structures into activity and coordination of their interaction made it possible to obtain complete picture characterizing activity in predefined conditions for α and β wave ranges:

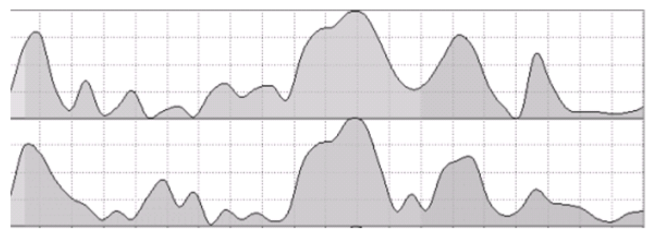

Figure 5: Visualization of α and β portions of wave distribution.

Activation patterns of synaptic units based on electric activity were analyzed. A pattern was postulated as the vector of pulse time from reference point to the first event in discharge picture. Dimensionality was determined by the number of channels. Intervector distance was considered as the norm of difference in n-dimensional space.

$$S_{abs}(p, q) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(t_i^p - t_i^q)^2} \qquad (1)$$

where t_i^p, t_i^q were the components of pattern activation for the p-th and the q-th discharge series. Upon prediction of relative measure S_{rel} , the components t_i^p and t_i^q were normalized with respect to duration of the whole activation pattern.

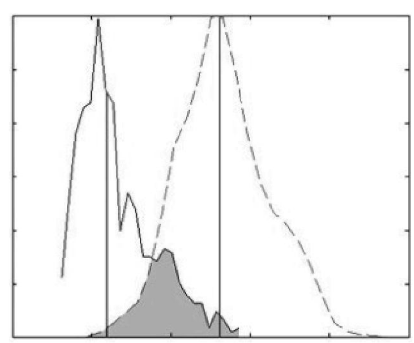

Figure 6: Absolute intervector distances (S_{abs}).

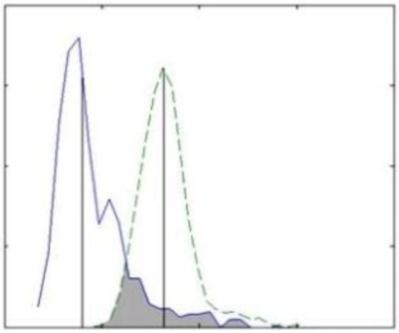

Figure 7: Relative intervector distances (S_{rel}).

Statistically valid differences can be observed by means of distribution histograms at the distances S_{abs} and S_{rel}. This fact evidences formation of repeated vibration and wave patterns during generation of cyclic packet wave pulses upon recording of electrophysiological activity. The patterns form distribution clusters which can be subsequently processed. This distribution of pulse diagrams can be scaled up in statistical order of repeatability of general picture of distribution of wave packets upon variation of fixation scale with variable time frames

5. DISCUSSION

Other studies were also carried out including spectral, wavelet, and Fourier conversions; on the basis of the obtained results, preliminary conclusions were formulated, which facilitated possibility of development of model describing individual characteristics interrelating activity of human brains and wave patters recorded by BCI. As described above, such models would protect identification and authentication as much as possible

6. CONCLUSION

The proposed solution can be applied not only as a procedure of biometric authorization in access to soft- and hardware, it is also a method to determine whether this procedure is carried out voluntary or under duress. Estimation of user psychoemotional state would permit to reveal immediate threat with sufficient reliability and to apply adequate measures in such situation.

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