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DEVELOPMENT OF SOFTWARE FOR NEUROMARKETING BASED ON ARTIFICIAL INTELLIGENCE AND DATA SCIENCE USING HIGH-PERFORMANCE COMPUTING AND PARALLEL PROGRAMMING TECHNOLOGIES

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Summary. *This paper deals with the scientific research in a new area of human activity – neuromarketing. The development of new software for neuromarketing research based on modern methods and tools of artificial intelligence and data science (neural network technologies) using technologies of high-performance computing and parallel programming are considered in this paper. The results of experimental measurements of electrical activity of the consumer's brain based on electroencephalographic signals depending on various types of marketing stimuli are presented in this paper. The quality of the developed software for neuromarketing is evaluated on the basis of various quality metrics.*

Key words: *neuromarketing, electroencephalographic signals, neural network technologies, artificial intelligence, data science, high-performance computing technologies, parallel programming.*

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Statement of the prroblem. At present neuromarketing is one of the fastest growing areas of marketing. It is well known [1, 2, 3], that neuromarketing investigates sensory, cognitive, and emotional responses of consumers of goods and services to various marketing stimuli.

The main concept of neuromarketing is based on the statement that the lion's share of human thinking and emotions (more than 90%) on the basis of which consumers make decisions occurs at the subconscious level, which is below the level of consciousness.

In their activities, neuromarketers use various technologies: functional magnetic resonance imaging, electroencephalography (EEG), etc. for measuring the states of consumer brain activity depending on the stimuli in the form of certain goods and services.

Determination of dependencies between goods and services on the one hand and the decisions made by consumers regarding them on the other hand, based on their measured brain activity, is the main scientific problem solved in neuromarketing.

Various new software systems are being developed for neuromarketers for practical convenience, ease and speed of determining such dependencies in real business.

Analysis of available investigation results In order to predict consumer behavior towards goods and services neuromarketing activities are carried out not only in the academic sphere of university research, but also in a large number of research laboratories of various big companies. As an example, let us present famous neuromarketing laboratories of Google, Frito-Lay, CBS, and E-Television, which use neuromarketing research to measure consumer opinions concerning their advertising and products. At the same time, it is worth noting that neuromarketing companies such as «Neurosense», «Gerry Zaltmann», etc. have been operating since the late 90s of the twentieth century.

Complete and constructive overview and analysis of neuromarketing field, the specifics of research in this area can be considered in papers [1, 2, 3].

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The objective of the paper. For neuromarketers is to develop new application software that establishes dependencies between marketing stimuli and active states of the consumer's brain determining their behavior in purchasing certain goods and services and to evaluate the accuracy of newly developed application software.

Statement of the problem is to carry out experimental measurements of electrical activity of consumer's brain based on electroencephalographic signals depending on various types of marketing stimuli; to develop new application software for neuromarketers and evaluate its accuracy on the basis of measurements data.

Presentation of the main material. In neuromarketing, the activity of certain areas of cerebral cortex responsible for the perception of specific characteristics of goods and services is often measured while various types of research are carried out in order to determine dependencies between the activity of the consumer's brain and various types of marketing stimuli. For example (Fig. 1), the visual impact of the product or service appearance on the consumer's brain is determined by the activation of visual cortex; acoustic (sound) effect of the product or service on the consumer's brain is determined by the activation of auditory cortex; the tactile impact of the product or service appearance (for example, hardness, humidity, roughness, temperature, etc.) on the consumer's brain is determined by the activation of somatosensory cortex, the taste impact of the product or service on the consumer's brain is determined by the activation of gustatory cortex; the effect of the product smell or service on the consumer's brain is determined by the activation of olfactory cortex.

For example (Fig. 1), the visual impact of the appearance of a product or service on the consumer's brain is determined through the activation of the visual cortex; the acoustic (sound) impact of a product or service on the consumer's brain is determined through the activation of the auditory cortex; the tactile impact of the appearance of a product or service (e.g., hardness, humidity, roughness, temperature, etc.) on the consumer's brain is determined by activation of the somatosensory cortex; the taste impact of a product or service on the consumer's brain is determined by activation of the gustatory cortex; the smell impact of a product or service on the consumer's brain is determined by activation of the olfactory cortex.

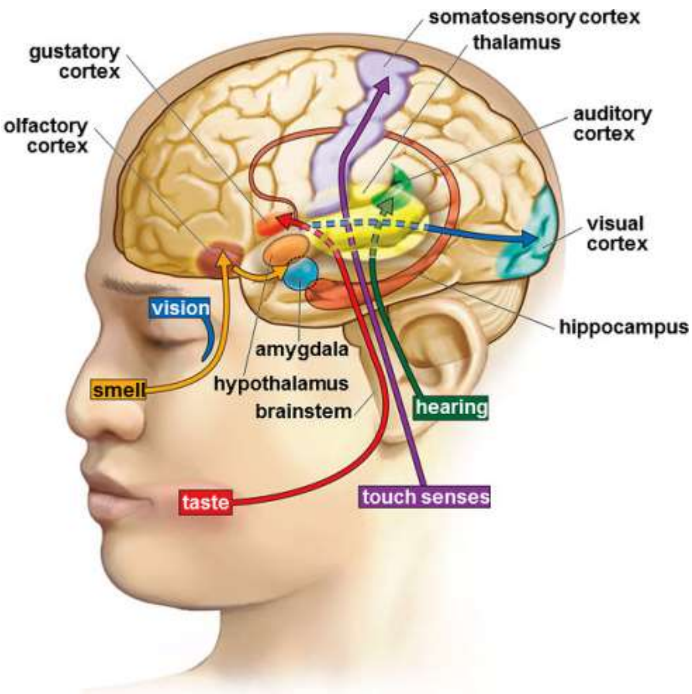

Figure 1. Areas of the consumer's cerebral cortex that are activated under the influence of relevant characteristics of goods and services [4]

In this paper, we have measured experimentally the electrical activity of the consumer's brain based on electroencephalographic (EEG) signals depending on various marketing stimuli. Since it is the consumer's subconscious that determines his behavior by more than 90%, EEG signals were measured at 500 Hz frequency. Let us remind that the consumer's stream of consciousness, which determines his or her conscious behavior, operates at 40 Hz frequency. Thus, measurements at higher frequencies made it possible to take into account the consumer's subconscious activity.

In order to illustrate schematically the selection of EEG signal sampling from consumer, the image is shown in Fig. 2 [5].

16-channel electroencephalographic NEUROKOM complex produced by medical equipment manufacturer KHAI-MEDYKA was used (Fig. 3) in this investigation for the selection of EEG signals [6].

Thus, experimental measurements of the electrical activity of consumer's brain were carried out on the basis of EEG signals depending on various types of marketing stimuli: from the consumption of delicious and unpalatable food (Fig. 4, Fig. 5), from the smell of pleasant and unpleasant odors (Fig. .6, fig.7), from listening to heavy and light music (Fig.8, Fig.9), from watching funny and sad videos (Fig.10, Fig.11).

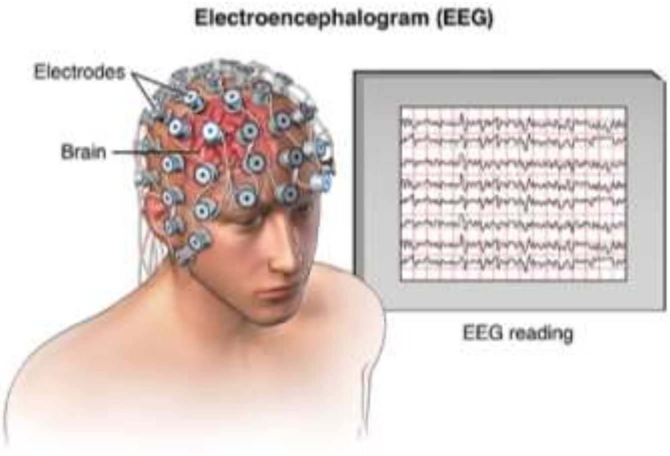

Figure 2. EEG and brainwaves [5]

Figure 3. 16-channel electroencephalographic NEUROKOM complex produced by medical equipment manufacturer KHAI-MEDYKA [6]

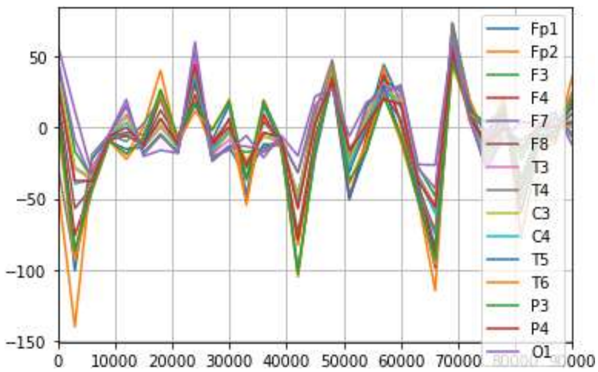

Figure 4. Visualization of EEG signals caused by eating delicious food

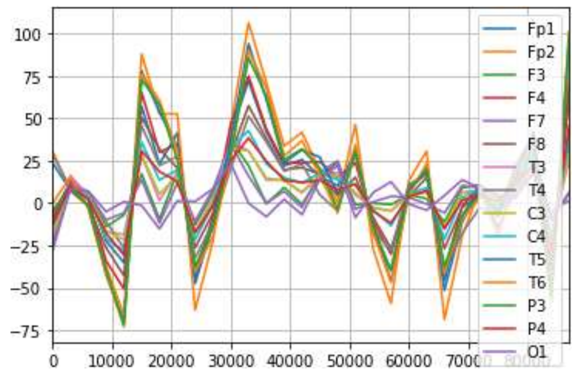

Figure 5. Visualization of EEG signals caused by unpalatable food

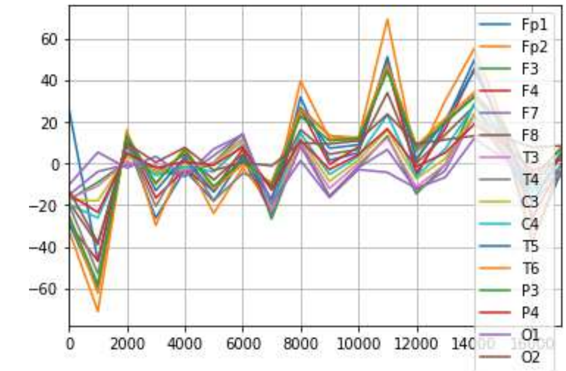

Figure 6. Visualization of EEG signals caused by pleasant odor

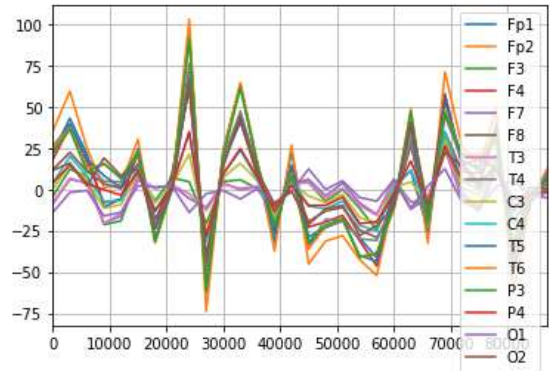

Figure 7. Visualization of EEG signals caused by an unpleasant odor

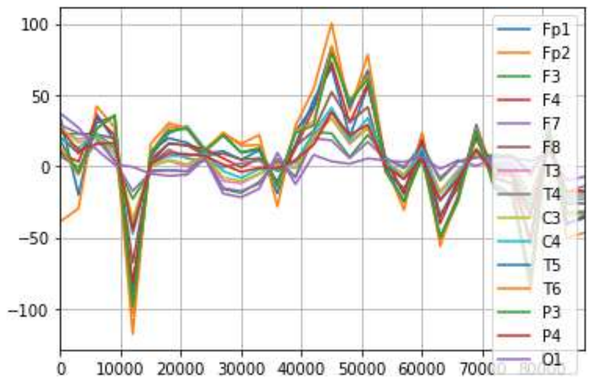

Figure 8. Visualization of EEG signals caused by listening to heavy music

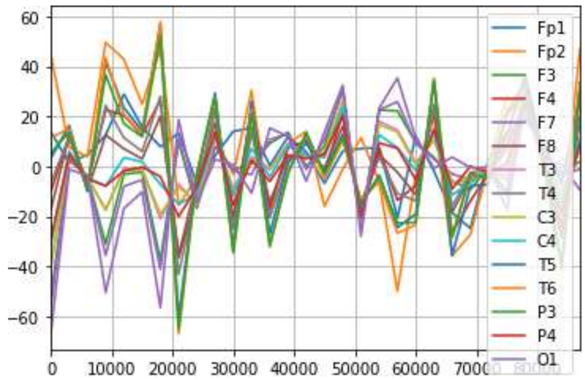

Figure 9. Visualization of EEG signals caused by listening to light music

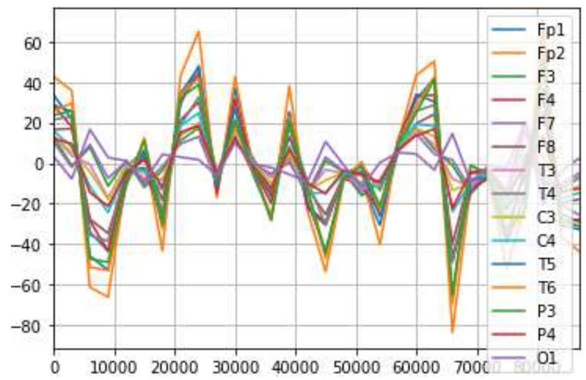

Figure 10. Visualization of EEG signals caused by watching funny video

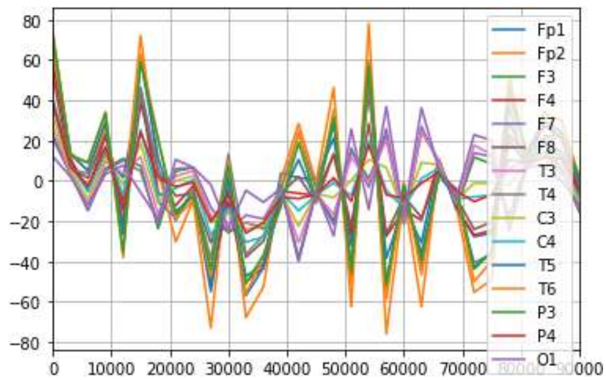

Figure 11. Visualization of EEG signals caused by watching sad video

For each of the above mentioned marketing stimuli, the task of binary classification of electrical activity of consumer's brain based on EEG signals caused by these marketing stimuli was set. Thus, on the basis of experimentally measured data, the real behavioral differentiation of consumer's brain states was determined.

In order to solve these problems, binary classifications, artificial intelligence algorithms such as algorithms based on neural network technologies were used. In particular, the architecture of artificial neural network – multilayer perceptron was used. In order to obtain the optimal hyperparameters of the multilayer perceptron and to achieve its maximum accuracy, hyperoptimization based on cross-validation was performed. The obtained optimal architectures of multilayer perceptrons were used as the basis for the developed application software for neuromarketers.

The accuracy of the developed new application software was also evaluated on the basis of various quality metrics, namely, accuracy, f1 and roc_auc.

Thus, the quality metrics of the developed new application software for the classification of electrical activity of the consumer's brain on the basis of EEG signals caused by various marketing stimuli have the following values: accuracy=92%, f1=92% and roc_auc=97% from the consumption of delicious and unpalatable food; accuracy=92%, f1=96% and roc_auc=96% from the smell of pleasant and unpleasant odors; accuracy=97%, f1=97% and roc_auc=99.6% from listening to heavy and light music; accuracy=88%, f1=88% and roc_auc=96% from watching funny and sad videos.

Normalized error matrices are presented for visual interpretation of accuracy classification by class differentially, and ROC curves are presented for evaluation of the stable accuracy, regardless of unbalanced data. Depending on the marketing stimulus in the experiment, this information is realized in Figures 12–19.

Thus, the obtained performance quality metrics of the developed new application software for neuromarketers shows high accuracy of classification of different active brain states depending on different marketing stimuli.

The results of the experimental measurements and their high-precision processing based on neural network technologies provide grounds for their further use in solving new neuromarketing problems, namely, the definition and differential identification of various memes as units of information represented in the consumer's brain.

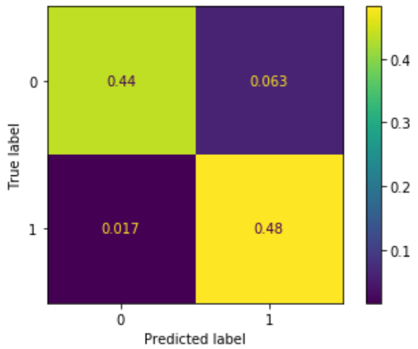

Figure 12. Normalized error matrix for classification of EEG signals caused by consumption of various food

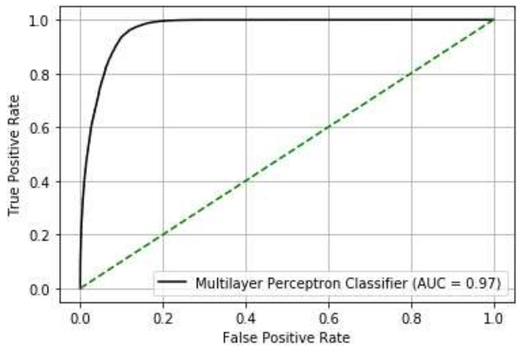

Figure 13. ROC curve for classification of EEG signals caused by consumption of various food

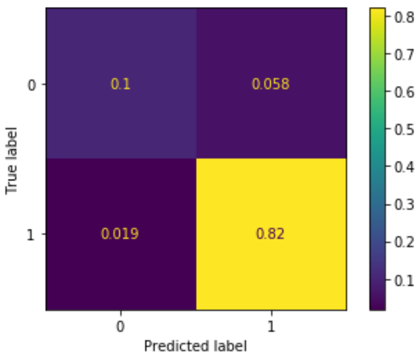

Figure 14. Normalized error matrix for classification of EEG signals caused by different odors

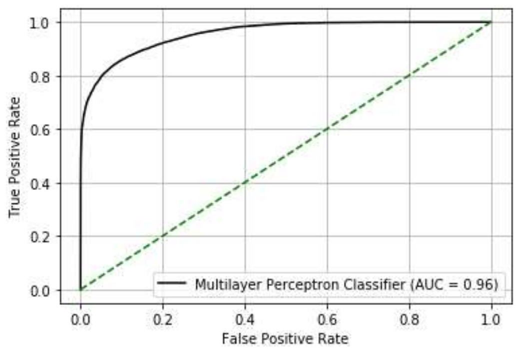

Figure 15. ROC curve for classification of EEG signals caused by different odors

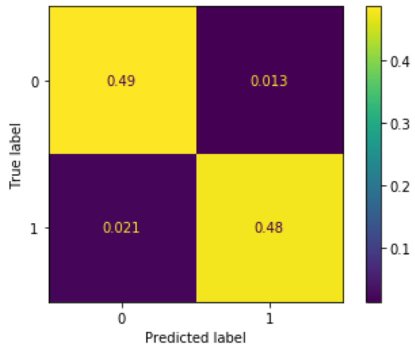

Figure 16. Normalized error matrix for classification of EEG signals caused by listening to different kinds music

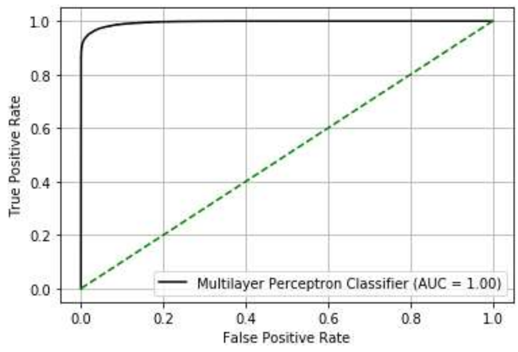

Figure 17. ROC curve for classification of EEG signals caused by listening to different kinds music

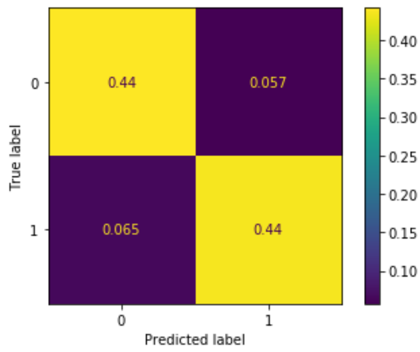

Figure 18. Normalized error matrix for classification of EEG signals caused by watching different types of videos

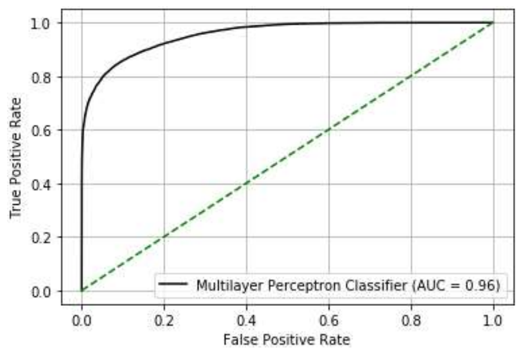

Figure 19. ROC curve for classification of EEG signals caused by watching different types of videos

Conclusions. Software which makes it possible to carry out practical investigations for neuromarketers has been developed on the basis of measurements of the electrical activity of consumer's brain based on electroencephalographic signals, depending on various marketing stimuli. Accuracy of the developed software which makes it possible to affirm its practical value is evaluated on the basis of various quality metrics.

References

1. Cialdini R. Pre-Suasion: A Revolutionary Way to Influence and Persuade, 2017, 413 p.
2. Genco S. J., Pohlmann A. P., Steidl P. Neuromarketing For Dummies, 2013, 408 p.
3. Ramsoy T. Z. Introduction to Neuromarketing & Consumer Neuroscience (English Edition), 2015, 206 p.
4. Regulatory biology. Sensoryand movementcoordination. Available at: http://physiology. elte.hu/eloadas/szabalyozasbiologia/eng/movement_sensory_coordinatiom.pdf (accessed 04.11.2023).
5. Bright brain – London's eeg, neurofeedback and brain stimylation centre. Available at: https://www.brightbraincentre.co.uk/electroencephalogram-eeg-brainwaves/ (accessed 07.09.2023).
6. Medic XAI. Available at: https://xai-medica.com/en/equipments.html (accessed 02.05.2023).

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РОЗРОБЛЕННЯ ПРОГРАМНОГО ЗАБЕЗПЕЧЕННЯ ДЛЯ НЕЙРОМАРКЕТИНГУ НА ОСНОВІ ШТУЧНОГО ІНТЕЛЕКТУ Й НАУКИ ПРО ДАНІ З ВИКОРИСТАННЯМ ТЕХНОЛОГІЙ ВИСОКОПРОДУКТИВНИХ ОБЧИСЛЕНЬ ТА ПАРАЛЕЛЬНОГО ПРОГРАМУВАННЯ

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Резюме. *Присвячено науковому дослідженню в новому напрямі людської діяльності – нейромаркетингу. Актуальна важливість нейромаркетингових досліджень і розроблення для їх проведення програмних систем зумовлена сучасними можливостями встановлення патернів поведінки між споживачами та різними маркетинговими стимулами. В основі наукового дослідження щодо розроблення нового програмного забезпечення для нейромаркетингу використано сучасні методи й засоби штучного інтелекту й науки про дані (нейромережеві технології) з використанням технологій високопродуктивних обчислень та паралельного програмування. Проведено експериментальні вимірювання електричної активності мозку споживача на основі електроенцефалографічних сигналів залежно від різних маркетингових стимулів. На основі даних вимірювань розроблено прототип нового прикладного програмного забезпечення для нейромаркетологів. Оцінено якість роботи розробленого прототипу програмного забезпечення для нейромаркетингу. Зокрема, оцінено точність роботи розробленого нового прикладного програмного забезпечення на основі різних метрик якості, а саме, accuracy, f1 та roc_auc. Метрики якості розробленого нового прикладного програмного забезпечення для класифікації електричної активності мозку споживача на основі електроенцефалографічних сигналів, викликаних різними маркетинговими стимулами, набули значення: accuracy=92%, f1=92% та roc_auc=97% від споживання смачної та не смачної їжі; accuracy=92%, f1=96% та roc_auc=96% від нюху приємного та не приємного запахів; accuracy=97%, f1=97% та roc_auc=99.6% від прослуховування важкої та легкої музики; accuracy=88%, f1=88% та roc_auc=96% від перегляду смішного та сумного відео. Для наочної інтерпритованості точності класифікації диференціально по класах використано нормовані матриці помилок, а для оцінювання стійкої точності (не залежно від незбалансованих даних) використано ROC-криві. З отриманих метрик якості роботи розробленого нового прикладного програмного забезпечення для нейромаркетологів випливає висока точність класифікації різних активних станів мозку залежно від різних маркетингових стимулів.*

Ключові слова: *нейромаркетинг, електроенцефалографічні сигнали, нейромережеві технології, штучний інтелект, наука про дані, технології високопродуктивних обчислень, паралельне програмування.*

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