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Труды конференции

ТӨРКИ ТЕЛЛӘРНЕ КОМПЬЮТЕРДА ЭШКӘРТҮ ТЕХНОЛОГИЯЛӘРЕ БУЕНЧА "TURKLANG 2024" ИСЕМЛЕ XII-НЧЫ ХАЛЫКАРА ФӘННИ КОНФЕРЕНЦИЯ

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Analysis of Classification and Recognition Methods of Hand Gestures Recorded with Electromyography Sensor

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***Abstract*—The article is devoted to automatic recognition of gestures, which is a necessary component of human communication and provides remote control of contactless interaction systems. Communication devices that are regularly updated and have a more user-friendly interface have expanded user capabilities. Keeping up with the scientific and technological development of people is a requirement of modern times. In the current era of the fourth industrial revolution, contactless controlled technological innovations await people. Automatic recognition of gestures is one of the main factors in building and improving contactless controlled systems. The article clarifies the method of recording the parameters of the hand showing the gesture with an electromyography sensor. Recognition methods based on these parameters are analyzed. The use of hybrid methods is proposed to ensure high-accuracy recognition of gestures in real time.**

Keywords—information technologies, electromyography, recognition technologies, robotics, artificial intelligence, machine learning

I. Introduction

Historically, as a result of scientific and technical progress, which is one of the main factors in the development of mankind, fundamental quality changes have occurred in all fields. The dynamic development of ICT, the expansion of the Internet and the provision of information sharing are based on scientific and methodological principles. The application of science to production has had a positive effect on the leap development of the communication field as well as other fields. Dynamically developing ICT has increased the role of information in all areas of society, positively influencing the development of society, becoming one of the main factors and causing the fourth industrial revolution.

IV industrial revolution is a new stage of human development and is based on artificial intelligence. This period is characterized by the development of modern automation, robotics and production technologies. The development of artificial intelligence and digital technologies has also contributed to the field of gesture-human-machine interface. Contactless interaction with multi-level information systems has penetrated all areas of human activity and expanded user capabilities. The introduction of interfaces that support and recognize gestures has improved the speed and quality of work. Moreover, they facilitate the communication of hearing-impaired people and ensure their adaptation to society.

The process of remote control of devices in the field of robotics is implemented by gesture recognition systems. The scope of application of systems based on gesture control technologies is quite wide, from personal computers to surgical robots. Transferring information with gestures or controlling certain devices with gestures is faster than traditional touch or voice control from the user's point of view. Contactless, gesture-controlled systems are successfully used.

Accurate classification of gestures is the basis of recognition systems. Automatic recognition of gestures is one of the most urgent issues in the construction and improvement of gesture-human-machine interface.

The article clarifies the method of recording the parameters of the hand showing the gesture with an electromyography sensor. Comparative analysis of recognition methods based on these parameters is shown. The use of hybrid methods is proposed to ensure high-accuracy real-time recognition of gestures.

II. Classification of Gestures with an Electromyography Sensor

Hearing and speech impaired people communicate through gestures. Gesture means eye expression, facial expression, head, hand and body movements. In fact, gestures are important in the communication of even non-verbal people. A person who speaks verbally uses gestures to express his thoughts more fully during communication. Gestures clarify speech. Historically, sign language is a language that arose independently. Every nation has its own sign language. Like spoken language, sign language has evolved over time. Gestures of sign language can mean different things in different nations. In order to accurately analyze and recognize the national sign language, as well as arbitrary voice language, its database should be genrated. This database is an electronic dictionary containing descriptions and symbols of sign language elements [1].

The establishment of contactless control systems is realized due to the automatic recognition of gestures. Gesture control technologies for computer and robotic systems have great potential. Replacing wired technologies with gesture-controlled technologies not only increases the quality and speed of work, but also provides interaction between the system and the user in a non-standard environment.

Recognition of hand gestures is based on the processing of their characteristic features. Electromyography (EMG) sensors are successfully used in the work of gesture recognition systems. It is possible to recognize different positions of the hand by using the EMG sensor and decoding methods. The EMG sensor is capable of classifying the muscle signals of the hand making the gesture. The activity of the muscles of the hand showing the gesture is recorded as a signal with a special device (fig.1). The device consists of an EMG sensor connected to an electrode, a microcontroller and a power supply. When the hand moves, the muscle fibers change shape and are accompanied by bioelectrical activity signals. The signals recorded by EMG sensors are input parameters for gesture classification methods [2].

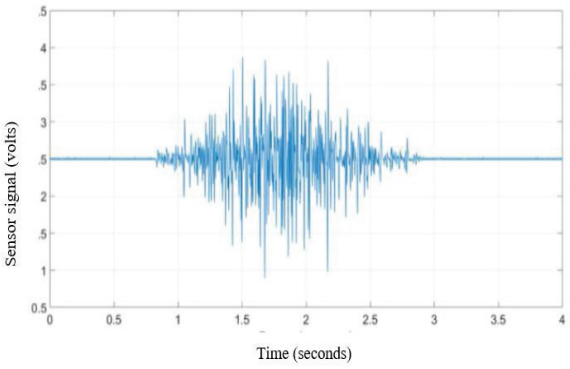

Fig. 1. Muscle signals recorded by the EMG sensor of the hand showing the gesture.

The advantage of EMG sensors is the small dimensions and the possibility of using them as portable devices. One of the main advantages of EMG is that the user's hands can move more freely (they don't have to stand in front of the camera). But the EMG sensor records background noise in addition to basic data. The process of recognizing gestures recorded by the EMG sensor begins with passing the signals through a filter and removing background noise. Then, the main feature vector containing the gesture is extracted and passed to the classification method (fig.2). Determining signs of gestures and accuracy of classification depends on the recognition method used. The working scheme of the training method is shown in the following figure [3]:

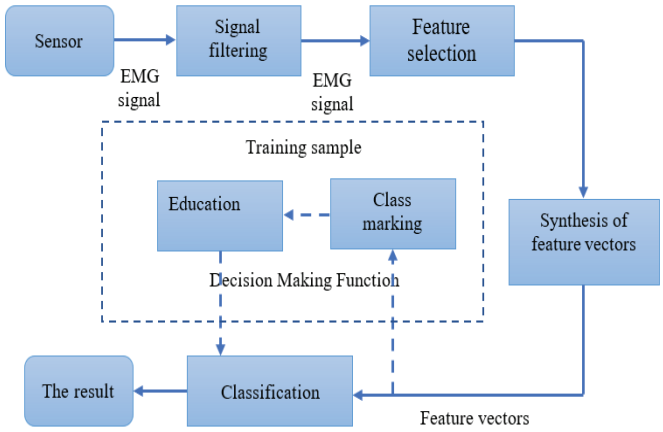

Fig. 2. Working scheme of the training method in the process of classification of EMG sensor signals.

III. Analysis of Training Methods Based on Emg Signals

Accurate classification of gestures and detection of signs is the initial stage of recognition systems. Due to the wide possibilities offered by ICT, there are many methods for classifying signals recorded by EMG sensors: k-nearest neighbors method, Naive bayes method, random forest method, hidden markov method, neural network method, support vector method, etc. These methods are used to obtain prompt and accurate classification results in real time. Below are the working principle of several recognition methods:

K-nearest neighbors method. One of the simplest classification methods is the k-nearest neighbors method. This method is based on classifying the object in the space of multidimensional features. The set of features includes the average of the EMG signal, the wavelength, and the features of the moving object. The distance between points is calculated to find the nearest points (neighbors).

The K-nearest neighbors method is a widespread and widely used approach. The method first finds k similar samples from the samples database. Based on the selected proximity metric, the closest sample to the viewed sample among similar samples is determined. The degree of proximity of two samples is determined based on the degree of proximity of the corresponding characteristics of the samples. Each attribute is assigned a weighting factor that reflects its relative importance. The following formula (1) can be used to find the proximity metric of two samples for all attributes [4]:

$$\boldsymbol{sim(i,k)} = \frac{\sum_{j=1}^{n} w_j + sim(e_{ij}, e_{kj})}{\sum_{j=i}^{n} w_j} \qquad (1)$$

Here: sim – is the proximity metric; wj – j is the weight of the sign; ei and ekj – are the values of the current samples i and k, respectively, of the sign ej

As can be seen, the working principle of the k-nearest neighbors method involves inputting a test data set for training and calculating the distance between the points of the "k" parameter to find the nearest points. The main drawback of the K-nearest neighbors method is that it takes a lot of time for classification. The recognition accuracy of the method is 92.50% when the hand is free or in motion. The k-nearest neighbors method can work hybridly with the linear discriminant analysis method. At this time, the recognition accuracy increases: it is 93.03% when using eighteen optimal EMG channels, and 94.50% when using fifty-six EMG channels [5].

Naive Bayes method. Naive Bayes is a machine learning method that allows gesture classification based on probability. The Naive Bayes method can provide real-time recognition of gestures. The method is based on Bayes' theorem and the assumption that the signs are conditionally independent. The classification aims to determine which class the studied object belongs to. The method is characterized by a low degree of complexity and a short operation time, and at the same time it can work with large volumes of data. Based on the Bayesian classifier, the maximum likelihood estimates of data ($\mathbf{x_j} \in \mathbf{R^q}$, $\mathbf{y_j} \in \mathbf{C\{1, \dots, C\}}$) with N number of attributes ($\mathbf{x_j}$,$\mathbf{y_j}$) is calculated by the formula (2). The disadvantage of this method is characterized by low classification accuracy and instability of predictions. The recognition accuracy of this method with the use of three EMG sensors is 69%. The Naive Bayes method can work hybridly with the random forest method. In this case, the recognition accuracy of the method increases to 90.20% [6].

$$\widehat{P(C_J)} = \frac{X_j}{N} \qquad (2)$$

Here: $\boldsymbol{P(C_j)}$ – probability assessment, Xj –Cj is the collection of all instances marked with class.

Random forest method. The random forest method is successfully used in real-time hand gesture recognition and classification. The random forest method consists of a set of decision trees. The most important issue in the operation of the method is the construction of optimal decision trees. An arbitrary decision tree is a tree-like graph consisting of nodes and branches where attributes are written. The decision trees in the training set are regularly split into two branches. That is, each node (except the last one) has two branches divided according to the characteristics of the sample. The division process is based on a logical comparison of signs. In the branches, the characteristics of the sample are evaluated and it is predicted which category it belongs to (fig.3). As a result of the classification, it obtains a set of predictions for each tree separately and selects the best decision. The average recognition accuracy of the random forest method using eight EMG sensors is 91.47% [7],[8].

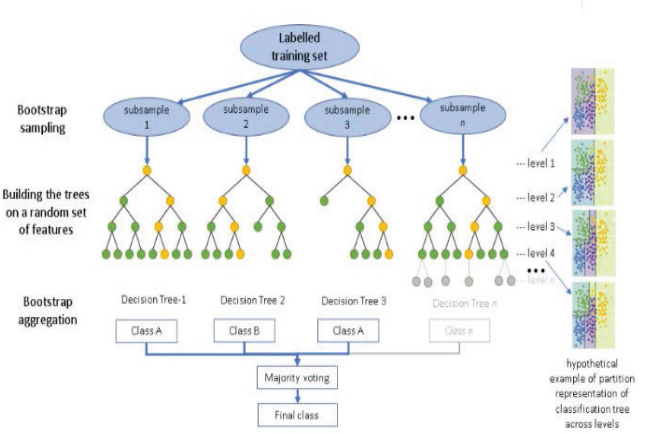

Fig. 3. Working scheme of classification of EMG sensor signals by random forest method.

The final decision of the method is the result of classification of several decision trees. In most cases, decision trees predict the same outcome. In this case, the independence of the decision trees provides a basis for high-quality recognition of the pattern. If most trees in the forest fail to classify the same sample, but one or a few trees succeed, no decision is made, the method sends this sample to retraining. The upper limit of error for the final result, taking into account all cases, is calculated by the following (3) formula [9]:

$$GE = \frac{1-S^2}{S^2} \quad (3)$$

Here, GE – upper limit of total error; S – shows the classification quality of each individual tree.

The final result of the random forest classifier is determined by the majority of trees. This result is calculated by the formula (4) below [8]:

$$A = arg\ max\ Y_c(x) \quad (4)$$

Here, Yc(x) – is the set of successful trees in class c; x – is the number of trees in class c.

Hidden Markov method. Mathematical apparatus of the hidden Markov method is a universal tool for gesture recognition. There is no single mathematical model for the operation of this tool. In gesture recognition issues, a separate model is usually built for each gesture detection (fig.4). In the operation of the method, the signs of the mathematical model change according to the state of the gesture. Building the right classifier architecture that fits each task is the complexity of the markov method. Recognition of dynamic and isolated static gestures described by sequential hand movements is possible with the hidden markov method. The hidden markov method recognized eighteen gestures recorded using twelve EMG sensors with an accuracy ranging from 76% to 98%. [10].

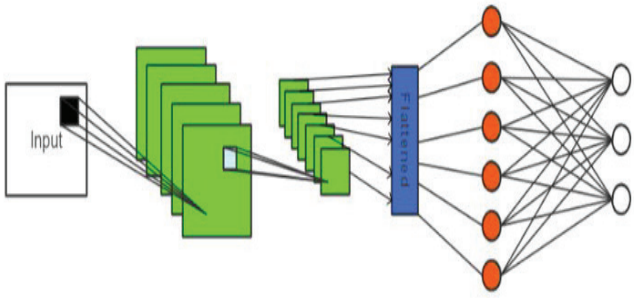

Fig.4. Scheme of the process of extracting the main signs of gestures using the hidden Markov method.

Neural network method. One of the popular methods used for gesture recognition is the neural network method. Along with other methods, the neural network method is successfully used to solve the issue of detecting and classifying the main signs of a gesture. The neural network method is a mathematical model based on the principles of organization and activity of biological neural networks [11].

The neural network method selects features necessary for classification from the data set in the training process. In recognition issues, the features of the gesture are normalized and transferred to the input of the neural network, and the gesture is obtained at the output. Neural networks differ from each other according to the training method and structure [12]:

- Recurrent neural network,
- The Kohonen self organizing map
- Elman artificial neural network
- Competitive training of Khebba
- and so on.

The method uses a multi-layer pattern with a high degree of connection and analyzes the features of the gesture. Classification problem solving is performed in several stages (fig.5) [13]:

Data collection;

Introduction of machine learning for classification;

Determination of neural network architecture;

Selection of the number of layers and the activation function;

Transfer of classified data from the training set to the input of the neural network;

Calculation of output values (this process is repeated until the specified level of accuracy is reached);

Conducting test or inspection work.

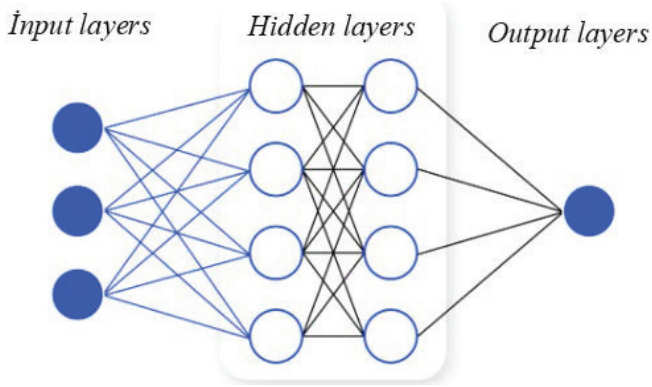

Fig. 5. Scheme of the process of extracting the main features of gestures using the neural network method.

The advantages of the neural network method include the speed of processing, the guarantee of accuracy, the simplicity of data processing and the high detection rate of the main features of the hand object showing the gesture. However, the drawback of the method is that it has a complex mathematical structure and requires a lot of resources. When recognizing six gestures, the maximum recognition accuracy of the neural network method is 98.8% [14].

Support vectors method. The method of support vectors is a convenient method for classification of gesture features and solving regression problems. The method is successfully used in solving linear and non-linear problems. The method of support vectors creates a hyperplane in multidimensional space. This method is based on categorizing the set of points representing the signs of the gesture through a support vector in the hyperplane (fig.6). Support vectors consist of the set of points closest to the boundary between classes. The distance between these vectors and the hypertop minimizes the probability of the classification error of the algorithm. The advantage of the method is that it can provide maximum classification accuracy for high-dimensional spaces. However, when the number of points is large, the classification process takes a lot of time and finding the optimal support vector becomes complicated. This is a shortcoming of the method. Support vectors method was used for gesture recognition of healthy and stroke patients. The recognition accuracy of three gestures using eight EMG sensors was 94.3% for healthy people and 78.8% for stroke patients [15].

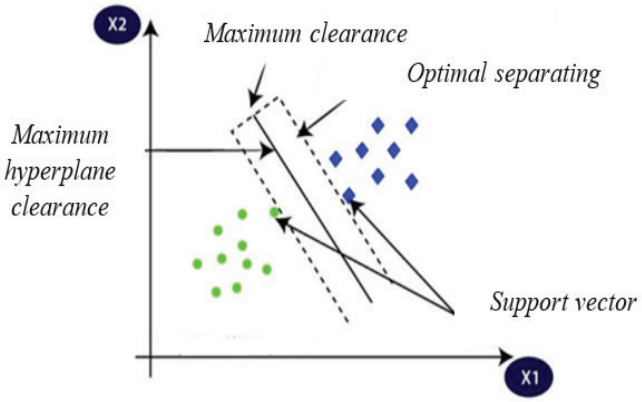

Fig. 6. Scheme of the process of extracting the main signs of gestures by the support vectors method.

Methods for classifying signals recorded by EMG sensors have both advantages and disadvantages. Table 1 shows a comparative analysis of the advantages and disadvantages of gesture recognition methods [16]:

TABLE 1. ADVANTAGES AND DISADVANTAGES OF GESTURE RECOGNITION METHODS

The Name Of The Method		Advantages	Disadvantages
1.	K-nearest neighbors method	It's simple	Time-consuming to classify, sensitive to noise
2.	Naive Bayes method	Low level of complexity, characterized by a short operation time, it can work with large volumes of data	Recognition accuracy is low
3.	Random forest method	In the training process, signs are selected automatically, the prediction quality is high, retraining is possible	It is complicated and time-consuming to train
4.	Hidden Markov method	The training process is fast, flexible and transparent	It is complicated, the settings need to be adjusted
5.	Neural network method	It can detect complex non-linear relationships between variables	It cannot run when the data is low
6.	Method of support vectors	Provides maximum classification accuracy	The number of support vectors increases linearly with the size of the training set

Above, an analysis of the effectiveness of different machine learning methods is performed to solve the problem of gesture recognition using EMG signal. Sometimes it is more convenient to use a hybrid of methods to achieve a higher result in solving the problem of gesture recognition.

The hybrid approach also allows to increase the recognition accuracy. When the methods work in a hybrid way, the percentage of recognition accuracy is partially higher. As mentioned above, the Naive Bayes method can recognize gestures with 69% accuracy when working individually. However, its hybrid operation with the random forest method increases its recognition accuracy to 90.2% [3].

IV. CONCLUSION

This article explored the recording and classification of the muscle signals of the hand showing the gesture with the EMG sensor. It analyzied the machine learning methods based on the EMG sensor and identifying hand gesture features with the highest accuracy in real time.

In modern times, the achievements of training methods that recognize gestures expressed by hand signs have shaped the general picture of technology use. The process of remote control of technologies with gestures is carried out by the achievements of gesture recognition systems. Recognition of hand gestures, among other methods, is also successfully realized by recognition of signals received from EMG sensors. The EMG sensor provides high accuracy recognition of various hand movements. This article suggested the use of hybrid methods to be more appropriate for machine learning methods in hand gesture recognition to achieve faster and more accurate results**.**

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