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作品編號 **090028**

參展科別 醫學與健康科學

作品名稱 **Development of a neurointerface glove with tactile feedback**

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關鍵詞 **hybrid brain computer interfaces、neurorehabilitation**

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Research Question or Engineering Problem

A stroke continues to be the most important medical and social problem of the modern world. Stroke is a type of acute cerebrovascular accident (ACVA) and is characterised by a sudden (within minutes, less often - hours) appearance of focal neurological symptoms (motor, speech, sensory, coordinating, visual and other disorders) and / or general brain disorders (depression of consciousness, headache, vomiting, etc.) that persist for more than 24 hours or lead to death of the patient in a short period of time due to a cause of cerebrovascular origin. There are two clinical and pathogenetic forms of stroke: ishemic stroke (cerebral infarction) is caused by acute focal cerebral ischemia, leading to infarction (zone of ischemic necrosis) of the brain; hemorrhagic stroke (non-traumatic intracerebral hemorrhage) is caused by rupture of an intracerebral vessel and blood penetration into the brain parenchyma or rupture of an arterial aneurysm with subarachnoid hemorrhage (SAH). ACVA also includes transient disorders of cerebral circulation, characterised by the sudden occurrence of focal neurological symptoms that develop in a patient with cardiovascular disease (arterial hypertension, atherosclerosis, atrial fibrillation, vasculitis, etc.), last for several minutes, less often hours, but no more than 24 hours, and ends with a full restoration of the impaired brain functions. Transient disorders of cerebral circulation include: transient ischemic attack (TIA), which develops as a result of short-term local cerebral ischemia and is characterised by sudden transient neurological disorders with focal symptoms; hypertensive cerebral emergency, which is a condition associated with an acute (usually significant) rise in blood pressure (BP) and accompanied by the appearance of general cerebral (less often focal) neurological symptoms secondary to hypertension. The most severe form of hypertensive crisis is acute hypertensive encephalopathy, the basis of pathogenesis of which is cerebral edema. Cerebral infarction generally is the result of the interaction of many etiopathogenetic factors, which can be subdivided into local and systemic ones. Local factors include: morphological changes in the brachiocephalic or intracerebral arteries (pathological tortuosity, etc.), atherosclerotic lesions of the vessels of the aortic arch and cerebral arteries, cardiac lesions as a source of thromboembolic cerebral infarctions, fibromuscular dysplasias of the walls of the brachiocephalic and cerebral arteries, brachiocephalic artery dissection, vasculitis (arteritis), changes in the cervical spine with the formation of extravasal compression of the vertebral arteries, anomalies in the structure of the vessels of the neck and brain (hypoplasia of the vertebral artery, trifurcation of the internal carotid artery), etc. Systemic factors include: disorders of central and cerebral hemodynamics (a sharp change in BP or a decrease in cardiac output, etc.), hereditary and acquired coagulopathies, polycythemia, certain forms of leukemia, hypovolemia, psychoemotional stress / distress, etc., hypercoagulative / hyperaggregatory side effects of a number of medications (oral contraceptives, etc.). In the Russian Federation, more than 500 thousand people have a stroke every year. About 25,000 new cases of stroke occur in St. Petersburg every year. The incidence of stroke in the Russian Federation is 3.48 ± 0.21 cases per 1000 people. The incidence of various types of ACVA varies widely, in particular, cerebral infarctions account for 65–75%, hemorrhages (including subarachnoid hemorrhages) – 15–20%, transient cerebral circulation disorders account for 10–15%. The frequency of cerebral strokes in the population over 50–55 years old increases by 1.8–2 times in each subsequent decade of life. Medical and socio-economic consequences of ACVA are very significant, in particular, death in the acute period of stroke occurs in 34.6% cases, during the first year after the end of the acute period in 13.4% cases; severe disability with the need for constant care is present in 20.0% of stroke patients; 56.0% have limited working capacity and only 8.0% return to their previous work activity. Disability due to stroke (the national average is 56–81%) in our country ranks first among all causes of primary disability, amounting to 3.2 per 10 thousand people. Stroke mortality among working-age population has increased in the Russian Federation by more than 30% over the past 10 years. The annual death rate from stroke in our country is 175 per 100 thousand people.

Stroke annually becomes the main cause of disability: 85% of victims experience a decrease in strength or a complete lack of ability to control the muscles of half of the body and only half of them recover limb functions partially or completely; the rest of those who have suffered a stroke remain paralysed and require care, since they are not able to completely independent existence. In this regard, recently, in the process of rehabilitation, the technology of brain-computer interfaces (BCI) has begun to be actively used. on the basis of this technology exercise machines are created. These exercise machines are controlled directly by the patient himself. This feature of the technology increases the effect of the procedure by providing a direct connection between the patient's desire and effort with the work of the simulator. The greatest development of this technology is observed in the field of medicine, where BCIs are used as a means of communication or as one of the tools of neurorehabilitation. In this regard, it seems very promising to develop the most optimal brain-computer interfaces. The goal of our project was to create an automated training complex in the form of a neuro-controlled glove with tactile feedback, designed to simplify access to rehabilitation means.

Methodology

Currently, there is an active stroke control. The basic principles of the recovery of patients who have suffered a stroke include the early start of rehabilitation measures with the activation of the patient, the systematicity, duration, consistency, adequacy of rehabilitation measures and, of course, the active participation of the patient himself. It is all based on neuroplasticity – a fundamental property of the brain to restore impaired motor activity by reorganizing old neurons and involving new ones in this function. In recent years, the rehabilitation of patients after a stroke, having passed a long way, has reached a fundamentally new level. The traditional methods (manual therapy, simulators, physiotherapy, medicines) have been supplemented by advanced developments based on the use of digital technologies and non-standard approaches.

One of the key problems that hinder the effective launch of neuroplasticity processes during the rehabilitation of patients after a stroke is the disability of the executive motor mechanisms caused by the pathology itself. Under these conditions, the patient's proactive intention to perform a motor act cannot end with the expected afferentation as a result of its fulfillment. As a consequence, this volitional effort of the patient is not enough to reorganise the cortical mechanisms of motor skill formation. In this regard, it seems relevant to search and develop technologies for temporary replacement of the external contour of the motor act in order to support the functional activity of the central mechanisms of motor control, that preserved after injury, and create conditions for the formation of new skills based on the reorganisation of the corresponding brain systems. Obviously, the main link of this technology should be instrumental detection of a person's intentions to perform a motor act. The volitional effort of a person detected in this way can be transformed into command signals and, bypassing the inoperative motor system, executed by electronic-mechanical devices. Such biotechnical systems for translating mental commands to executive devices are called brain-computer interfaces (BCIs).

BCI is a technology within which a person can transform his mental efforts into specific changes in the electrical activity of the brain, which, after being encoded, can be used to communicate with the external environment without using muscle activity. It is basically the ability to broadcast commands to external devices directly from the brain. The greatest development of this technology is observed in the field of medicine, where BCIs are used as a means of communication or as one of the tools of neurorehabilitation.

Recent studies have shown the effectiveness of using BCI technology, as well as tactile stimulation, but this method of rehabilitation is not a daily practice. For this reason, we consider it necessary to create a simulator for the recovery of patients. Last year, we studied the literature on the project, learned about the brain-computer interface technology, learnt the electroencephalogram (EEG) registration and the 3D-printing method, wrote the program code for the Arduino board that controls the simulator, printed the glove on a 3D-printer, connected LEDs and vibration motors.

As a basis for our simulator, we took the principle of operation of the virtual reality system and "mirror therapy": the patient will receive the view of his moving fingers as a result of his volitional efforts. In addition, we connect sensory sensations from the vibration motors to reinforce positive feedback and combine this with kinesiotherapy (massage).

Let's consider the technical possibilities of implementing this system. You can bend your fingers with the help of servo drives, vibration motors will help to reinforce feedback and massage, a system of LEDs and an EEG will catch the patient's will. To put this together into a well-functioning simulator, you need a microcontroller. We took the already developed Arduino board with a microcontroller and free software, thanks to which combining the listed components wouldn’t be very difficult. In addition, learning the basics of programming in Arduino took a little time for us, since it is based on the C language, which we learn on our IT lessons. In the process, we had to create two prototypes, the second of which was the final one. In order to connect the wires of the first, pilot, prototype, we used a breadboard due to the simplicity of working with it. To create a second prototype with a similar purpose, we used a soldering iron with accompanying consumables (rosin and tin), since it ensures reliable contact and durability of the connection. It was necessary to solder the contacts of the LEDs and vibration motors with wires, as well as solder these wires to the board and solder the board for further work with a larger number of outputs (with servomotors).

In addition to electrical components, our simulator contains a glove. It, in turn, consists of a hard plastic frame and a soft, flexible fabric glove.

A plastic frame is needed to provide support and flexion to the fingers. It was decided to 3D-print it because this method provides good shape and texture with the least amount of difficulty. First, slicing, meaning preparing the model for printing, was carried out, and then it was necessary to process the printed models from unnecessary elements.

The fabric base provides support and liaison between the plastic parts. We took a random work glove as a fabric base for the first prototype, but then we analysed our experience (the size of that glove was large and the fabric was too thick) and took a thinner neat cosmetic glove. To bond the plastic and fabric together, we used hot melt glue as a safe, comfortable and flexible material.

Registration of the electroencephalography and analysis of the obtained results were no less important stage of development. An EEG is a non-invasive method for studying the functional state of the brain by recording its bioelectric activity. EEG, revealing the functionality and reserves of the central nervous system, has become the standard of brain research, doctors consider it appropriate in many cases and in various conditions: in the presence of seizures and epileptic seizures; to confirm or exclude complications of inflammatory processes caused by neuroinfection; with vascular lesions of the brain; with mental disorders of all kinds. Signs of dysfunction of brain structures in children and suspicion of degenerative changes in the nervous tissue of the brain in the elderly (dementia, Parkinson's disease, Alzheimer's disease) can also be a reason to make an EEG. We performed EEG registration in order to obtain experimental records of brain activity. Subsequently, with the help of code these records were analysed and converted into commands for the simulator. The EEG is recorded using an electroencephalograph through special electrodes. Each electrode is connected to an amplifier. The recording of the potentials from each electrode is carried out relatively to the zero potential of the referent, which generally is taken to be the earlobe. Before recording, the patient is put special EEG cap with electrodes filled with a conductive substance. The procedure is carried out in a specialised room that excludes the ingress of light and noise. During the EEG recording, we used activating procedures and functional tests, for example, the test with opening-closing the eyes, hyperventilation, and photo-stimulation. Thus, the electroencephalogram helped us to obtain the data that was necessary for further work.

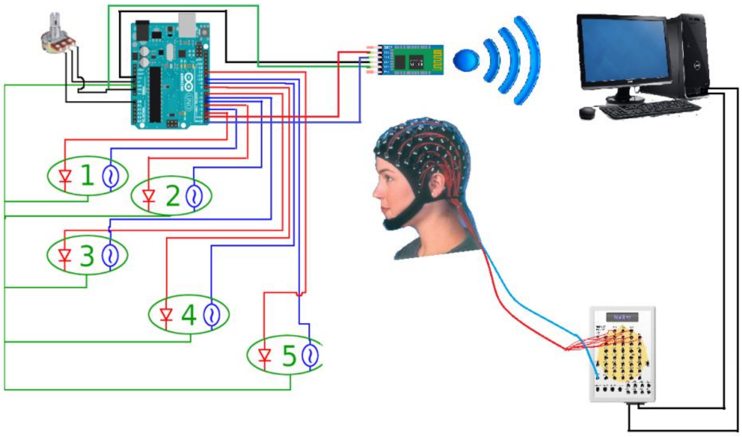
After converting the files of EEG recordings, data processing was carried out in the “matlab” environment. Processing included data analysis to remove artifacts, as well as interpolation of individual EEG channels (interpolation was used in case when the data from the channel could not be used, for example, due to loss of contact of the electrode with the scalp during recording). As a result of the conversion, we received EEG data presented in the form of a digital table, which reflected data obtained from eight EEG channels. To identify the most suitable channels for the further operation of the simulator, we had to analyze the data obtained from each individual electrode. Speaking about the analysis of

EEG data, there are 2 methods it: spectral and time-frequency. Spectral analysis is used when working with motion representation technology, since it is important for us to know about the activity of a certain part of the cerebral cortex. For example, when flexing the right arm, the left side of the motor cortex is active. Time-frequency analysis is used to implement the p300 component, since in this case the work is built on signals received after a certain period of time after the stimulus was presented.

In this way, the development of simulators for fine motor skills of the hand based on a BCI coupled with a physical phantom of the hand for patients after neurotrauma and stroke is a very significant area of development.

Results

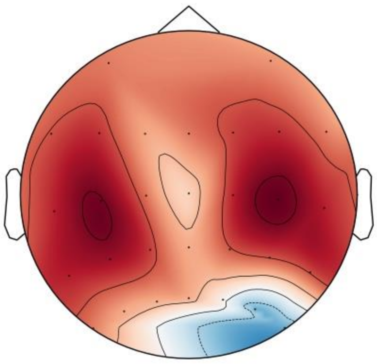
The final result of our work is a simulator prototype. The principle of its operation is quite simple at the moment: after switching on, it can turn on pairs of LED-vibration motor from one finger, selected at random. Subsequently, this will become the stage of reading the desire in the work of the finished simulator: it is enough to synchronise the flashes of light with the potentials caused by them, choose a specific response, the response to the expected flash. After this it will be possible to begin bending the corresponding finger. Also, a similar algorithm will be based on the calibration mode, designed to adjust the accuracy of the EEG classifier.

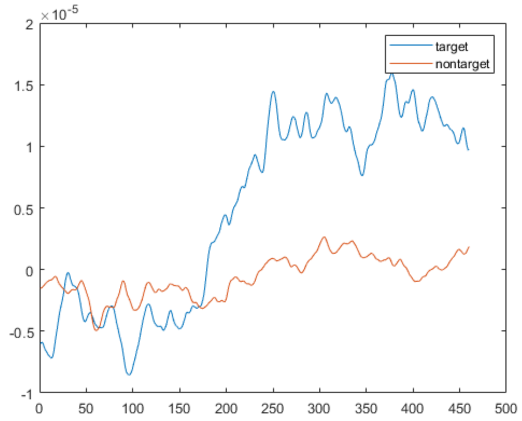



```
#include <Servo.h>
#include <SPI.h>
int val;
long randNumber;
int pot = A0;
int motorPin1 = 6;
int motorPin2 = 7;
int motorPin3 = 8;
int motorPin4 = 9;
int motorPin5 =10 ;
int led1 = 1;
int led2 = 2;
int led3 = 3;
int led4 = 4;
int led5 = 5;
int tm = 0;
void setup() {
Serial.begin(9600);
pinMode(motorPin1, OUTPUT);
pinMode(motorPin2, OUTPUT);
pinMode(motorPin3, OUTPUT);
pinMode(motorPin4, OUTPUT);
pinMode(motorPin5, OUTPUT);
pinMode(led1, OUTPUT);
pinMode(led2, OUTPUT);
pinMode(led3, OUTPUT);
pinMode(led4, OUTPUT);
pinMode(led5, OUTPUT);
}
void loop() {
tm = micros();
pot = analogRead(A0);
randNumber = random(5);
Serial.println(randNumber);
if(randNumber == 0){
digitalWrite(led1, HIGH);
delay(1000);
digitalWrite(led1, LOW);
Serial.println(tm);
Serial.println("1");
Serial.print("\t");
}

if(randNumber == 1){
digitalWrite(led2, HIGH);
delay(1000);
digitalWrite(led2, LOW);
Serial.println(tm);
Serial.println("2");
Serial.print("\t");
}

if(randNumber == 2){
digitalWrite(led3, HIGH);
delay(1000);
digitalWrite(led3, LOW);
Serial.println(tm);
Serial.println("3");
Serial.print("\t");
}
if(randNumber == 3){
digitalWrite(led4, HIGH);
delay(1000);
digitalWrite(led4, LOW);
Serial.println(tm);
Serial.println("4");
Serial.print("\t");
}
if(randNumber == 4){
digitalWrite(led5, HIGH);
delay(1000);
digitalWrite(led5, LOW);
Serial.println(tm);
Serial.println("5");
Serial.print("\t");
}

if (Serial.available()) {
int val = Serial.parseInt();
if (val == 0) {
analogWrite(motorPin1, pot);
Serial.println("большой палец вибрирует...");
delay(5000);
analogWrite(motorPin1, 0);
}
if (val == 1) {
analogWrite(motorPin2, pot);
Serial.println("уазательный палец вибрирует...");
delay(5000);
analogWrite(motorPin2, 0);
}
if (val == 2) {
analogWrite(motorPin3, pot);
Serial.println("средний палец вибрирует...");
delay(5000);
analogWrite(motorPin3, 0);
}
if (val == 3) {
analogWrite(motorPin4, pot);
Serial.println("безымянный палец вибрирует ...");
delay(5000);
analogWrite(motorPin4, 0);
}
if (val == 4) {
analogWrite(motorPin5, pot);
Serial.println("мизинец вибрирует ...");
delay(5000);
analogWrite(motorPin5, 0);
}
}
}
```

Interpretation of this results

We have collected a DataSet from EEG data at the moment. We carried out an offline classification of states, which allowed us to determine with which accuracy one of the functions of the simulator can be controlled. For example, you can use motion views to control vibration motors, and p300 to control servos. Combining these two technologies will be the most effective method, as each of them will be especially useful in a specific situation. In the future, there are many different ways to further develop our project. For example, you can do online classification, means recognise the patient's intentions in real time.





(Cortex activation in the representation of motion and the p300 component.)

Conclusion

1. Stroke annually becomes the main cause of disability, 85% of victims experience a decrease in strength or a complete lack of ability to control the muscles of half of the body and only half of them recover partially or completely. Existing rehabilitation methods do not give the desired results.
2. The use of physical activity, supplemented by visual and tactile stimulation in recovery from a stroke brings significant results.
3. The development of simulators for fine motor skills of the hand based on a BCI coupled with a physical phantom of the hand for

patients after neurotrauma and stroke is a very significant area of development.

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Great idea and a very neat design for building a BCI with tactile feedback. This study has potential on prosthetic application. It would be enhanced if the author could demonstrate that the prototype is really functional.