Modelling a project for the development of a neurocomputer interface based on EMG

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Abstract. Currently, around the world, various neurocomputer interfaces (NCI) are being actively developed for controlling prostheses, exoskeletons, robots, for interacting with virtual reality, for rehabilitation medicine, and even for professional sports. Development and research in the field of rehabilitation medicine will help partially and fully restore the functional capabilities of people with amputation or congenital defects of the limbs. Thus, the purpose of this work is to review the methods of recording the control signals of bionic devices based on the analysis of physiological and nervous processes in humans and modeling of a project for developing a neurocomputer interface based on EMG using flexible methods of project management. In this regard, first of all, it is interesting to develop a sensor and controller for further use in systems of robotic prostheses. At the moment, the design of the project using flexible methods of project management has been made and the first prototype with five channels for connecting sensors and a USB interface for communication with a personal computer has been manufactured. Also was made the first prototype with 5 channels for connecting sensors and a USB interface for communication with a personal computer.

1. Introduction

At present, various neurocomputer interfaces (NCI) are actively being developed all over the world to manage prostheses, exoskeletons, robots, to interact with virtual reality, as well as rehabilitation medicine and even in sports [1]. Campaigns such as Touch Bionics (UK), Biometrics Ltd (UK), Delsys (USA), Noraxon (USA), Ottobock (Germany), Mind Technologies (USA), Covidien (Ireland) and many others have been engaged in commercial development in this area for years. Even Elon Musk purchased and headed Neuralink. From the Russian segment campaigns such as: NeuroG, iBrain, United Instrument-Making Corporation, Cyber Myonics and Motorika.

It’s important to highlight the direction of rehabilitation medicine, and in particular prosthetics of human limbs [2]. Developments and research in this direction will help partially, and in the future, fully restore the functionality of people with amputation or congenital defects of limbs.

In this regard, during the implementation of a research project to develop a neurocomputer interface based on EMG and conducting both parallel and sequential tasks within it, for the successful implementation of the planned volumes of work, for the implementation of neurocomputer interfaces for identifying control signals of bionic devices based on physiological analysis and nervous processes in humans, it was required to apply a list of modern methods of project management and design research to achieve optimal results.

When modeling a research as part of the design research using flexible methods of project management - Scrum and Kanban [3], in conjunction with the Eisenhower principle [4, 5] and G. Gantt’s method of planning [6] - it is important for the design of a research project and its implementation consistently display and fix the stages of work in different software systems; so that:

1. identify known and unknown facts,
2. to clothe the facts in a certain form (in each software package its own type of display, fixation and presentation of information),
3. to formulate the main question that identifies the problem,
4. substantiate the relevance and importance at the moment in the framework of the research,
5. identify, formulate and outline the blocks of tasks, the tasks themselves and the subtasks of the research project.

Thus, the main value of using flexible methods of project management for research design in the framework of project management is the movement from theory to practice, when we test theory by practice.

2. Methods
Digital transformation [7, 8, 9, 10] within the scope of a research project required a cross-scientific approach, using the methodological basis for project design at an early stage using the following methods:

a. in the part of the research design, the following were considered and applied methods:
   - Scrum method [3],
   - Kanban method [3],
   - in conjunction with the Eisenhower principle [4, 5],
   - G. Gantt's method of planning [6],

b. in the part of the research, the following were considered and applied methods:
   - several methods for recording physiological and nervous processes in humans and a method based on surface EMG has been selected,
   - a differential amplifier was used to record the surface EMG signals,
   - for preliminary hardware signal processing, an active second-order low-pass filter was used in the strapping of the terminal inverting amplifier,
   - object oriented programming method,
   - multithreaded programming method.

Data based on some criteria allowed to get other data.
All this made it possible to develop a sequence of problem solving during the research, as well as to determine the necessary set of methods to achieve problem solving during the research on the development of a neurocomputer interface based on EMG.

2.1 Design of research project
Digital transformation allows:
   - to virtualize and modify business processes,
   - to realize faster data collection,
   - to speed up the decision-making processes,
   - to create new forms of social interactions in the digital space,
   - to display, record and present information for the purpose of its subsequent dissemination.

Also, digital transformation leads to the fact that it is more difficult for a person to unambiguously interpret digital objects.
Work with data (which may be different) is associated with:
- extracting information,
- adaptation of information,
- using information.

The research design was divided into two stages: “preparatory” and “main”.
In the early phase, during the preparatory phase, the following important milestones were identified for the implementation of the research project:
   - to formulate blocks of tasks, to carry out their decomposition into tasks and subtasks,
   - identify parallel and sequential tasks,
   - based on the initial conditions to set the scope of work,
   - clearly set time steps for all levels of tasks,
   - distribute roles and responsibilities,
• define tasks as processes and tasks as projects within the study,
• reflect causal relationships in stages,
• to formulate a general strategy for the implementation of the project and individual scenarios for tasks,
• formulate the expected end results.
As a result, the preparatory stage allowed us to identify a significant relevance for this research the need:
• for all research participants to possess complete information to ensure the correct interaction at all levels of research management,
• to display labor functions and professional competencies through tasks and expected results,
• to reduce the interaction time,
• to eliminate data loss.
Based on the relevance, methods of management were chosen - Scrum and Kanban [3], in conjunction with the Eisenhower principle [4, 5] and the planning method of G. Gantt [6] - for the design of the research project and its implementation. The use of different methods of project management and software systems, interconnected, allowed us to create a comprehensive understanding of the stages of research, the amount of work and make the development process achievable by the criterion of time and quality.
It should be noted that during the implementation of the project, in order to create a single knowledge base of the design of the research project, its participants were forced to:
• use from 4 - 7 software systems,
• apply a set of additional “packages” (libraries, databases),
• use project management software and the information in it had a different type of presentation and different formats,
• there was no opportunity to display big data on a single dashboard to perform work,
• the software used was different in functionality in connection with the version (free, shareware, paid: to get additional functions for a more fruitful, quick and convenient work on the project, some programs require expanding the functionality to the -pro version).
At the level of CAM (Computer-aided manufacturing): management systems, support calculations and engineering analysis (CRM, ERM, etc.), - in the scientific and expert activities on this research project, the following software systems were used:
1. to implement the Scrum method:
   1.1. Doist Ltd: Todoist,
   1.2. Asana: Asana,
   1.3. Xmind Ltd: Xmind,
   1.4. Other,
2. to implement the Kanban method:
   2.1. Atlassian: Trello,
   2.2. Atlassian: Jira,
   2.3. Atlassian: Confluence,
   2.4. Other,
3. to implement the assessment of tasks (subtasks) accordance with the Eisenhower principle:
   3.1. Evernote Corporation: Evernote,
   3.2. Xmind Ltd: Xmind,
   3.3. Google: Google Docs,
   3.4. Other,
4. for the implementation of planning in accordance with the method of G. Gantt:
   4.1. Microsoft: Microsoft Project,
   4.2. GNU General Public License: Ganttpro,
   4.3. Google: Google Docs,
   4.4. Other.
As a result, the design of the presented research project allowed:

- realize and automatize the process of implementation a project for the development of a neurocomputer interface based on EMG,
- to achieve final results on the list of blocks of tasks, tasks and subtasks by managing parts of the project for, developing a neurocomputer interface based on EMG using flexible project management methods,
- determine all the actions necessary to achieve the final result,
- to carry out the final verification and fixing of the results of research on the development of a neurocomputer interface based on EMG according to a predetermined goal and plan.

3. Results and Discussion

There are two main types of NCI for recording control signals: registration and processing of data on brain activity recorded by means of electroencephalography (EEG) and registration, processing of muscle biopotentials by means of electromyography (EMG). In turn, electromyography is invasive and non-invasive (surface). Also, would like to single out the neuroprostheses and neuroimplants interfaces developed in the framework of neuroprosthetics (sensory prosthetics) as a separate type. The most common is a cochlear implant designed to compensate for hearing loss in case of neurosensory hearing loss [11, 12].

There are fundamental differences between the interfaces of neuroimplants, and NCI in the direction of information transfer. Neuroimplants excite nerve endings related to the sensory system and realize the transfer function from the external environment to the nervous system. NCI is designed to transmit information from the central nervous system to the electronic computer complex.

The promising technologies for the implementation of NCI include magnetic encephalography. In 2018, scientists from the University of Nottingham and University College London published an article in the journal Nature about a magnetic encephalographic brain scanner in the form of a helmet that allows you to take readings in motion [13]. The technology at the moment has a number of restrictions for the implementation of NCI due to technical features. There are certain prospects for the implementation of such an interface.

3.1 Neurocomputer interface based on EEG (EEG NCI).

This NCI is based on the recording of the electrical activity of the brain by means of measuring electrical potentials by surface electrodes set at specific points on the surface of the scalp and subsequent mathematical analysis of the data obtained.

The implementation mechanism is rather complicated and consists of several stages. First of all, a set of EEG patterns is formed, corresponding to a specific mental activity, an imaginary action, or an evoked potential. On the basis of the received set, the classifier is trained and the pattern is then re-recognized. The set of EEG patterns for each person is individual [11].

This method is universal and can be used regardless of the nature of the amputation or defect, and, in my opinion, it is more effective for interacting with virtual reality. But at the same time, due to the complex mathematical apparatus and the large amount of data being processed, considerable computational power is required. Electroencephalography (EEG) is a non-invasive method for researching the functional state of the brain [14]. An invasive method for the functional research of the cerebral cortex - electrocorticography.

3.2 Neurocomputer interface based on surface EMG (surface EMG NCI)

This interface is based on the registration and processing of bioelectric potentials in human skeletal muscles by means of installing overhead electrodes on the skin surface directly above the muscle being measured and subsequent mathematical analysis of the data obtained [16].

The implementation mechanism is much simpler than that of the EEG NCI and consists in the direct measurement of the bioelectric activity of the muscle, and converting measurements into the control action of the actuator of the robotic prosthesis [17].
The main difficulties of the implementation of this NCI are: "Floating" electrical resistance of the skin surface (a similar problem occurs in the case of EEG NCI); Cross interference or “Wicking” of a bioelectrical signal is an extraneous signal of neuromuscular activity from other muscles spreading over the surface of the skin [18]. This interface is provided by a simple mathematical apparatus. As a result, data analysis and control generation can be implemented on the basis of embedded systems of small size and low power consumption, and these in turn are important factors for prosthetics. An interesting project of the surface EMG NCI is the bracelet “Myo” from the company “Thalmic Labs”.

Commercial implementation has already been launched, and the use of this NCI for controlling a robotic prosthetic has been actively developed by specialists from the private research university of Johns Hopkins (USA) [19]. Specialists from the Massachusetts Institute of Technology in April 2018 presented a new NCI "AlterEgo" based on the principle of registration of subvocalization using facial muscle surface EMG [20]. This development significantly expands the possibilities of using surface EMG NCI not only for limb prosthetics, but also for interacting with virtual reality.

3.3 Neurocomputer interface based on invasive EMG (EMG NCI)

EMG NCI is similar to surface EMG NCI except for the connection method. Invasive connection of the electrodes allows you to go from a global muscle electromyogram to an electromyogram of a separate muscle fiber, which gives a number of advantages over the surface EMG NCI:
- elimination of electrical resistance of the skin surface,
- increase the signal-to-noise ratio,
- significant reduction in cross interference (crosstalk),
- registration of neuromuscular activity of an individual fiber.

3.4 Development of a neurocomputer interface based on EMG.

First of all, the task was to develop a sensor of muscle biopotential. Figure 1 shows a prototype of a utility model of a hardware-software complex for measuring and recording skeletal muscle biopotentials. The maximum power consumption of the prototype does not exceed 50 mA at a voltage of 3.2 V. Also, as part of the task, software was developed for the microcontroller, computer and a data exchange protocol via USB interface between them. Work on these blocks of tasks in the research was carried out as part of the design of the project using flexible methods of project management.

![Figure 1. The prototype of the sensor of muscle activity.](image)

As part of the research, the AD8237 instrumentation amplifier was selected for development. As the microcontroller STM32F405 and to amplify the signal, the operational amplifier MCP6L from Microchip was used. Several hardware solutions of the sensor were developed, then in figure 2 where the prototype test is shown and the first positive results of their work are obtained.
Figure 2. Testing a prototype of muscle activity sensors.

Currently, software is being developed for the NСI controller and a personal computer, along with other tasks as part of the development of a neurocomputer interface based on EMG.

For the development of prototype boards for the sensor and controller, Altium Designer Automatic Design System (CAD) was used. Microcontroller software development was carried out in programming language C in the integrated development environment (IDE) Keil Embedded Development Tools. The software for the personal computer was developed in the programming language JAVA in the IDE IntelliJ IDEA. Software development is carried out with the distribution of tasks based on flexible methods of project management.

Based on the foregoing, surface EMG NCI is the most affordable and functional neurocomputer interface for development. The advantage is the availability and low cost of the element base, the absence of the need for direct participation of medical specialists, and the surface EMG NCI is more functional for use in systems of robotic limb prostheses. Existing developments in the Russian Federation are based on foreign hardware solutions. In this regard, in the first place, it is interesting to develop our own sensor and controller for further use in robotic prosthesis systems.

3.5. Project management of the development of a neurocomputer interface based on EMG.

As part of the management of the project and its design, the researchers needed to look for their own solution and approach to achieve the stated goals for the research tasks (subtasks). The advantage was the use of different methods of flexible project management in the complex. Visualization of all tasks, goals, criteria - all this provided an understanding of the sequence and scope of work. This, in turn, prevented the blocking of the execution of tasks within the working group team, made it possible for all participants to focus on the research as a whole, to quickly solve the research tasks and evaluate the result of the efforts made.

Since the main goal of the research project is the accumulation of scientific data about the studied object, process or phenomenon, the final result of the project is unknown. The process of developing a neurocomputer interface based on EMG involves developing and testing hypotheses and adjusting the further work plan for large blocks of tasks. Thus, the application of flexible methods of project management is limited within the current block of tasks, and designing a plan for subsequent blocks of
tasks (steps) is possible only after completion of the current and analysis of the results with further adjustment of the list of tasks.

Such an integrated approach to the management of the research project ensured the solution of tasks of scheduling, coordination and control of collective work with the presentation of information in the form of plans, schemes and work / task schedules based on the use flexible methods of project management - Scrum and Kanban [3], in conjunction with the Eisenhower principle [4, 5] and the planning method of G. Gantt [6].

Flexible methods of project management - Scrum and Kanban, in conjunction with the Eisenhower principle and G. Gantt's method of planning — allowed, based on the initial conditions, as well as taking into account criteria in terms of time and quality, to formulate a general strategy for the implementation of the project and individual scenarios for tasks.

Further, it is planned to conduct tests and optimize prototype circuits, optimize circuits and develop a “dry” connection of sensor electrodes, as well as develop software for transferring data to a package of applications for system analysis (MATLAB, Scilab, etc.) and a measurement database for further research.

4. Conclusion

The application of all selected flexible methods of project management for the design of a research project and the implementation of the development as part of sequential actions to solve certain tasks with certain goals in several software systems allowed:

- to get a more accurate display, fixation and presentation of information,
- to get more accurate results for each individual method.

In the end, based on the design of a project to develop brain-computer interface based on EMG, has been improved design of research project and the possibility of grading each phase of the research.

The implementation of a large block of project management tasks, in terms of project design, allowed us to automate the management process, reduce the labor costs of research participants, and also increase their communication skills to better perform their basic labor functions and professional competencies, which ultimately had a positive impact on the quality of the tasks being implemented and reduced the time for their completion by all participants in the research.

At the moment, the authors have developed several hardware solutions for the muscle activity sensor and the NCI controller. The first positive results of their work are obtained. Software development is also underway.

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