Walking support control system algorithms testing with brain-computer interface (BCI) and augmented reality (AR) technology integration

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Abstract. The article presents a perspective platform for the creation of robotic complexes for the effective and safe development of hard-to-extract minerals based on the walking support module. It describes the concept of automation control based on combining BCI and AR technology, and a method for testing control algorithms based on the application of the MTSS (Manufacturing and Transportation Simulation System) as part of the hardware and software complex for debugging and testing the applied software of the automated process control system for coal and ore mines. The reported study was partially funded by RFBR according to the research project No. 18-37-00356.

1. Introduction

As a result of the mining complex in Russia and abroad easily accessible and rich deposits exhaustion, the reserves that are characterized as difficult for development mining and geological conditions are being brought into operation - the occurrence is noted in steeply inclined and thick seams, the depth of bedding increases, and the coal seams are characterized by high gas content.

The need to increase the development efficiency of hard-to-extract minerals in difficult mining and geological conditions and in mines dangerous for gas and dust creates the need of transition to the minerals “uninhabited” excavation development technology with automated and automatic equipment developed to the level of robotic complexes [1].

In addition, as part of the long-term program for the Russian coal industry development till 2030, approved by the Russian Federation Government Decree of 24.01.2012 No. 14-p., the main direction of technological development with respect to the underground mining method is also the implementation of measures to develop and implement minerals “uninhabited” extraction systems on the basis of complex mechanization and automation. In accordance with Russia’s fuel and energy sector scientific and technological development forecast for the period up to 2035, coal mining...
technology without permanent presence of people in the working space, the introduction of robotic complexes for mineral development, were included in the priority critical technologies.

To date, the mining equipment and technologies which is used to extract minerals from thick steep and steeply inclined seams cannot operate without the constant presence of people at the mine face and preparatory faces due to the mining technology complexity. In this regard, not only new technical development solutions for thick steep seam deposits [2] extraction, but also modern automated equipment control tools are topical. In addition, the new development technological flow sheet [3] and the technical facilities for extracting minerals [4-7], for the equipment control and its diagnostics [8-11], allow them on their basis to create robotic equipment and machines for solving the tasks set.

2. Research objective
A promising platform for the robotic complexes creation for the effective and safe development of hard-to-extract minerals, with the underground method of development is a robotic module of a walking powered support [12, 13].

A hydroficated walking support module (figure 1) is designed to support the roof. Consists of two frames interconnected with each other through the hydraulic travel cylinders. Each frame is equipped with longitudinal top beams and cross beams rigidly fixed to each other, and is based through hydraulic props and supports on the ground.

In the working position, the travelling hydroficated support is strutted between the roof and the ground (thril). To move the support, strutting is removed from one of the frame’s support props, the frame released of strutting, sliding with the tops along the cross beam of the strutted frame, moves one travelling step. At the end of the travelling, pressure is applied to the piston cavities of the supporting hydraulic props and the moved frame is strutted [3].

![Figure 1. A module of walking powered shielding type support with a conveyor reloader.](image)

The second frame is moved in a similar sequence, completing the travelling cycle of walking. With hydroficated shields we achieve dosing of top coal caving from the roof and controlled fencing of the face zone. Coal transportation along the gallery to the conveyor is carried out by loading machine such as PSP-26.

To build the automated control system for the walking support module, the authors consider it promising to integrate the Brain-Computer Interface (BCI) based technology together with the Augmented Reality (AR) equipment into the system [14].
Currently, the authors, together with foreign colleagues from JIS Collage of Engineering, where specialists are already working on the control system basic modules study based on BCI [10, 11], are working on the operator's mobile working place organization concept and on integration of BCI equipment and augmented reality in automated control system (ACS) [15, 16].

The main aim is to organize the work of the ACS manager of technological processes (ACS TP) SCADA of mineral deposits underground mining in a new quality, without permanent presence at the working place, reducing the likelihood of error, loss of visual contact with the control object parameters.

The main idea is to organize the work of the dispatcher of the process control application for underground development of mineral deposits (ACS of technological processes - ACS TP) in a new quality, without constant binding to the workplace with a reduction in the probability of making an error, loss of visual contact with the parameters of the control object, based on virtualization of control and monitoring instruments.

Within the conceptual framework, the possibility of displaying information about the state of the complex directly in front of the operator with the complex interactive elements control rendering is provided by the augmented reality systems, the access to the main emergency control functions is provided through the adaptive automated control system based on the BCI control interface technology. The general diagram of the walking support control devices is shown in figure 2.

**Figure 2.** General diagram of the walking support control devices.

Brain-computer interface and augmented reality technology application is designed to solve problems such as a long time period eye contact loss with indicators displaying working complex status information. The opportunity to enter additionally a backup control channel from the dispatcher or the operator of the equipment, to equip better the ergonomics of the operator's workplace and reduce his fatigue.

Hardware based on the BCI has entered the market recently – from 2003. Existing brain-machine interfaces critically investigate in order to assess the maturity of this technology and estimate the improvements that it could yield [17-22]. However, existing brain-machine interfaces is insufficiently researched and tested in real and virtual conditions in the direction of application at industrial enterprises, especially for dispatching tasks. Therefore, the robotic walking support modules creation and integration into the production environment question consideration in the NeuroNet orientation plane and the introduction of digital production elements at mining enterprises and at coal mining machine building enterprises certainly involves the use of simulation modeling.
Integrated debugging and testing of ACS TP applied software at the early stages can significantly improve the reliability and safety of ACS TP, it can reduce the time and cost of starting-up and debugging work and test operation, facilitate the maintenance, upgrading and optimization of the applied software [23].

3. Methodology
Integrated debugging and testing of ACS TP applied software is a complicated task. Main problem is the difficulty to generate the complete set of coordinated signals like from the real technological equipment and the impossibility of artificial situation creation that go beyond normal operating modes at a real object. To solve this problem, the software and hardware complex of debugging and testing of applied software was developed at the ICT SB RAS. It includes simulation models of both technological processes and control programs for the technological process automated control system (ACS TP). They are used for simulating of the technological equipment sensor signals and for the technological process automated control system (ACS TP) components emulation.

There are a number of physical and software signal simulators that can be used in development and testing of ACS TP. Most effective is to have specialized software and hardware complexes that contains in their structure a problem-oriented, mathematical models of automated technological processes that, in turn, ensure the consistent generation of signals from sensors and control signals.

The specialized software and hardware complexes that implement the generation of test signals based on the technological process model or the whole enterprise include:

- WinMOD [24];
- MiMiC [25];
- xPC Target [26];
- Simulation model of the hydraulic unit for testing the algorithms of the ACS TP [27];
- Testing and debugging area for automation means and systems [28];
- Training and control software and hardware complex for chemical technology facilities [29];
- A test bench for aircraft onboard equipment software debugging [30];
- Test bench automated control system for submersible electrical equipment testing [31];
- Complex for automated control system technological process projects development and debugging [32];
- A test bench of semi-realistic simulation for development and for the embedded real-time computer systems [33]
- Development and validation of flight control system for small unmanned aerial vehicles [34];
- Application of the model-based design approach for robot arm software development [35];
- Technology of design and debugging of the control system software of bench nuclear power station with use of tool and software complexes of modeling [36];
- Management of the built-in model in semi-natural simulation for industrial wireless networks of enterprises using WirelessHART standard [37];
- some others.

Similar software was developed in ICT SB RAS. It is called “Software and hardware complex for testing of the applied software for ACS TP for coal and ore mines” [23]. This complex contains simulation modeling system MTSS (Manufacturing and Transportation Simulation System), also developed in ICT SB RAS and already used for technological process simulation models creation [38, 39].

A complex performs testing of the applied software on the principle of replacing the real signals from sensors of the processing equipment with virtual signals, generated on the basis of the simulated parameters of the processing equipment [40].

To solve the tasks of mining technological processes control within the MTSS, a specialized library of technological equipment models (TEM) of coal and ore mines has been developed. The TEM library is implemented using the Eclipse platform and the Java programming language.
Each TEM in the MTSS system consists of the following parts: a conditional graphic image as its visual part; list of parameters; a list of input and output signals; an operation algorithm that in particular involves the relationships between parameters; the list of states in which the TEM can while the modeling evolves; a list of control commands that switches the TEM from one state to another; additional blocks that extend the functions of the TEM (for example, the communication interface with external systems).

4. The expected results discussion and conclusion

Thus, for debugging and testing of BCI technology integration in conjunction with the use of augmented reality tools in the walking support control system with the Hardware and software complex for coal and ore mines ACS TP applied software testing, it is required to:

1. Develop an algorithm for controlling the automation system of walking support using the equipment of the Brain-Computer Interface;

2. Develop the TEM of the supporting-protecting type walking powered support module, in accordance with the technological equipment model description;

3. Develop the technological process simulation model of mineral deposits unmanned mining with an underground method when integrating the concept of the operator's mobile working place in conjunction with the use of augmented reality;

4. Adopt the algorithms and technical support of specialized simulation software and hardware complex for debugging and testing the applied software of the walking support system ACS TP for mineral deposits underground mining.

When carrying out the tasks, a specialized software and hardware complex will be obtained with an integrated simulation model of the mine industrial environment to solve control algorithms testing problems of travelling support complex automation.

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