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Fuzzy Cognitive Control System of Autonomous Vehicle: Brain Neurointerface and Soft Computing Modes

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Abstract

The article show the possibility of neurointerface application based on cognitive helmet with different traditional types of controllers for the vehicle driving. Extraction of knowledge from electroencephalogram based on knowledge base soft computing optimizer demonstrated. The commonly application of computational intelligence and cognitive toolkits improve the reliability of fuzzy control system operations.

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Keywords: Type your keywords here, separated by semicolons ;

1. Introduction: problems of cognitive and intelligent control

So far the theory and design processes of intelligent control systems (ICS) as knowledge-based control systems (in the form of relevant knowledge base (KB)) was carried out by an experts themselves through computational intelligence as soft computing using genetic algorithms or fuzzy neural networks.

The role of the human operator in control loop considered in an explicit form or it described by simplified transfer functions. The including of human operator in control loop was often suppose as a source of emergency or increasing risk information from the human decision-making.

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It has so far proved (Petrov, Ulanov and Ulyanov, 1977) that in large multiple control loop connected management systems to 75% of information often there is an excess quantity which isn't used or hinders decision-making. Therefore, one of the central problems of developing cognitive control system (CCS) was finding a constructive solution of design KB tasks in a given issue oriented applications.

However, cognitive abilities of operator (such as intuition, instinct and emotions) decision in unpredicted situations is both informational resource that enables to improve the effectiveness of the development and application of KB. Experimental studies of the brain and behavior of the human operator confirmed the hypothesis about the relationship of electroencephalogram (EEG) of individual sections of the brain (neurons or groups of neurons) with determination and prediction of human behavior.

Thus, there is an opportunity to apply cognitive processes of the brain the human operator as friendly "brain-computer interface" with a view to enhancing the effectiveness of predictive control to guarantee the achievement of management objectives in the face of uncertainty, contingencies and the increasing risk of information uncertainty (Brandt and Stark, 1997).

The aim of this work is to show the possibilities of experimentally effective application of cognitive interface ("brain-computer-actuating device") on the example of driving small car (mobile robot) reveal the modern management technologies. And show the role and necessity of application of computational intelligence in the work of the "brain-computer interface" to improve the reliability and robustness of the fuzzy control system.

In particular, the paper considers the possibility to control the movement of the object (forward, backward, left, right, bypass obstacles) through cognitive helmet using building block commands recognition and different types of control systems, including those based on soft computing.

For removal of brain, activity used cognitive helmet Emotiv EPOC+ (fig. 1), in conjunction with the supplied software (EPOC Control Panel).

The software includes a block record and recognition of mental commands generated by the operator. EPOC has 14 electrodes, which are passive sensors that allow registering electromagnetic signals and transmit them via Bluetooth to a computer for processing.

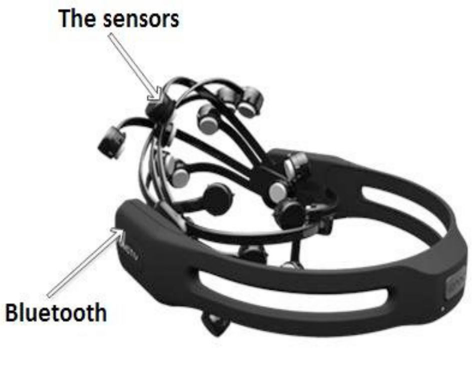

Fig. 1. Cognitive helmet Emotiv EPOC+

The electrodes are mounted on the surface of the skin (not submersible, non-invasive interface) and require wetting special liquid for better contact of the so-called "wet" interface.

Structurally the Emotiv EPOC+ consists of 14 channels AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4 (plus CMS/DRL and P3/P4). Sampling method sampling is serial. Sample rate 128 samples per second (inner 2048 Hz). Resolution is of 14 bits. Bandwidth of 0.2-45 Hz, digital notch filters for 50 Hz and 60 Hz. There is an additional filtering of digital filter.

The software supplied allows you to retrieve, identify and record the EEG signal with helmet, mental commands and assign certain actions to them (for example, to send a signal to a Bluetooth device for autonomous robot movement forward, backward, left and right). Mental training signal is resting and recording conditions, when the subject is the image of any action, concentrating in certain brain activity part of the brain. The entry of these signals takes 8 sec.

Figure 2 shows an example of the EEG signal, as well as the arrangement of electrodes of cognitive helmet.

In fig. 3 electrodes are presented in accordance with the functional areas of the brain (Sotnikov, 2014; Kane, 2014; Anatomy of the Brain, 2016).

Operator training takes place as follows: the operator is put on a helmet and through special software recorded signal its "neutral status" (resting state), then it is a signal of mental commands. To that end, the operator monitors and control object generates a mental command to its movement in the right direction, focusing and stimulating certain parts of the brain (the frontal, occipital or temporal lobes).

From the point of view of the control system, the operator must be able once again generate the recorded signals that interpreted by the control system to control the movement of the device, for each mental commands recorded individual signal.

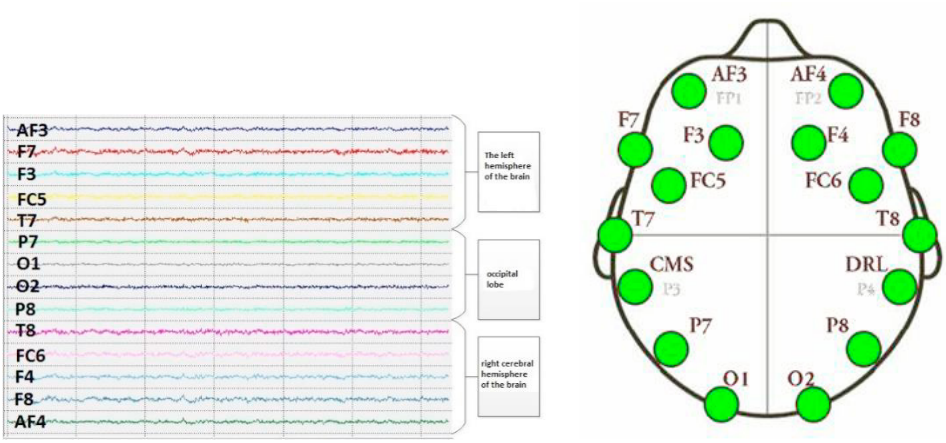

Fig. 2. On the top the signal is EEG electrode from EROS. (The below arrangement of electrodes on the head)

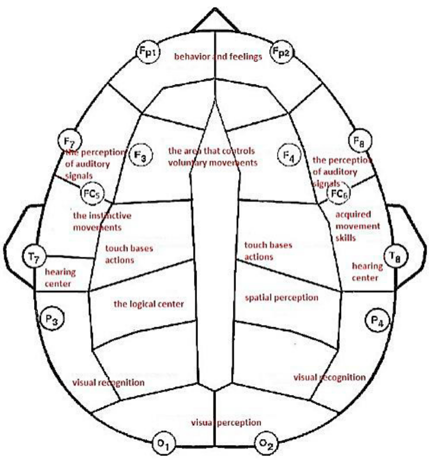

Fig. 3. Functional areas of the brain

One of the major technology components of cognitive neurointerface is gaming simulators. In the training case, control system acts on the screen as a model of the control object, this in turn allows you to not only train your brain to generate mental commands, but also customize the object control system control adjusting it to the operator, in order to enhance the effectiveness of the "brain-computer" system. This kind of feature is due to the fact that how a person learns to work with the helmet, and the program itself should be adjusted to the particular person by configuring a control system.

Recognition quality of such control system is usually associated with the level of training of the operator to generate different mental commands. Bundled software supplied specialized games-teachers, that using in the process of learning and training. Usually, for this use of computer games, where the operator must hold level an activity that will be associated with a system command that is used to manage the object. While playing, the operator develops his skill in working with a helmet that gives the ability to control in the future and the real technical devices (manipulators, wheelchairs, etc. devices).

Figure 4 presents software games simulators-left program Tetris in which the operator is invited to training commands left and right, as well as switching between forms, the program on the right - Spirit Mountain, where the operator training the brain for generate the commands forward, backward, left, right, up, down, for controlling the character in the virtual world (Anguera, 2013).

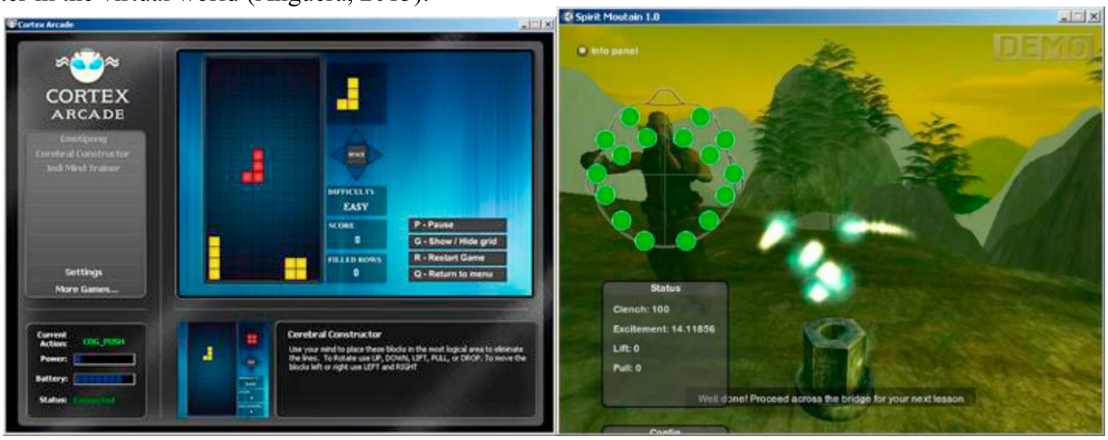

Fig. 4. Software games in EPOC package

Depending on the number of mental commands that you must generate, workout divided into levels of complexity. Workouts can be active with external stimuli, such as light of a certain frequency, video and audio material, pictures, etc., and passive, if in the process of generating mental commands the operator presents it without external influence. Duration and classes of workouts affect recognition quality and quantity of mental commands. At the first temporal interval a person can learn to generate signals in the brain to one command. For good recognition of two or more commands, need some training.

Accordingly, the control and the achievement of control objectives will influence how the Psychophysiological features of the human condition (including his position in space) and its level of training. Normally (by the manufacturer) for a good operation of the system using four commands, it is necessary to conduct regular workout 2-3 weeks, and after practice, the operator was experiencing fatigue and accordingly need time to recuperate.

Figure 5 shows the EEG, shot in a neutral State and in the State where the operator is far ahead.

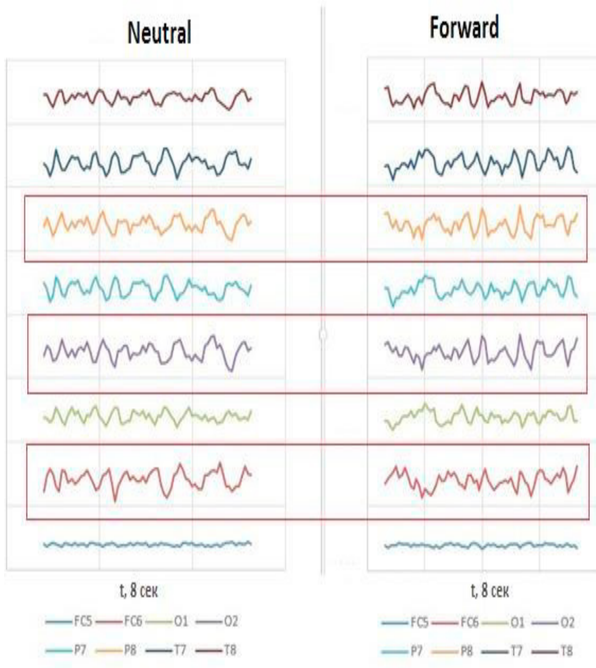

Fig. 5. EEG without mental commands (neutral State) and EEG with mental command (forward)

Usually, for the evaluation and recognition of signals used statistical techniques, including calculation of dispersion and math expectation. Figure 6 contains a table that highlights the most distinct signal associated with the traffic ahead and neutral State.

FC5	FC6	O1	O2	P7	P8	T7	T8	
126,66	3459,63	2108,80	3791,51	2940,07	3757,97	3768,52	2523,59	Neutral
103,47	4201,47	1644,94	3894,85	3072,52	3129,58	3455,78	1613,89	Forward

Fig. 6. Signal dispersion during the neutral status and with the mental command.

The table highlights the most distinct signal associated with the operator with the traffic ahead and neutral State. Dispersion of signals generated by the operator, it is quite a simple and effective method of comparing signals mental commands. Further, various methods are well showed in (Sotnikov, 2014).

Figure 6 shows that on electrodes FC6, T8 and r8 the difference signal dispersion is most essential. This gives grounds to classify control signal in software.

In fig. 7 shows the location of these electrodes.

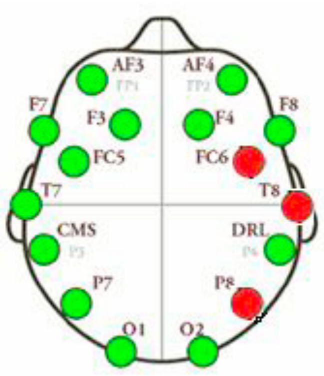

Fig. 7. Electrodes with the greatest difference in dispersion

It is important to note that in the case of training, the object control system is also tuned to improve the efficiency and robust of the brain-computer system. Thus, the control object is the system of the control model. This allows you to train your brain to generate mental commands and tuning software of the control system. This kind of feature is because how a person learns to work with the helmet and the program itself can tune to the particular person by adaptation of control system.

Structure of cognitive regulators

One of the objectives of this paper is to compare different regulators for operating a device using cognitive Slam, evaluate the possibility of using methods and means of intelligent control and soft computing optimizer (SCO) of KB (Litvintseva and Ulyanov, 2006) to improve reliability and efficiency of the on-board control system.

- Proportional controller.

The structure of this control system is based on the principle of the relay and making the control action proportional to the detected signal. From the power of recognition, the value of the output signals is received in the range of - 1 to + 1. Number of outputs equals to the number of recognized recorded commands. For our task it was team forward, backward, left, right. Movement device begins when output signal of recognition becomes more (or less) of a certain specified threshold, the direction of movement is determined by the sign of the output values and speed of movement (control) is proportional to the output signal size from recognition. Thus, for the command "movement forward" and "backward movement" was chosen range from + 1 to – 1 respectively.

Block diagram of the system presented in fig. 8.

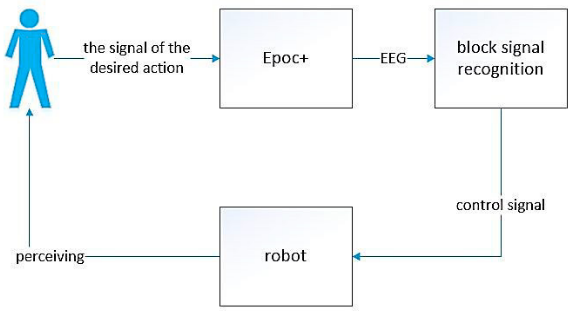

Fig. 8. Block diagram of proportional regulator circuit cognitive control

Recognition signal unit is supplied together with the used equipment and integrates as a library in the development Wednesday.

- Proportional-integral (PI) controller with fuzzy output block.

In the shown structure of output and signal recognition unit come on fuzzy output unit with an integrated knowledge base. The knowledge base has two inputs for proportional and integral component of the signal recognition unit, knowledge base thus implements the PI regulator input values are the corresponding values of the signal, and output value of control action fed engines of vehicle. Structure scheme shown in fig. 9.

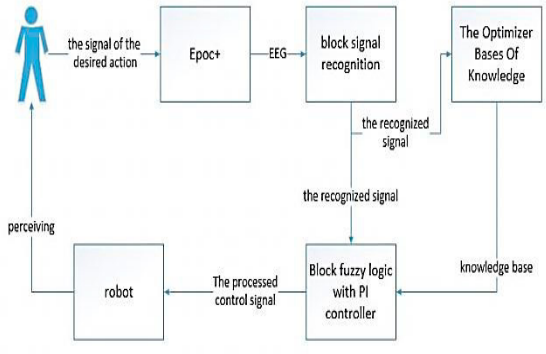

Fig. 9. Block diagram of the program with a block of fuzzy inference and knowledge base

For more effective operation of the control system, you can use a more complex controller, for example, proportional – integral - derivative (PID) controller, where depending on the received command with the block of recognition, is implemented by maintaining an appropriate speed and rotation angle to achieve certain values of control. Control effect in this block is consulate to the follow formula:

$$u(t) = P + I + D = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{de}{dt} \tag{1}$$

PID controller with different coefficients of amplification (fig.10).

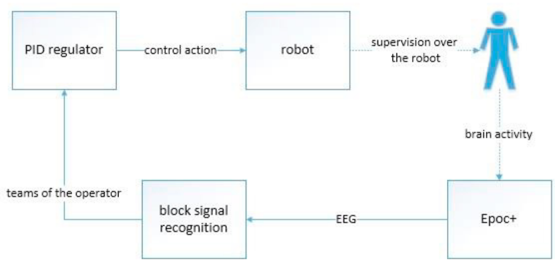

Fig. 10. Block diagram of the program with PID regulator

PID has three components, which depending on the incoming signal with the block recognizer in sum produce control signal. PI and PID regulators respectively set limits on the terms integral and differential component.

This work does not considered task of tuning gains of ratios of PID regulator, but shows that the choice of reinforcement ratios significantly affects system performance. Next, in the conclusions of the work shows the possibility of using modern types of calculations to add functions of learning and adaptation in the structure of the control system on the software level.

2. Designing cognitive control regulator for autonomous robot

For the experiment was been select the object of control - mobile robot in the form of three-wheel vehicle with Bluetooth control (fig. 11).

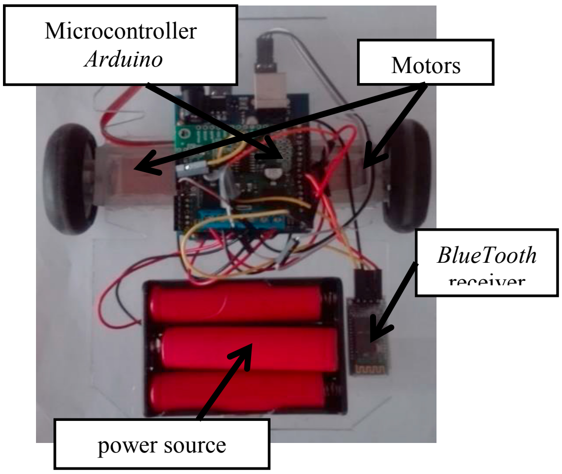

Fig. 11. Control unit.

The control device as a control processor used the Arduino Uno. Together with the engine driver- Pololu Dual MC33926. 2 (micromotor) Motor- DC 9V Motor Bluetooth module- HC-05. Power supply serves 3 3.7V Li-On battery.

The first and easiest implementation regulator for vehicle is a proportional controller. Such a regulator sends a proportional value of motors cars (Barker 1985) depending on which team has the greatest affinity to recorded in advance mental command (fig. 12 and fig. 13).

Fig. 12. Activating the commands in the proportional controller

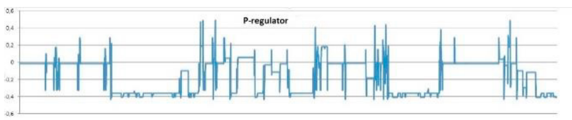

Fig. 13. Control impact produced p-controller while moving back and forth

For example, activation command associated in pairs of movement forward and backward made according to the difference of activation levels for these commands.

Next, let us look at the process of design PI regulator using SCO. To do this, in the first phase the expert generates a training signal, driving based on proportional regulator machine. During system operation, recording the signals received from the block recognizer. Coming from this signal by adding formed integral component (fig. 14) than the expert put the respective control impact based on previous experience with the system.

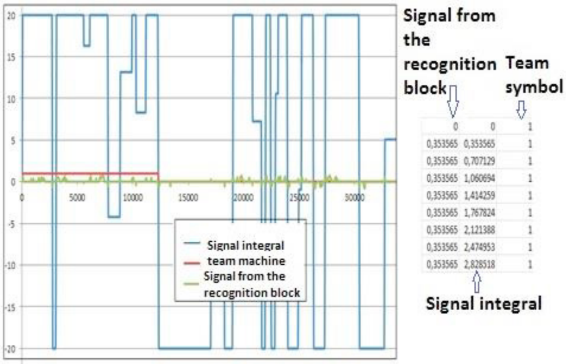

Fig. 14. The training signal.

At the next stage of design for fuzzy knowledge base withdrawal is carried out in automatic mode formation full knowledge base and further optimization of right-hand sides (fig.15).

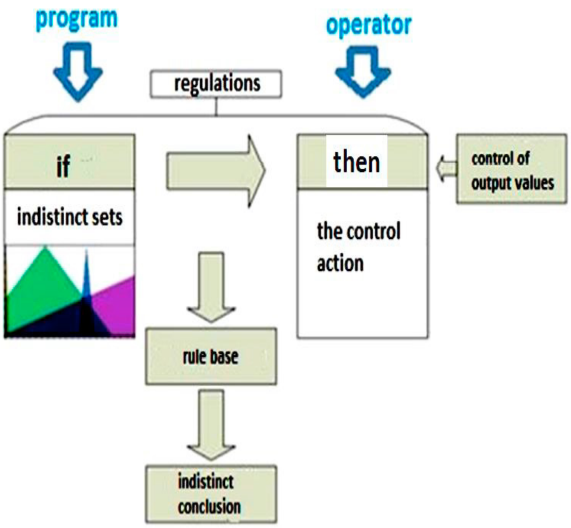

Fig. 15. Block diagram the formation rules in the knowledge base

In other words, at the entrance to the neural net receives commands from the software module signal recognition (forward, backward, left and right) the output value is the commands that receives vehicle.

The knowledge base applied in conjunction with PI controller. For the design a "flexible" control structure the technology of soft computing needs using. For this purpose created linguistic variables (LV) for each of the commands recorded in the system, was formed a complete knowledge base (fig. 16). The right side of the regulator contains appropriate values for control action using PI controller. Thus, the activation level of rules in base corresponds to the activation level of the control action.

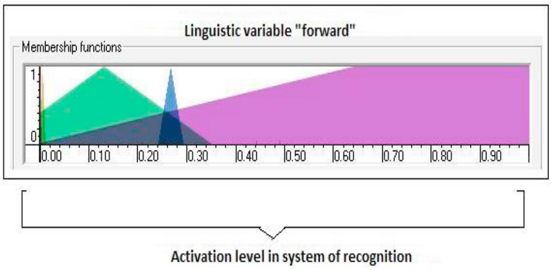

Fig. 16. An example of the linguistic variable for the team forward

Figure 17 shows the result of cognitive motion control of mobile robot in maze based on the PI-regulator.

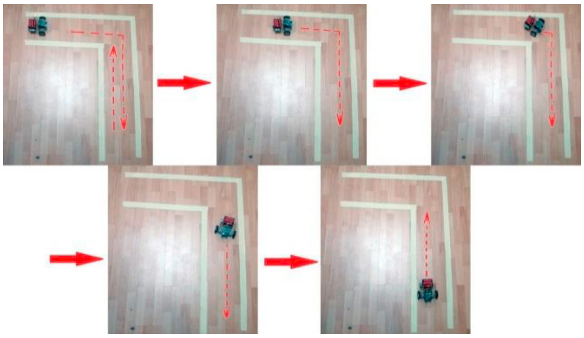

Fig. 17. When controlling the trajectory of mobile robot based on the PI-regulator

The following verified regulator to control machines was PID controller with constant coefficients. The coefficients of the regulators were PID 1 [1 0.1 1] and for PID 2 [3 0.1 10].

3. Results: modeling and experiment

In fig. 18 and fig. 19 show the commands of control systems to manage control object. The first chart, green introduced the target signal, which corresponds to a movement back and forth, and the rest of the colors allocated to the activation levels (Epoc) and PI controller with knowledge base.

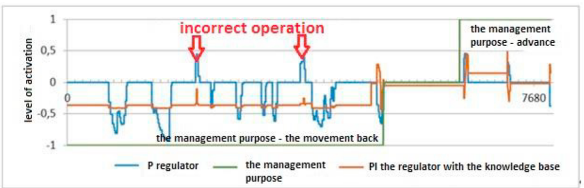

Fig. 18. Controlling actions produced by standard signal and PI regulator. Forward and backward

As can be seen from the graphs in Fig. 18, when the task motion vehicle is back, and concentration occurs thinking process on that team, recognition block is not always correctly identifies and control the machine. Vehicle work in spurts or even goes to the other side (false positives), PI control compensates this, and additional add it as an integral component in the knowledge base, allows a smooth sequence of commands and reduce errors in reaching the goal. Moreover, the system becomes adaptive and learnable, because the base is the software toolkit SCO.

On fig. 19, move to right corresponds to + 1, and the movement to the left corresponds to – 1.

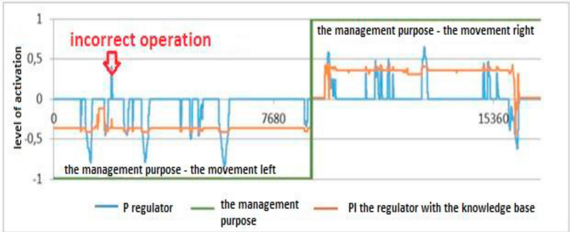

Fig. 19. Control actions produced by relay and PI controller when moving left and right.

Additionally there was described the problem of the motion using control system with PID regulator (fig. 20).

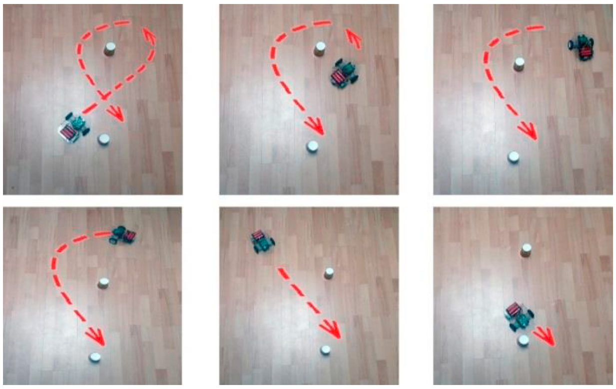

Fig. 20. Detour obstacles control system with PID controller

Figure 21 presents the results of an experiment using PID controllers with different coefficients of gain control action. The odds were set in manual mode. Differential component in PID controller associated with the speed of the operator activates the mental command.

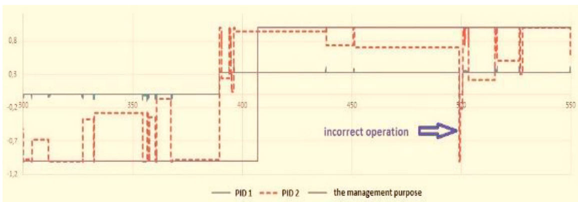

Fig. 21. Control actions produced PID controller when driving forward

The choice of gain factors influence naturally on the computation the action of controller and the operation of the system as a whole. However, establishing the optimal values of coefficients for each point in time is relevant and very interesting task. When incorrect (false) installation values the same way there has been an incorrect actuation, control object moves in spurts.

To compare the results obtained in the experiments used value is the mean deviation from the desired result. As can be seen from table 1 and fig. 22, using a more complex controller, the deviation has reduced. However, the wrong setting of the gain increases the deviation of the system from the intended target.

Table 1. Compare mean deviation of different types of controllers

Value / Controller	P	PI	PID1	PID2
Mean deviation	0,846	0,853	0,860	0,505

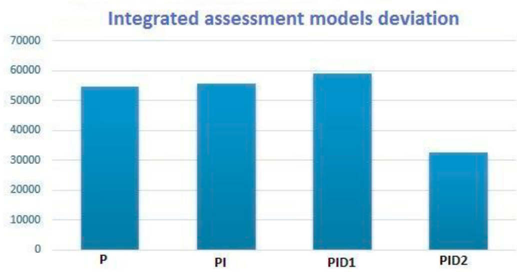

Fig. 22. Cumulative score deviation module

Analysis of results of experiments showed that quality control is greatly improved when more complex control schemes is applied.

4. Development prospects

Currently, for the training of cognitive abilities of the operator are widely used simulators-games. One of the main problems of the application of the cognitive system control technologies "brain-computer" is the problem with the physiological features of the human condition-operator. Exhaustion, excitement, distracting noises, etc. affect the physical condition that naturally affects recognition quality teams and quality of control target device. At the moment do not possess specialized simulators software module for adaptation and learning control system (the program itself) to the characteristics of the operator (Lee, Chang and Hsieh, 2012; Charaboti, et all., 2017). Experience with such weights indicates that virtually no mechanisms of adaptation and learning for practices imposed by the entry signal and its repetition, which interpreted as the generation of commands.

In turn, proved in a wide class of areas Soft Computing (genetic algorithms, fuzzy logic and fuzzy neural networks), can design intelligent cognitive control system with improve robust.

The fig. 23 show robust cognitive control system.

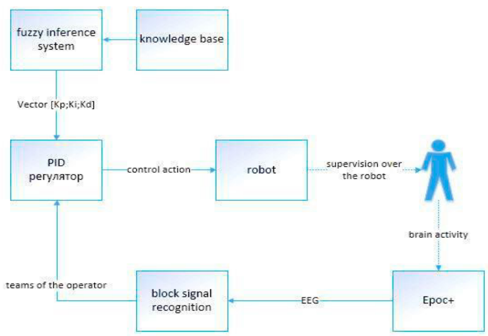

Fig. 23. Robust cognitive control system

In such a structure, the control of the central element is a fuzzy system with integrated knowledge base to it knowledge base contains type if-then rules. In the right parts of production rules set contain relevant factors in the formulation of control action. In the left parts are indicators of recognized and unrecognized commands, for example, the values of the variances from sensors of the helmet.

For the design of this kind, you must use the appropriate knowledge base. Generalized technology design can represented as a diagram in fig. 24.

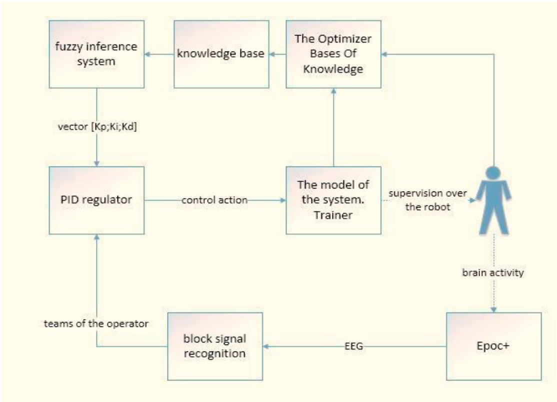

Fig. 24. The structure of the design technology of cognitive control systems

In such a structure control system with model is a central element, that rendering action that needs to be done. For the control of vehicle it can be a game where you must control the machine.

The first step is getting the teaching signal, for example, on the screen of the operator demonstrates the movement of cars on a certain track (line, circle). The signal of movement vehicle is recorded at the same time with EEG sensors. This signal will be base material for approximation of the fuzzy neural network and establishment of the left parts of the rules. The right-hand sides of the rules matched in the second stage of the design process, when the operator needs to operate a vehicle. While his attempt to repeat previous (recorded) signal is not required since the right parts not formed. They are formed in the process of the movement of cars on the highway, where traffic speed is determined on the basis of PID controller.

5. The conclusions

The results showed that quality of control greatly improved with intelligent cognitive control scheme based on SCO. This work demonstrates the need to develop a unified information technology of design of control system for neurointerface (Noor, 2015).

It is worth noting that the further development of cognitive control technologies inseparable with brain training methods. Now, operators using specialized filters, smoothing signals of the EEG and remove interferences and noises caused by psycho-physiological condition and external factors, but for global better the use of intelligent cognitive technologies, the software level of control system should be have executive mechanisms for learning and adapting the control system.

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