MODELLING OF BIOFEEDBACK USING CONTROL PROCESS

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Abstract: This paper deals with modelling of biofeedback using control process. The goal is to show how the different types of the biological feedback may be modelled using control process well known from cybernetics control theory. This research has been supported by MŠMT under research program MSM6840770012.

Introduction

In this section we define the term *biofeedback.* It is a term for a *negative feedback* whose sender and receiver is a *biological system* (e.g. human organism). The biological system receives an information about state of its own specific biological variable in order to regulate it. On the basis of this definition we may divide two similar meanings of the term biofeedback.

The first meaning of the biofeedback is a biological negative feedback that is realized inside the biological systems and it is necessary for their controlling. Such a control process is known as a homeostasis. *Homeostasis* means automatic maintenance of balance and stability inside the organism though an external and internal influences on organism comming. For example: maintenance stability of internal environment, temperature or blood circulation. The type of biological negative feedback operates automatically (involuntary) and it exists in all biological systems (from a cell to a human).

The second meaning of biofeedback is a process of measuring an aspect of a human physiology, analyzing the data, and then feeding back the information to the subject in a sense perceptible form that allows the subject to change the physiological state by his volitive activity. So biofeedback describes a process in which a subject is given immediate information about his or her bodily processes, which are usually unconscious. The subject is able to control those processes through his free will and through training and practising. This meaning of the biofeedback represents a training or therapeutic method that is used for therapy of disturbances of bodily regulation.

When we use the term biofeedback, we usually mean the second meaning of the term biofeedback, thus a training or therapeutic technique that enables to influence bodily functions that are not normally controlled voluntarily. Now, in the article, we will use the term biofeedback only in this meaning.

Applications of biofeedback

The best-known applications of biofeedback enable to alter *brain activity* (EEG Biofeedback or neurofeedback), *blood pressure* (blood pressure biofeedback), *muscle tension* (EMG biofeedback), *heart rate* (HRV biofeedback), *galvanic skin response* (GSR biofeedback), *hand temperature*, etc.

The EEG Biofeedback

The *EEG Biofeedback (neurofeedback)* (this section is taken from [3]) is a learning strategy (a therapeutic method) that enables persons to alter their brain waves. When information about a person's own brain wave characteristics is made available to him, he can learn to change them. The EEG Biofeedback is used for many conditions and disabilities in which the brain is not working as well as it might. These include attention deficit hyperactivity disorder (*ADHD*) and more severe conduct problems, specific *learning disabilities* and related issues such as *sleep problems (insomnia)*, *enuresis* in children, *speech disorders*, *teeth grinding*, and chronic pain such as *frequent headaches* or *stomach pain* or *pediatric migraines*. The training is also helpful with the control of *mood disorders* such as *anxiety* and *depression*, as well as for more severe conditions such as medically uncontrolled *seizures*, *minor traumatic brain injury* or *cerebral palsy*. The brain waves are monitored by means of an amplifier and a computer-based instrument that processes the signal and provides the proper feedback. This is displayed to the trainee by means of a video game along with audio signals. The trainee is asked to make the video game go with his brain. The trainee's goal is to increase certain EEG frequency bands (e.g. SMR) while decreasing others (e.g. theta and high beta). Mostly is used only single-channel EEG. As activity in a desirable frequency band increases, the video game (e.g. „The Car Driving“) moves faster or some other reward is given (for every 300 ms that his brainwaves stay in the desired state, he scores another point). As activity in an adverse band increases, the video game is inhibited. The patient

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interacts with the game computer for the next 45 minutes (one session) and the recovery usually requires some tens sessions. Gradually, the brain responds to the cues that it is being given, and a „learning" of new brain wave patterns takes place. The new pattern is closer to what is normally observed in individuals without such disabilities.

Figure 2: Therapeutic method EEG Biofeedback

The other types of biofeedback

The *blood pressure biofeedback* is used for decreasing of high blood pressure (hypertension).

The *EMG (muscle tension) biofeedback* allows the patient to facilitate or extinguish his muscle action. In patients with low back pain, the objective is to reduce pain by reducing muscle tension. In patients with headache, it may relieve the pain and restore muscle movement and strength. In patients (women) with pelvic floor muscle dysfunction (anal incontinence), the goal of biofeedback training is teach these patients how to make their muscles work more normally and improve their ability to defecate.

The *(hand) temperature biofeedback* (and/or muscle tension biofeedback) is used for teaching of patients how to deeply relax (by warming their hands) and how to relax certain muscles. Acquiring and regularly practicing relaxation skills has been shown to often reduce the frequency and severity of both migraine and tension-type headaches.

The *GSR (galvanic skin response* or *skin conductance) biofeedback* or *EDA (electrodermal activity) biofeedback* is also usually used for teaching of ability to relax and for teaching of anxiety suppression. It also may be used for redress of the attention deficits (e.g. ADHD) like that EEG Biofeedback. The patient learns to make the skin less conductive and the skin conductance amplitude the smallest.

The *HRV (heart rate) biofeedback* may be used for attenuating heart-rate responses during exercise and for decreasing of the stress (for training of the relaxation).

Feedback control process principle

Now we will describe feedback control process principle that is known from the cybernetics control theory. We have a *controlled system* within which we regulate a *controlled variable* by using a regulator, a correct value of controlled variable and a negative feedback loop. The *regulator* receives information about difference between the controlled variable and a desired correct value of controlled variable (a *command variable*). This variable difference is called a *control deviation*. On the basis of the control deviation the regulator creates a corrective reaction called *actuating variable*. The actuating variable influences the controlled system in order to keep the controlled variable the nearest to the command variable. The influence is called the *negative feedback*. The controlled system is also influenced by a *disturbance variable* (e.g. a noise signal). The disturbance may divert the controlled variable and then the goal of regulation is to hand back the controlled variable to the desired value.

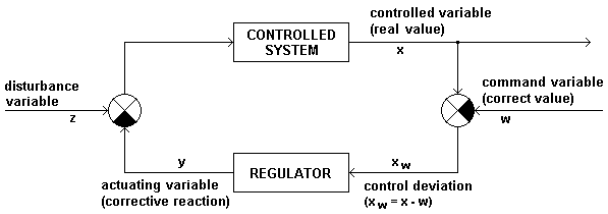

Figure 1: Operating scheme of a control circuit with the negative feedback

The easiest view on modelling of biofeedback

Now we introduce the easiest view on modelling of biofeedback using control process. We will use only one simple control circuit and we will suppose that the controlled system and the regulator are realized by a human. The view we will demonstrate using fourth following examples.

The first example of modelling follows. Let us take a *plump woman* (a biological system) as the regulator and her body fat quantity as the controlled system. Her weight is the controlled variable and a value showed by a weighing machine is the biological signal carrying the information about state of the controlled variable. The women knows her right weight (command variable) and so she may create the actuating variable (the corrective reaction): she decides reduce her weight and after that she will eat not so much.

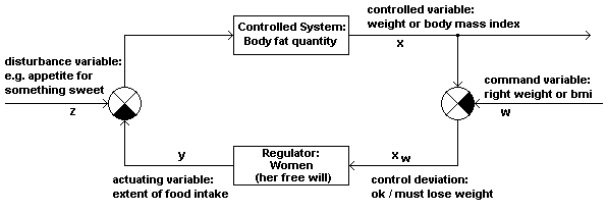

Figure 2: The control circuit models the plump women that want to reduce her weight

Let us have another example. A *patient with high blood pressure* is the regulator, his blood circulation is the controlled system and his pressure is the controlled

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variable and a value showed by manometer is the biological signal carrying the information about state of controlled variable. But the patient doesn't know what is a correct value of his blood pressure. A doctor knows it. When patient's blood pressure is increased, the doctor discovers it and recommends a corrective action: for example stop drink coffee or less fuss. But, only the patient (as the regulator) may realize the corrective action.

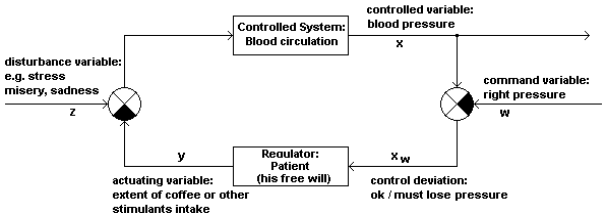

Figure 3: The control circuit models the patient with high blood pressure

Let us have the third example. A *car driver* is the regulator. His vigilance level is the controlled system and his EEG is the controlled variable because its carries an information about state of the controlled system. A computer system or a human's expert must determine, when the EEG belongs to the alert driver or to the very tired driver. The driver receives the information about his own vigilance state and possibly creates a corrective reaction in order to stay alert, e.g. stop the car and fall asleep.

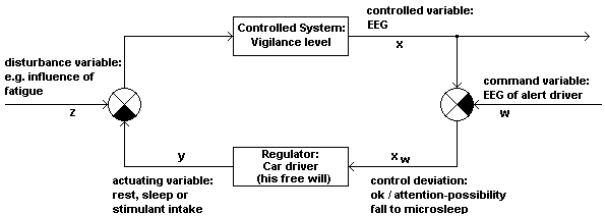

Figure 4: The control circuit models the car driver that mustn´t fall to microsleep

And final example of the easiest modelling of biofeedback follows. A *child patient with ADHD* (attention deficit hyperactivity disorder) is the regulator, his attention ability is the controlled system and his EEG is the controlled variable because its carries an information about state of the controlled system. The therapist knows a desired structure of EEG that gives evidence about no ADHD (command variable), but the child doesn't know it. Therefore the information about the attention state must be transformed for example to a computer game or another type of remuneration. The child is getting the rewards (e.g. successes in the game) if his EEG approaches to the desired correct value. Therefore the child tries to regulate the game (and consequently also his own EEG and also his attention ability) in order to experience a success in that. Thus the child is the regulator which creates the actuating variable, not the therapist, therefore the child must be motivated in order to want to correct his attention deficit. This mentioned therapeutic method (a learning strategy) is called „EEG Biofeedback".

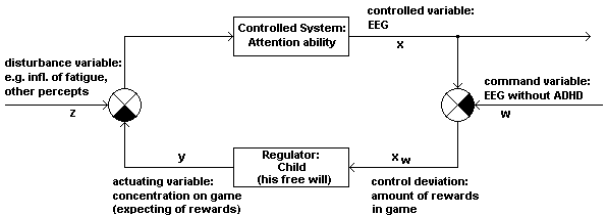

Figure 5: The control circuit models the child patient with ADHD that learns to keep his attention on a game

The more detailed view on modelling of biofeedback

Now, we may see that the real situations mentioned above is possible to model by this simple way but the modelling cann´t catch the complexness these situations. There are several common phenomenons in these situations:

- The regulator and the controlled system are realized inside a human.
- Activity of the human´s regulator depends on free will of the human.
- It is necessary to motivate the free will, for example to give to human some rewards when he controlling right or to start an alarm when the controlling is very necessary.
- The volitive control process requires human´s effort, because it often must go across some already existing automatic involuntary control process (that maybe doesn't work all-right).
- In some cases we want to improve the existing automatic involuntary control process and learn it to work better.
- Therefore, it is necessary to use an external technical regulator that will be monitor the human controlled variable and will be generate some motivational stimulants in order to inspirit the human free will in order to regulate.

Thus for more exactly modelling of biofeedback we must use more detailed way how to model. We offer following diagram that includes three nested control circuits. An internal control circuit corresponds to the automatic involuntary control process mentioned above. A middle control circuit corresponds to the volitive control process. And the external control circuit corresponds to the external technical regulator which generates the motivational stimulants for the volitive regulator.

The diagram will be showed for the mentioned examples.

ISSN: 1727-1983

Add the first example

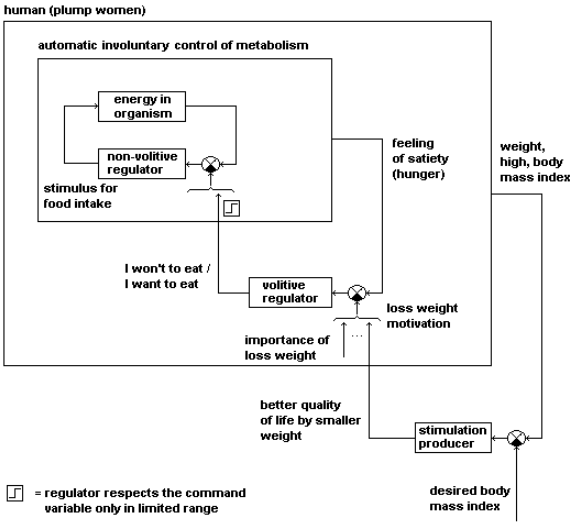

Figure 5: More detailed way how to model the biofeedback from the first example (the woman which want to reduce her weight)

Add the second example

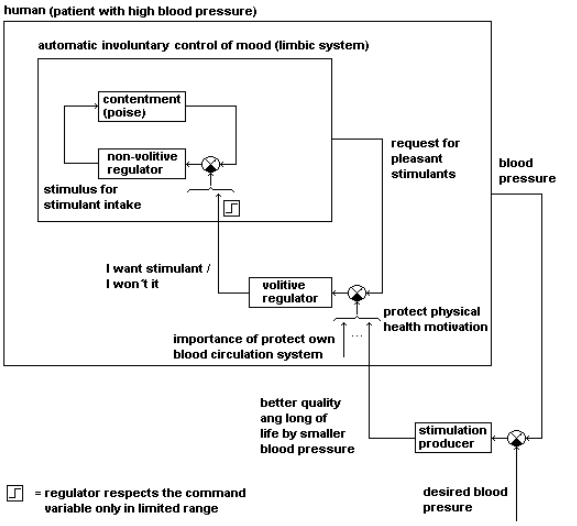

Figure 6: More detailed way how to model the biofeedback from the second example (the patient with high blood pressure)

In the second example we may see that the control process is running on the different level than we would expect. We don´t control the blood pressure directly (although it is possible for example by medicaments) but with the aid of influence on the patient's mind. Besides, we may suppose that the patient is calmed by pleasant stimulants, his blood pressure will decrease. But some stimulants (e.g. coffee) have an opposite influence – they increase the blood pressure. Thus the problem of blood pressure decreasing isn´t only a physical problem but also a life style problem.

Add the third example

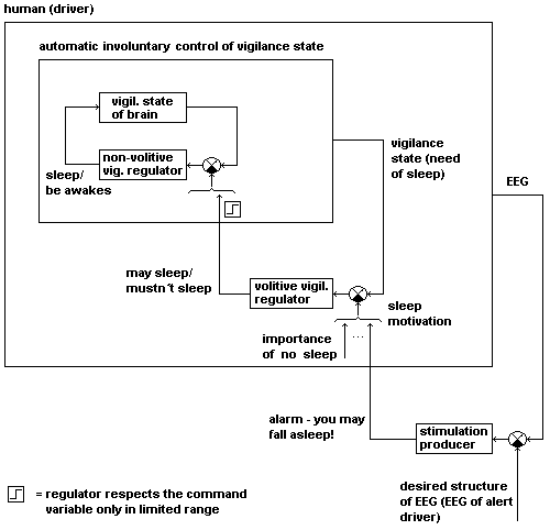

Figure 7: More detailed way how to model the biofeedback from the third example (the driver who mustn´t fall to microsleep)

Add the fourth example

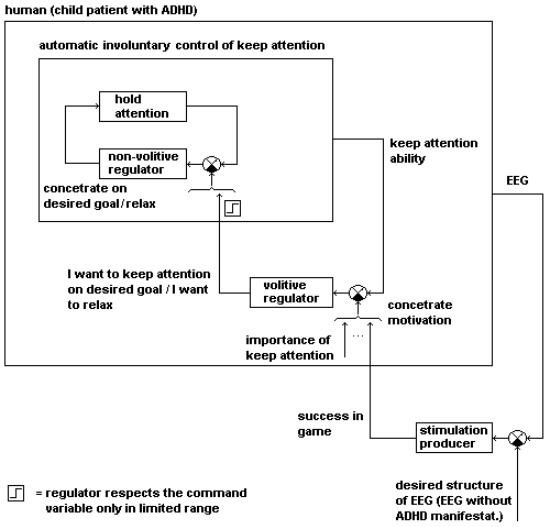

Figure 8: More detailed way how to model the biofeedback from the fourth example (the child patient with ADHD)

Results

The modelling of biofeedback is used for better understanding to modelled biological process and the control mechanism that are running inside one. In this article were mentioned some examples that using a simple abstraction level only. Though the real situation is often more complicated, we think that the modelling (although simple) is necessary. The modelling that use the control process may aid to more understand the modeled situation. Besides, it is necessary for creating

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every proposal of a therapeutic method that is based on the bioffedback.

Conclusions

The goal of the paper is to outline a method of modelling different kinds of the biological negative feedback. In this paper was introduced the term biofeedback mainly as a therapeutic method that enables to influence bodily functions that are not normally controlled voluntarily. Then we introduced some concrete kinds of the biofeedback, e.g. EEG Biofeedback. And finally, there was outlined method how to model the biofeedback using control process known from the cybernetics control theory. Though the modelling is very simple, it is necessary for creating every new biofeedback method or for understanding already existing method. Besides, the modelling of biofeedback using control process is helpful for more strict understanding to intuitive concept of the biofeedback.

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