PHYSIOLOGICAL FEEDBACK MODELLING IN MEDICAL EDUCATION

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Abstract

Regulations are an ever-present element of each life process, determining its diverse behaviour depending upon various physiological or pathological effects. Textbooks and lecture notes represent the static and lexical overview of these systems. However, the practical education provides almost no means how to experiment with biological signals, thus examine the system‘s dynamical characteristics and relations to it‘s parameters in detail. We try to pass this limitation through the use of simulation experiments, which provide interactive methods for understanding feedback system behaviour, its basic features, stability conditions and process of parameter influences under certain external conditions. Also, examples of several physiological models are included. The aim of our educational application is to provide an interactive tutorial that explicates the behaviour of basic control systems and their dependencies on input signal and inner structure. The definitions and conceptions needed for control system description as well as methods for system characteristics determination, graphical and analytical expressions are introduced in necessary extent. All topics are structured into succession of tabular frames, thus creating one complex executable from the Internet using the ClickOnce technology (part of the .NET framework). We suppose the application to be an interactive opportunity for students to gain some virtual experience with simple control models along with basic knowledge of computer modelling and regulation theory. In this manner, the application may be thought of as a part of biocybernetics methodology, whose topics cover not only simple control systems, but also every complicated and complex dynamical system of living organisms that contain control circuits, including those with emergent properties.

Keywords: Educational software, Simulation models, Physiological control models, Interactive animation, MS .NET framework

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1 Introduction

Regulations are an essential part of life processes organization. They are part of the homeostasis mechanism, effective control of goal-oriented motion and automatic compensation of casual influences on inner and outer environment. The aim of this application is to provide an interactive tutorial that explicates the behaviour of basic control systems and their dependencies on input signal and inner structure. This interactive walkthrough is implemented in 15 successive panels. The definitions and conceptions needed for control system description as well as methods for system characteristics determination, graphical and analytical expressions are introduced in necessary extent. The application complements the lectured topics taught within the scope of physiology and pathophysiology through interactive practical tasks. Following simulations present experiments that would be undertaken on living subject only with difficulty – if even possible. The scale of offered experiments is quite extensive and, regarding the user-friendly graphical interface, it could be explored without any preliminary theoretical or technical knowledge.

2 The Topic

Regulations are an ever-present element of each life process, determining its diverse behaviour depending upon various physiological or pathological effects. The structure and dynamic properties of biological control systems are extremely diverse, eventually even changing under physiological and pathophysiological conditions.

Textbooks and lecture notes represent the static and lexical overview of these systems. However, the practical education provides almost no means how to experiment with biological signals, thus examine the system‘s dynamical characteristics and relations to it‘s parameters in detail. The project is conceived in proceeding from the simple to more complex.

Computer simulation in applied education of biomedical topics uses contemporary system of concepts and corresponding way of scientific thinking which medical students are seldom familiar with.

It was also the very biological systems complexity and their characteristics that triggered current systems science advancement more than a half century ago. Systems science is not an explicit part of regular medical studies, but a series of topics in biomedical literature e.g. applied biocybernetics or computational neuroscience don’t dispense with understanding to mathematical and computer modelling.

We suppose the application to be an interactive opportunity for students to gain some virtual experience with simple control models along with basic knowledge of computer modelling and regulation theory. In this manner, the application may be thought of as a part of biocybernetics methodology, whose topics cover not only simple control systems, but also every complicated and complex dynamical system of living organisms that contain control circuits, including those with emergent properties.

3 The Methodology

The project comprises of several parts, which require interdisciplinary teamwork (see for instance [8]). The scenario design is based upon a long term experience of physiological control systems lecturing at the 1st Faculty of Medicine, Charles University in Prague [1,6,7,9]. The physiologist arranges each exercise’s scenario, i.e. prepares the mathematical model according to the theory that is supposed to be explained in the relevant exercise. The model’s validity is tested in the Matlab/Simulink environment. The computer programmer designs the framework for model’s control and visualization outside of modelling environment, thus creating user friendly graphical interface. Visual and eventually other graphic control components (e.g. in form of interactive Adobe Flash animations) are designed by a graphic designer.

3.1 Development environments used for simulation, graphics and programming

Due to the project’s complexity, the Microsoft Visual Studio .NET was used as a suitable framework for educational simulator implementation. Visual Studio .NET enables communication with imported libraries containing the mathematical model along with the graphical components and animations [4].

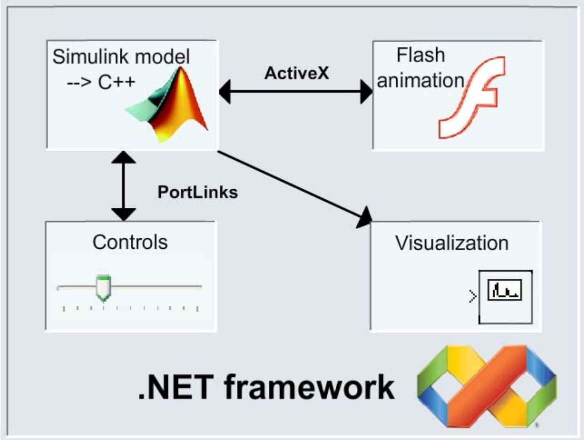

Fig. 1: The components interconnection concept in the Microsoft .NET framework

The Matlab/Simuling environment was chosen, since it enables easy design and export to C/C++ code using the Real-Time Workshop [5], for the modelling and simulation purposes. The code is subsequently imported into the .NET framework in the of a DLL file.

For the graphic components and animations design, the Adobe Flash was picked, as it contains the ActionScript 2.0 language, which enables communication with ActiveX components.

The functional interconnection of used components is depicted in the figure 1.

3.2 The model export to the .NET framework

The final model designed by the physiologist has to be modified before the conversion to the .NET framework C/C++ code.

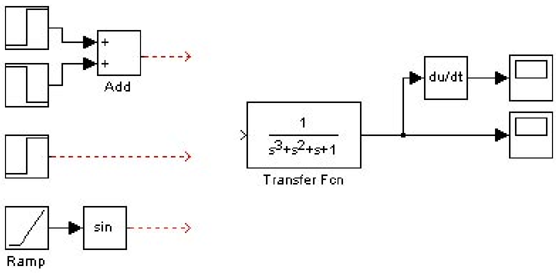

Fig. 2: The simple model design

The conversion is performed by using the proprietary template [10], which encapsulates the model with the object congaing control methods that facilitate the communication with visual components and animations. The figure 2 depicts designing of a theoretical model, which is intended to demonstrate the effect of various input signals (step, impulse and sinus function) on the third-order system. The same system ready for export to the .NET framework is depicted in figure 3.

The main difference between these two models is in the method of the parameters modification. All changes in e.g. amplitude, input signal frequency or system parameters have to be made using the input ports. All function outputs are connected to the output ports.

Additionally, the solver step is changed to fixed-step length (the Simulink uses the variable-step solvers by default). The model is aplicable in the .NET framework after these changes.

3.3 The model DLL export (Wizards)

The tool for the communication enhancement between the mathematical model and the .NET framework was developed in the Laboratory of Biocybernetics and Computer Aided Teaching in the Institute of Pathophysiology of the 1st Faculty of Medicine, Charles University in Prague.

The Real-Time Workshop component available in the Matlab/Simulink environment enables the model conversion into the C/C++ code and the Wizards [10] modify the DLL to be able to communicate with PortLinks [10]. The exported model is easy to use in the .NET application. The Wizards application encapsulates the C/C++ code to the object and adds some input/output ports control methods that facilitate all requests for setting the input or reading the output. It also performs the simulation steps according to the adjusted parameters and the event is set up after each step for contingent reaction. If these Wizards are not available, each simulation step must be handled and in each simulation step all outputs must be read and all inputs must be set, which would be highly complicated for such a number of models.

3.3.1 The communication between the model and framework components

The PortLinks are used for the communication of the model's input and output ports with interactive components. The PortLinks are connection classes, which automatize the data handling between the model and visual components.

The demonstration of the communication using PortLinks is shown in the figure 4. From the one side, the PortLink is connected to the model's port and from the other side it is linked to the graphic component. In

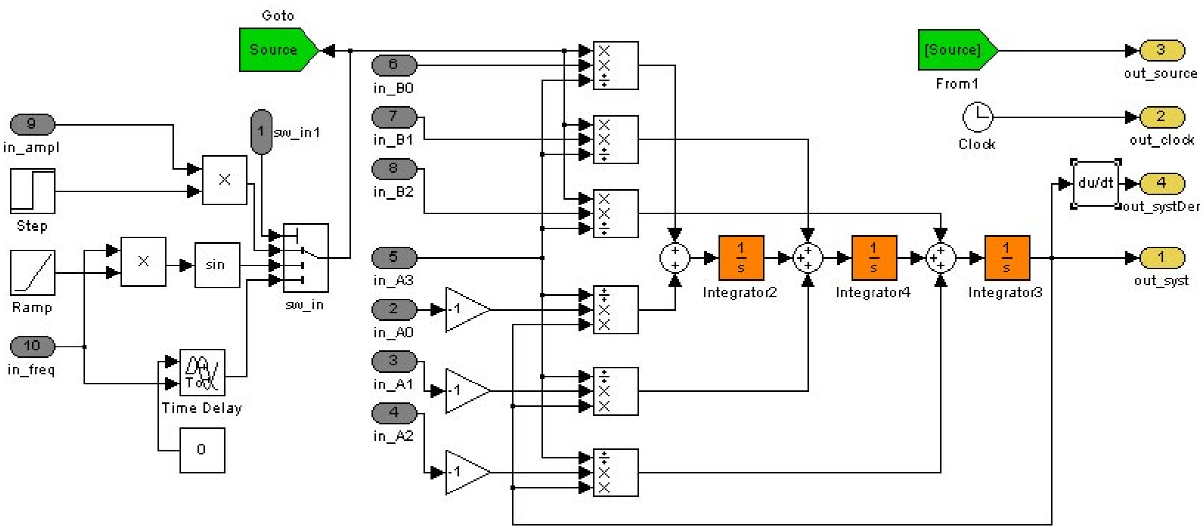

Fig. 3: The modified model, prepared for an export

case of connection of the visual component to the model's output port, all changes registered are immediately automatically passed to the graphic component. The connection of the visual control component with the model's input port results in the immediate passing of the component's value to the model.

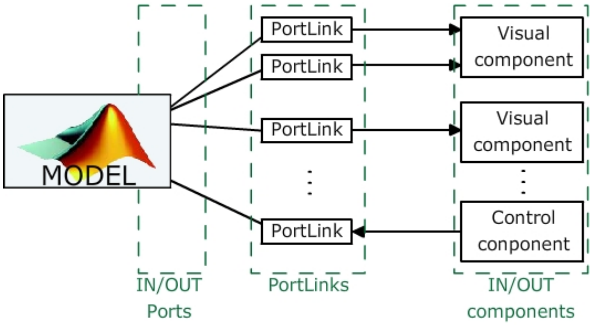

Fig. 4: An example of communication between the model and visual components using Portlinks

This feature represents a great contribution as to the code affectivity, since there is no need for concerns about passing the values between the model and visual components when using the PortLink correctly.

3.3.2 The communication between the .NET application and interactive animations

The animations used in this project are designed to represent the results of the model's computations. For this reason, result values are needed to be passed to them.

The communication between the animation and the .NET application is provided by the ActiveX component, which is a part of the .NET framework. The communication may proceed in the following ways:

- One-way communication (figure 5): Animations are controlled by the model, i.e. model sends data to the animation. The ActiveX method is used for changing the animation parameters (performing a motion, showing an information) through global variable included in the ActionScript v2.0 (is a part of the animation).

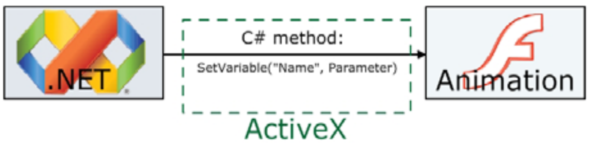

Fig. 5: One-way communication example (.NET -> Flash animation)

- Two-way communication (figure 6): The above mentioned method is used for the .NET-Flash direction of communication. The backward direction of communication is facilitated by the FSCommand method, which is able to set up an event in the .NET framework and hand over two String parameters („Command" and „Parameters").

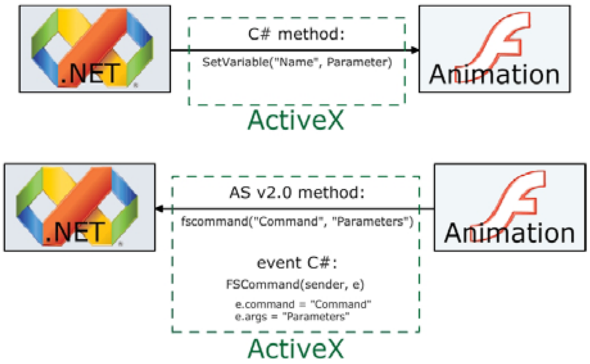

Fig. 6: Two-way communication example (.NET -> Flash animation, Flash animation -> .NET)

4 The Application structure

The whole application is structured into the separate panels that follow in a successive order. Each panel (task) may be divided according to the topic.

4.1 Introduction

Panel 0. Opening screen acquaints the user with the application scope and operating elements.

4.2 Regulation system components

Panels 1. - 4. This group of tasks enables the user to try out and to watch the influence of various time-varying signals upon several simple dynamic components. Following panels demonstrate some basic procedures of static and dynamic characteristics identification and inspection of phase-space of simple linear systems.

4.3 Feedback systems – the regulation

Panels 5.1, 5.2. Basic structure of the model with negative feedback is shown in two panels allowing wide range of modifications. The user can modify the linear regulatory system with proportional control. In addition P, PI, PD or PID regulator can be added, along with transfer delay. The dynamic component can be connected to feedback.

4.4 Models of physiological regulatory systems

Panels 6. - 10. Physiological regulatory systems may frequently differ from systems introduced in previous panels (they have, however, at least one negative feedback). Differences may for example be multiple feedbacks, feedforward, parametrical feedback, antagonistic feedback etc.

4.5 Selected panels description

4.5.1 Simple systems

Dynamical systems with input and output can be of various type and property. Variants selected for this panel serve as an example of some dependencies between the input/output values and system properties, which can be traced when examining the physiological systems. The basic way to examine these properties is

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to evaluate the system's response to a standard input signal (step, impulse, sinus function). Using this function has a substantial theoretical reason and under certain circumstances it can be the basis for system identification (type, or differential equation).

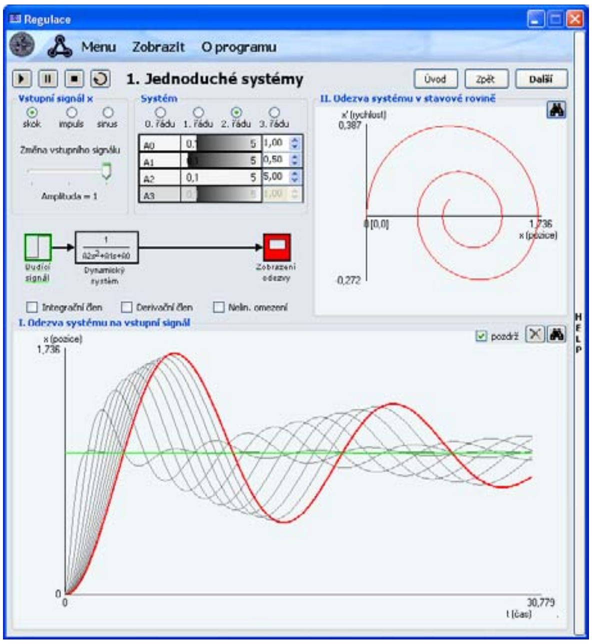

Fig. 7: The panel with simple systems

Figure 7 depicts the influence of parameters on second order system. Archiving the history of system behaviour enables to examine the influence.

4.5.2 The mechanical dynamic system

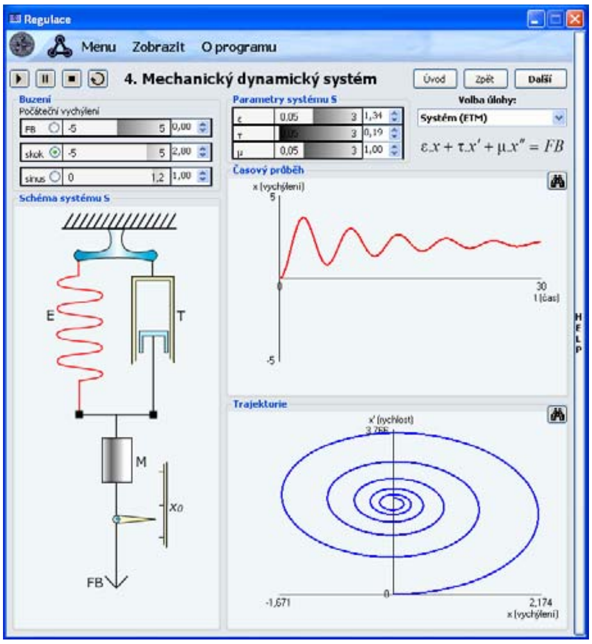

Fig. 8: The panel with a mechanical system

Linear differential equations are frequently used for describing the physiological system dynamics. Usually it is and approximation of empirical measurement and estimation of dependencies. The idealized model's component characteristics are defined by means of mathematical functions, thus allowing the interpretation of each parameter's meaning in an exact and objective way.

Figure 8 depicts the panel representing the analogy between the mathematical function (differential equation) and a dynamic mechanical system.

4.5.3 The control loop

The controlling system is a stable dynamical system, for example when there is no disturbance signal at it's input, the regulated output stabilizes itself within certain bounds. The output values tend to resume their steady-state values (equilibrium points) when deviated by the disturbance variable. This tendency is caused by the information about a deviation from the equilibrium point, which implicitly affects the system input through a control loop. Such a feedback is called negative.

This panel enables to examine the influence of such factors on a regulation process under various inputs.

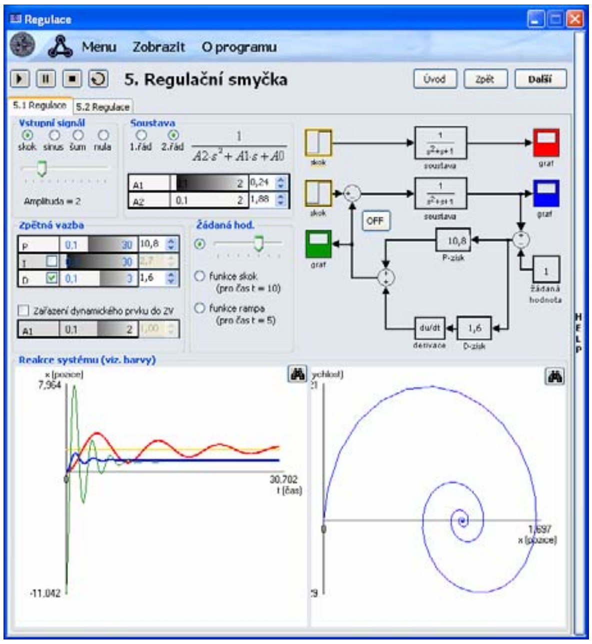

Fig. 9: Alternate feedback systems

Figure 9 shows the system's output for different input signals and the effect of feedback on results.

4.5.4 The example of Pco2 regulation

It is not always possible to establish an error measuring element when examining the physiological control system [2]. Controlled parameter value at equilibrium point is at the intercept point of static characteristics of circuit components in the opposite direction and corresponds to a requested value. The reverse slope of characteristics works as a negative feedback, since the rising input value evokes the fallback on the regulator's output through the opposite system characteristic, thus lowering the system input .

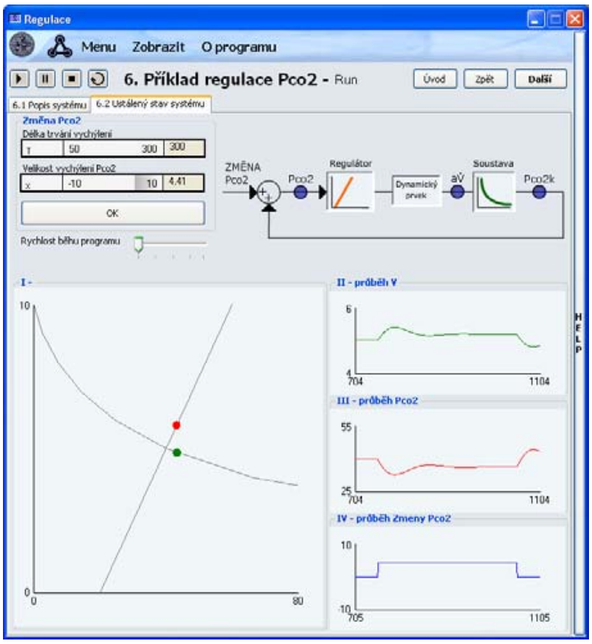

Fig. 10: The system equilibrium point (desired value) as a intersection point of static characteristics (Pco2 regulation according to Millhorn)

4.5.5 The enzymatic system model

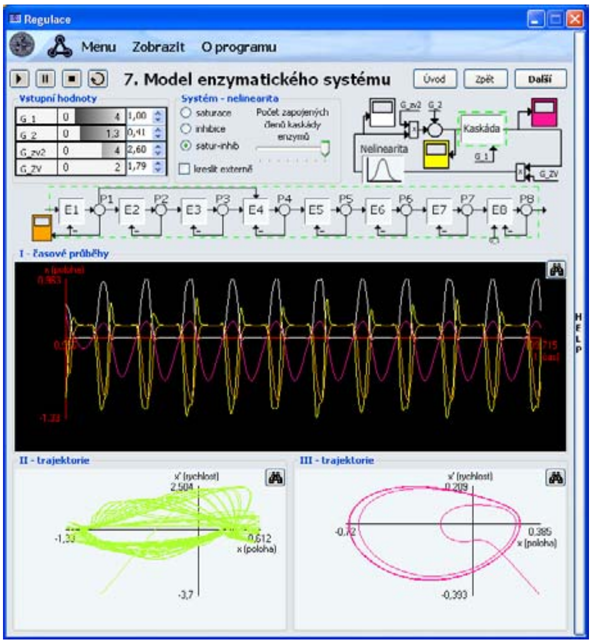

Fig. 11: The model of an enzymatic system with multiple feedbacks

Sudden, enduring or periodical changes of outer physiological or chemical parameters of metabolical (e.g. on enzymatic level) cause the disturbance of equilibrium point, which is followed by a reequilibration, or a new equilibrium point is established. The observation of various components of cell metabolism revealed, that different types of transitions may occur. Monotonous, aperiodical, cyclical, oscillating and also persistent oscillating transition were described.

This panel's task is not a factual example of some examples mentioned above. It rather has some of the indicated features, such as chaining the reactions, multiplicity of feedbacks and characterise non-linearities.

4.5.6 The model of circulation regulation

The model demonstrates the hypothesis explaining the heart rate and systemic pressure spontaneous variability [3] as a result of deterministic chaos-like behaviour of baroreflex control system. The two feedbacks are taken in account – the baroreflex feedback affecting the heart rate and baroreflex feedback affecting the myocardium contractility, thus controlling the stroke volume. The transmission delay is involved in both feedback at the baroreceptor and sinoatrial knob.

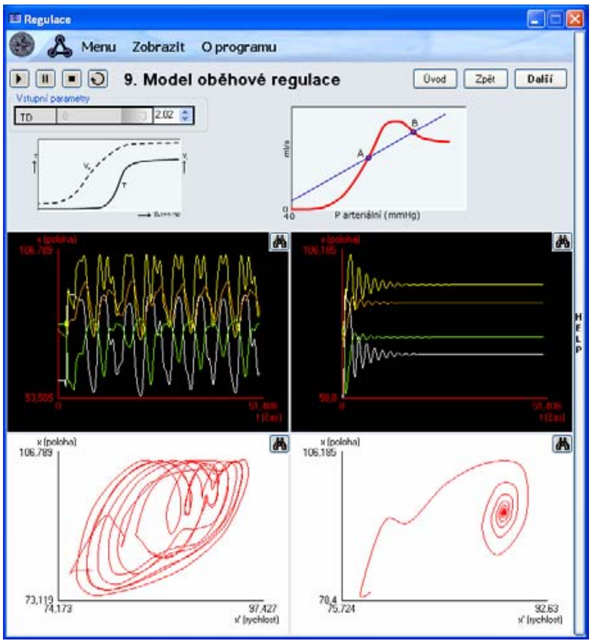

Fig. 12: the transmission delay influence/effect on the model of circulation regulation

Figure 12 depicts the effect of changing the transmission delay length on the circulation model behaviour.

5 Conclusion

The software resources used for the simulation application development turned out to fit every requisition for creating a user-friendly and well-controllable interface with graphic output. It should be taken as a fundament for future development of simulation applications for education.

The educational application offers wide range of experiments in an area, which is otherwise way too much difficult to be realized on a living subject. It also mediates some generally utilizable concepts and guidelines that constitute various forms of biocybernetics model application. It utilizes the previous experience and recent software tools for the creation of similar interactive simulation applications.

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