Latvia University of Agriculture
Faculty of Engineering

5th International Scientific Conference

ENGINEERING FOR RURAL DEVELOPMENT

Proceedings
May 18 – 19, 2006

Jelgava 2006

CONTROL OF BIOLOGICAL OBJECT AS COLLABORATION OF BIOLOGICAL AND ARTIFICIAL CONTROL SYSTEMS

Egils Stalidzans
Latvia University of Agriculture
Egils.Stalidzans@llu.lv

Abstract. Biological object is a separate autonome system that behaves according to its internal biological control system (BCS). Implementation of artificial control system (ACS) is analysed as simultaneous collaboration of two control systems.

Biological objects – plants and animals are observed as systems having task to fulfill main targets: to survive and multiply. Thus, their behaviour is the activity of BCS to fulfill its targets.

Any interference in biological processes can be considered as control of biological object or process regardless if it was target orientated (agriculture, industry, medicine, forestry aso.) or unplanned (ecological problems, side effects of planned actions).

Biological object acts according to its genetically coded BCS that is unchangeable. Thus, planed target-orientated control of biological object by human-made ACS is possible only by changing the environment of biological object to achieve necessary reaction of BCS. ACS is an artificially created control system that acts simultaneously with BCS creating competition of two control systems. That has to be taken into account during design of ACS analysing possible transition processes.

In context of effective Precision Agriculture (PA) understanding of different BCS that participate in agricultural process is a necessary precondition to develop rational and efficient ACS. The paper contains methodology of two main stages of ACS development based on ACS and BCS modelling.

First stage: development of BCS model. In case of complex and insufficiently studied systems when BCS can not be described using methods developed for technical control systems, methodology of development of a dynamic model of BCS is proposed. The methodology includes the definition of control target, development of static topological model involving experts of biological object, analysis of cycles of the static model, implementation of functional relations, development of the dynamic simulation model and its validation.

Second stage: development of ACS. Methodology includes choice of parameters to be controlled, development of model of ACS, optimising of scope and sequence of ACS according to efficiency criteria and evaluation of harmlessness of transition processes arising during collaboration of BCS and ACS.

Key words: biological system, control task, modelling, insufficient information.

Introduction

Precision Agriculture (PA) and other precision industries where biological objects are used in most of cases are based on existing understanding regarding used biological object or process. PA includes development of individually oriented control signals regardless on the way of its implementation (by human, by technical system or else). Quality of control directly depends on quality of knowledge about biological system to be controlled. In case of PA control targets should be reached in harmony with biological system and not in spite of it. A key to that approach is understanding of biological object as a separately functioning system.

Holistic approach drives newly emerging science Systems Biology (SB) where dynamics of behaviour and interaction of elements within functioning biological system is studied (Palsson, 2000; Ideker et al., 2001). SB can be considered as a science for precision control of biological, ecological and health processes covering aspects of functioning of biological object from its genome until its behaviour. Being new science SB just indicates the trend to change biology from mainly descriptive science to precise and mathematically described one as it is in most of technical systems. PA actually needs methods to understand and simulate processes directly related to control of biological object without necessity to understand molecular and genetic processes of particular object in details if that knowledge is not available yet.

It is proposed to describe biological object as an independent control system. A verified model of biological control system is a necessary precondition to develop a rational control system as an element of PA.

Simulation of biological system from the control system viewpoint is related to several problems that are not characteristic for technical systems. In the case of biological systems, there is no unambiguous information on the principles of the construction, relations of causes – consequences and interaction with the environment because this system has not been constructed by a man for particular targets by the means selected by a man. This factor restricts the possibilities of application of the simulation methods of the technical systems.

Control of the biological system means the modification of the parameters of the environment where it is located, and the biological system reacts to any deviation in the environment parameters as the biological control system to compensate the changes taking place. Thus, there is a task of balancing two control systems: one control system (usually several mutually linked loops) is the biological control system (BCS) of biological system itself, and the other control system is the artificial control system (ACS) which has been created by a man for the control of BCS. Consequently the analysis of the transition processes is required.

The goal of the paper is to create the methodology for the development of the control system for the biological system under the conditions of incomplete information on the regularity of its operation. The methodology has to provide the correspondence of control system to the criteria of efficiency and harmlessness.

Development of the model of the biological control system (BCS)

The operation of the set of the parameters B of the biological system existent in the nature under the conditions of set of environmental parameters V can be described in the form of the model:

$$M_b = F_b(b_1,...b_k,...b_K;\ v_1,...v_s,...v_S;\ t), \tag{1}$$

$$b_k \in B,\ v_s \in V,\ B \cap V = \varnothing,$$

where $b_1...b_k$ – the variables characterising the biological system (internal control loop) belong to the set of the parameters B of the biological system;
$v_1...v_s$ – the variables characterising the environment, belong to the set of the parameters V characterising the environment,
t – time.

As it is necessary to take into consideration many functional correlation's relating the variables of the biological system $b_1...b_K$ to the variables of the biological system and environment $b_1...b_K$ and $v_1...v_S$, the initial model is developed by means of the topological modelling. In this stage of the development of the model, cooperation of the experts of the biological system and knowledge engineers is necessary. The algorithm for the development of the BCS model M_b is shown in Figure 1. The description of the operations contained in the algorithm (**in bold**) has been provided for every step of the algorithm.

Definition of control targets is intended for the specialisation of the model from the point of view of control system to be developed.

The control task is being solved to satisfy the set of control targets $G\{g_1,...,g_q\}$:

$$G = F_g(b_k,\ v_s,\ t), \tag{2}$$

where $k = 1,...,K;\ s = 1,...,S.$

The control targets G can be clearly defined in the definition of the control task, or these should be reduced to the particular parameters characterising the system when the targets have been defined generally. Further detailed study of the system will be devoted only to the processes related to the control target thus permitting to reduce the extent of the model to the minimum required.

The development of the model starts with the application of the topological simulation (Osis, 1967). Use of topological modelling is caused by its flexibility regarding implementation of changes. That is very important in circumstances of insufficient amount of information, which requires possibility of easy and quick structure change of the model. **The initial static topological model** is the first iteration of the following topological model $M_t = F_t(b_1,...b_k,...b_K;\ v_1,...v_s,...v_S)$.

It is necessary as the basis for further statements by the experts at the stage of the expert survey. The initial model is developed referring to the data in the literature or with the participation of some of the experts to be invited later on.

Further improvement of the model is done by the experts introducing the changes to the model M_t (Stalidzans and Markovics, 2000; Stalidzans, 2005).

Incidence matrix and the topological model as the kinds of the information reflection are applied for making the model more precise by experts in iterative process first individually (cycle: **individual expert work, testing individual experts, satisfactory model**).

Individual expert work is followed by **comparing of experts**. If the result is not **satisfactory model** and after **estimation of differences between experts** does not appear **basically correct** the initial topological model can be changed.

Following the development of the topological model **the analysis of the cycles of the model** should be performed defining the particular BCS loops in the biological system itself.

If the experts think that the topological model M_t sufficiently well depicts the relation of the biological system and the environment parameters the study of the system should be continued in the dynamics and **the introduction of the functional relations between the nodes** is required.

The static topological model $M_t = F_t(b_1,...b_k,...b_K; v_1,...v_s,...v_S)$ has to be homomorphly changed into the dynamic model $M_b = F_b(b_1,...b_k,...b_K; v_1,...v_s,...v_S; t)$. Dynamic model can be developed using the dynamic simulation software package *Powersim Constructor 2.51*. Advantages of this dynamic modelling software are determined by its flexibility in relation to the changes in a model, simple user interface and possibility to connect with the *Microsoft Excel* program for information exchange.

Under the conditions when sufficient information on the relations between the nodes is not available the surely known data, which can be expressed in the form of equation become the most valuable basic information of the model. Clear relationships (mostly chemical or physical processes) are tools to extract more information from low quality data. Instead of the unknown relations between the nodes it is necessary to introduce very approximate functions initially and they can be adjusted in the process of simulation. Holistic approach to the modelling including more linked parameters in simulations brings estimated values closer to their real values.

Development of the simulation model in dynamics (model M_b) comprises one of the most important stages of the work – tuning the model on which the level of similarity of the model to the simulated processes in the biological system depends.

Validation of the simulation model in dynamics should be performed using the data collected in the field experiments.

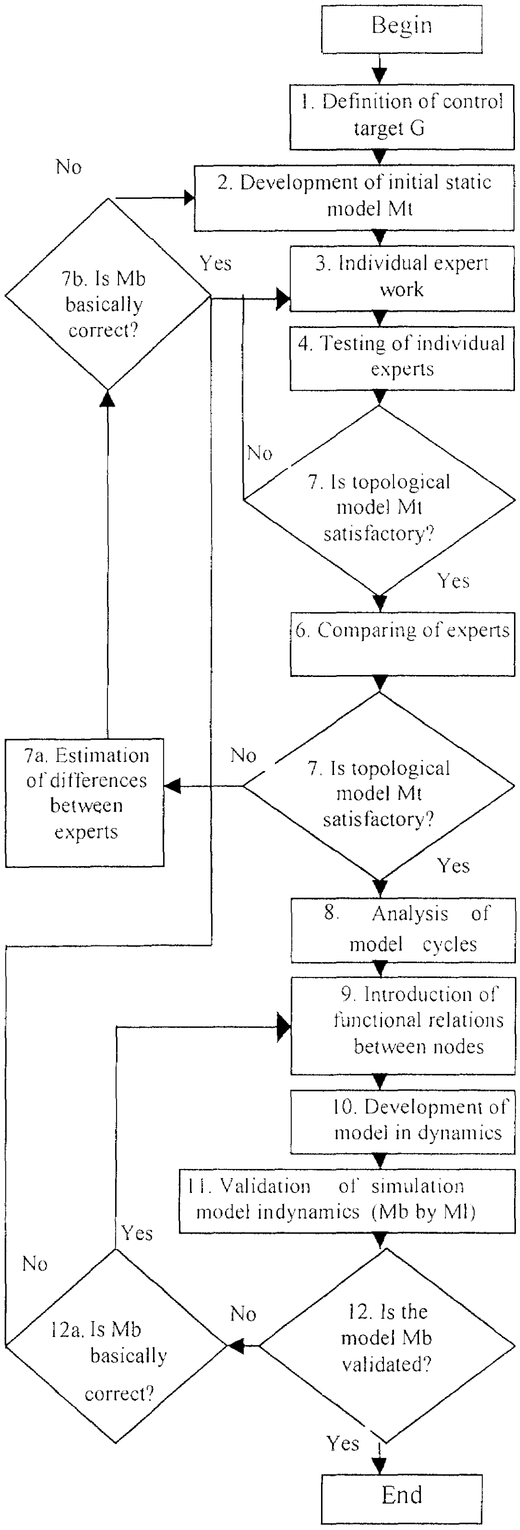

Fig. 1. **Algorithm of BCS development**

The validation operation is intended for checking the correctness of the simulated data of the model. It is necessary to minimise the deviations of the model from the measurements obtained in the field experiments $M_l \doteq F_l(b_1,...b_k,...b_K; v_1,...v_s,...v_S; t)$.

$$\Delta_{val} \geq |M_b - M_l| = |F_b(b_1,...b_k,...b_K; v_1,...v_s,...v_S; t) - F_l(b_1,...b_k,...b_K; v_1,...v_s,...v_S; t)|, \quad (3)$$

where Δ_{val} – difference between the field measurements M_1 and the system model M_b;
$k = 1,\ldots,K$; $s = 1,\ldots,S$.

The maximum permitted validation error δ_{mval} can be specified separately for every parameter of the set B:

$$\delta_{mval\,i} \geq \left| F_b(b_k) - F_1(b_k) \right|,\ k = 1,\ldots,K. \quad (4)$$

It is necessary to attempt to minimise the deviations from the measurements performed in the nature paying major attention to the comparison of the tendencies (growth, decrease, stagnation). When the difference between the test data M_1 and the model data M_b has become lower than the permitted Δ_{ver}, the **BCS model validation** has been performed and the model of the biological system $M_b = F_b(b_1,\ldots b_k,\ldots b_K;\ v_1,\ldots v_s,\ldots v_S;\ t)$ can be considered as established. In the further operations this will replace the biological system. Validation is done by software *Powersim Solver 2.0,* which works with model created on *Powersim Constructor 2.51*. It provides model flexibility and changes done in the BCS model does not need to be changed for *Powersim Solver 2.0* (Stalidzans, 2005).

Development of the artificial control system (ACS)

For the purpose of implementing the control of the biological system – collaboration with BCS – it is necessary to establish ACS, which would be able to control the first one. ACS usually is a technical system the structure of which depends on the task set for it (minimisation, maximisation, prevention of fluctuations, or the combination of these tasks for the sets of the parameters of the biological system).

The control task is being solved to satisfy the set of the control targets $G\{g_1,\ldots,g_q\}$ by ACS that is described by its model:

$$M_c = F_c(c_1,\ldots c_z,\ldots c_Z;\ b_1,\ldots b_k,\ldots b_K;\ v_1,\ldots v_s,\ldots v_S;\ t), \quad (5)$$

where c_z – ACS parameters ($z = 1,\ldots,Z$).

The criteria of efficiency of ACS are set in the task definition or with the help of experts as efficiency vector $Y = (y_1,\ldots,y_j,\ldots,y_m)$.

Most often the Y components are the criteria of economic character combined with the criteria of other kinds. A few examples of the possible criteria, which can be defined simultaneously: minimisation of the human work force, ecology, minimum time to reach the target, minimum deviations from the target value, etc.

It is necessary to integrate ACS in the model of BCS to perform the simulations of the efficiency of its introduction. In this stage the model can be sufficiently simple because more detailed analysis of it will take place if it turns out that the implementation is useful.

Optimisation of the proportion of the ACS loop in compliance to the efficiency criteria usually is related to the search for compromises because not everything a man can do for reaching the control targets complies with the criteria of efficiency (e.g. financial) in the particular case.

For the purpose of evaluating the control process it is necessary to combine BCS and ACS models in the real time including the transition processes. Simulations with sets of extreme real external impacts are necessary. The extreme external impact for the purpose of transfer processes are the cases when the environment parameters V varies with maximum speed and thus requires also a fast reaction of the BCS which in natural conditions in most cases can ensure the survival of the system.

During control of the biological system ACS must be correctly designed for extreme changes of the external parameters. The system must not be damaged during collaboration of BCS and ACS.

The permitted range of the changes of the system parameters under the natural conditions, i.e. without the influence from ACS may be set as the criteria of ACS harmlessness to biological object.

If simulations with sets of extreme external impact do not extend outside the range of the system parameters seen under the natural conditions the collaboration between BCS and ACS can be considered as harmless. Of course, the criteria of harmlessness can differ in their interpretation depending on the specific of the task because even killing the biological system can be set as a task for ACS (for instance: pest control).

Conclusions

1. Methodology for the development of the control system for the biological system under the conditions of incomplete information on the regularity of its operation is developed. The methodology covers correspondence of artificial control system (ACS) to the criteria of efficiency and harmlessness.
2. In field experiments observed range of parameters are proposed as harmlessness criteria to control the object. The transition process has to be analysed under extreme changes of the external parameters observed in nature.
3. In case of information insufficiency knowledge of experts has to be extracted first individually and afterwards in group work.
4. *Powersim Constructor* and *Powersim Solver* software packages are proposed as simulation and validation software for dynamic analysis of biological systems.
5. The established methodology of the development of the control system for a biological system can be applied in practice as the area of its application per types of the biological systems is very wide and the methodology pays special attention to the conditions of insufficient information. That is very often the case in Precision Agriculture.

References

1. Osis J. (1967). Minimisation of observation points. Automatic control. Riga, Zinatne.
2. Ideker T., Galitski T. Hood L. (2001). A new approach to decoding life: Systems Biology. In Annual Review Genomics Hum. Genet. 2.
3. Palsson B. (2000). The challengesif in silico biology. In Nature Biotechnology 18, pp. 1147-1150.
4. Stalidzans E., Markovitch Z. (2000) Expert based model building using incidence matrix and topological model. 12-th European simulation Symposium 2000. Hamburg, Germany. 328-332.
5. Stalidzans E. (2005) "Algorithms of computer control of multiobject biological systems." [in Latvian] Doctors work. Riga Technical University, Riga, 2005. 156. p.