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Precision Computer Control of the Biosystem in Closed Environment

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Abstract. Industrial biosystems could be more productive using the precise control methods, which will lead to minimization of resources and maximization of product quality. In this paper author shortly describes and summarises his research, which is done within the doctor thesis with the main goal to improve the implementation of Precision Agriculture approach using the integration of various mathematical models in precision computer control of a multiobject biosystems. To reach this goal, author developed architecture of automatized control system for precision control of closed biosystem and implemented specific automatized control system, based on proposed architecture. Control system was tested in real environment for monitoring the honey bee wintering process in specific honey bee wintering building. The results of this research are mentioned distributed, adaptive, automatized control system architecture that can be used for control of the bioprocesses in the closed environment, as well developed various algorithms and models for improving the honey bee wintering process by recognising different bee colony states based on temperature measurements.

Keywords: Precision Agriculture, Precision Apiculture, control system architecture, biosystem control

1. Introduction

Nowadays information and communication technologies (ICT) provide indispensable support for business, agriculture, and production processes. The rapid development of information technologies and computer control allowed for individual monitoring of biological and agricultural objects (plants or animals) with the main aim of controlling their development process. This, in its turn, allows controlling the biological objects in real time more effectively, taking into account object behaviour and environmental conditions. Such control of individual agricultural objects provided the foundation for a new interdisciplinary field called Precision Agriculture (PA) (Berckmans, 2004; López Riquelme et al., 2009; Mancuso, Bustaffa, 2006; Morais et al., 2008; Proffitt, 2006). PA methods are still developing but they are already adapted for a big number of agriculture related sub branches like Precision Farming (Auernhammer, 2001; Reichardt, Jürgens, 2008), Precision Livestock Farming (PLF) (Berckmans, 2004), Precision Viticulture

(PV) (Bramley, Hamilton, 2004; Morais et al., 2008; Proffitt, 2006; Santesteban et al., 2012), Precision Horticulture (Zhou et al., 2012), Precision Apiculture or Beekeeping (Zacepins et al., 2012; Zacepins, Stalidzans, 2013) and others.

The author of this paper puts an emphasis on the research of control of multiobject biosystems. In the paper title a term „Precision computer control" (PCC) is used, which is defined based on Precision Agriculture (PA) concept and approach where individual object observations are very significant. Precision computer control is production or technological process control using the computer, taking into account the individual measurements of the objects involved in the process. Precision computer control of the multiobject biosystems directly indicates that many biological objects are individually monitored and controlled using various ICT tools. Based on individual object behaviour parameters, a control action is chosen with the main aim to prevent important parameters to exceed the critical limits, thus providing the necessary object development at any moment. In many cases control of the biosystems comparing to control of the technical systems is more complicated, because biological systems are self-regulated systems and the activity of other control system can lead to biosystems instability and to death of the biological object (Zacepins, 2013).

Integration of precision computer control into practice will lead to minimization of resources and maximization of product quality, for instance farmer will not apply pesticides to the whole greenhouse, but only to individual agricultural objects. The same is with treatment application. Method of precision approach will guarantee minimal use of needed resources, which also reduces impact to the environment.

2. Concept for precision computer control of the biosystem

Biosystems and biological processes which take place in open environment, like forest growing process, cannot be directly controlled, but biological processes which take place in closed environment can be automatically controlled by the microclimate control system, based on measurements needed for the control. Examples of microclimate measurements are light intensity, humidity, temperature, air composition, etc. At the same time important parameters of the biological object can be measured using specified measurement system. Such individual parameters can be soil temperature and humidity, colour of the leaves or bee colony temperature. Measurement results should be transferred to the computational system, which performs data processing and analysis. Based on predefined models, computational systems recognize states of the monitored object. Taking into account additional data information sources (for example, weather forecast) computational system itself or involving the operator makes a decision about the necessity of changing the parameters of the microclimate control system with the main aim to affect biological object and change its state and/or behaviour.

2.1. Architecture of control system

Author proposes architecture of the adaptive, distributed control system for the control of closed environment biological process (Zacepins, Stalidzans, 2012; Zacepins, 2011) (see Fig. 1).

Architecture of the automatized control system is abstract depiction of the control system, where idealised models of the system components (elements) and its collaborations are described. Architecture elements are connected to each other and build whole automatized system and help to solve specific task on architecture level. On the same time system architecture leaves enough freedom for choosing specific technical devices and solutions and architecture is not linked to only one solution (Klir, 1990; Denisenko, 2009).

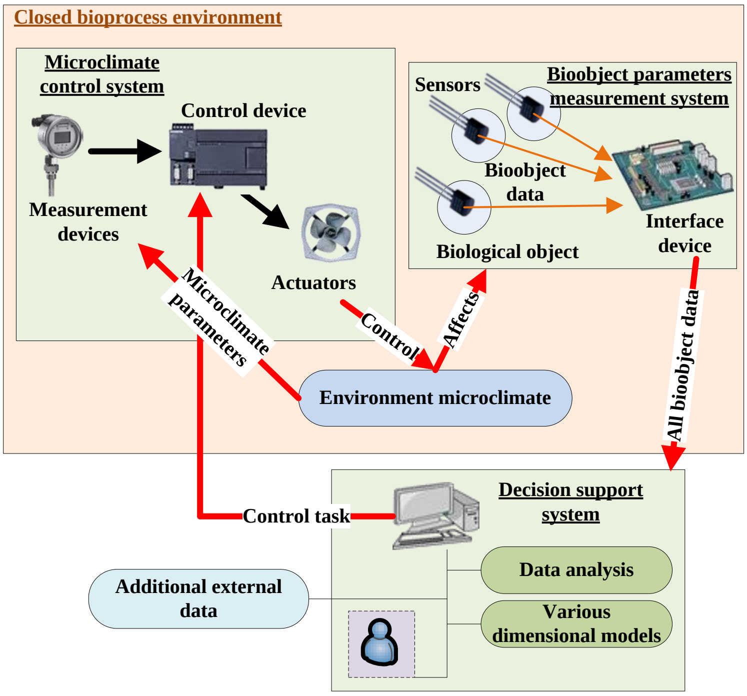

Fig. 1. Architecture of computer control system (Zacepins, 2013)

Proposed system architecture takes into account several features: it provides remote controlling of the system; system is distributed, which means that in the geographical location where biological process takes place only minimum of the needed system for autonomous control with low working environment requirements (wide range of humidity, temperature, vibrations) is situated. However, data processing system has to be situated in the environment suitable for the computational system. Also, it is needed to measure all involved object parameters to arrange the feedback for the control system. Therefore, the author proposes unified control system architecture for monitoring and control of the biological objects.

The proposed control system architecture can be used for biological processes, which take place in closed environment and where microclimate parameters affect both the biological process and functioning and development of the whole biological system.

Architecture for biosystem control proposed by the author can be divided in several system elements where each of them can be developed separately. The mentioned elements are microclimate control system, biosystem parameter measurement system and decision support system (Zacepins, 2013).

This elements representing three stages of Precision Agriculture system, like data collection, data processing for analysis and application of control action (Terry, 2006). So data collection is done using the biosystem parameter measurement system, data analysis is done by the decision support system and microclimate control system is needed to apply or change a control action.

2.2. Biosystem data collecting

A stage for selection of the biological object measurement system for data collection task is important one. For completing the data collection stage one or various measurement systems can be used, because in many cases monitored object could have various different parameters, therefore it is necessary to evaluate which parameter is the most important for monitoring procedure.

Selecting the correct and appropriate measurement system economic aspects should be taken into account, because sustainable agriculture or other branches should operate with a profit. One of the economic criterions is the rate of the return of investment (ROI). The author of the paper proposes formal method for rational measurement system implementation in precision computer control. The method will help to determine return of investment coefficient for measurement system implementation, and thus, evaluate gains and/or losses after recognition of different object states (Zacepins et al., 2013).

2.3. Biosystem data analysis

The data analysis stage can be performed by the human manually interpreting received data but human ability to process data and to make decisions without usage of additional technical solutions and tools, unfortunately, has some limits determined by both the physiological characteristics and the amount of available data (Mednis, 2013). Information technologies can at least partly replace a specialist in case of large data amount or if continuous analysis is necessary. Such approach could help operator which hardly could interpret the data by themselves. The computational support of operator can be done using DSS where different algorithms and models can be implemented (Fig. 2). (Zacepins, Stalidzans, 2013).

Decision making can be based both on directly acquired operational data that describes current situation and indirectly acquired historical data that describes similar situations in the past. The usage of historical data in current decision making process theoretically increases the possibility of more objective assessment of the situation and helps to take appropriate decision (Mednis, 2013).

Different states of biological system can be recognized with different level of reliability. Therefore, depending on the importance of detected state and importance of immediate action DSS may be delegated to make some decisions automatically or request the analysis of proposed decision by a specialist in data processing.

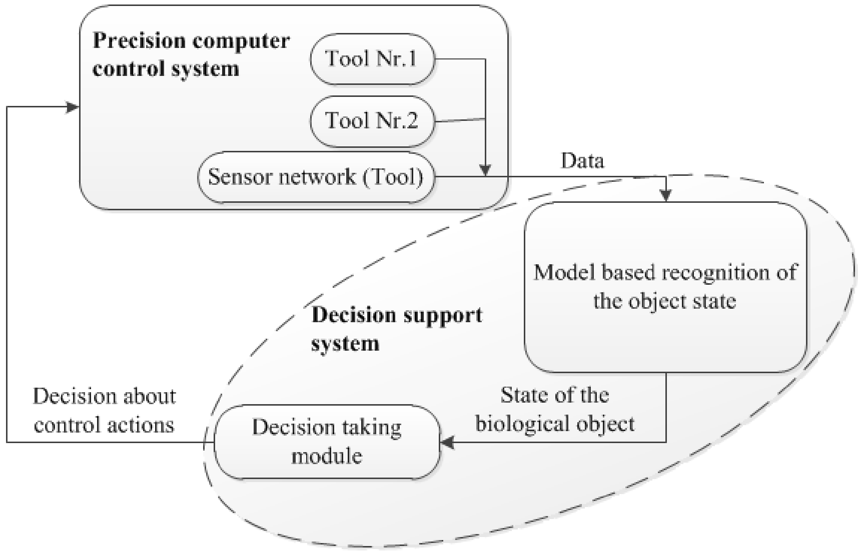

Fig. 2. Diagram of information flow for DSS implementation in PCC

Based on definition of model its task is to represent various real physical, biological, economical or other processes. Usually models give a simplified view about process, but nevertheless information, which is provided by the model, is useful for the detailed research of the process (Sokolowski, Banks, 2009). Models can be classified in various ways. One of them is to distinguish two categories of models: qualitative and quantitative models (Holjushkin, Grazhdannikov, 2000). For instance, qualitative models could be used to determine if biological object is in the some specific state where the answer is "yes" or "no" or name of the state. Quantitative models would predict, for instance, count of biological in particular date where the answer is a exact number of objects.

DSS may use different combinations of different model types to suggest particular decisions to the operator.

Author propose to divide decision making process in three levels (Fig. 3) (Zacepins, Stalidzans, 2013):

- input data level – where all needed data about process and object should be defined;
- model level – where input data is used by various different dimension models with main aim to determine the object state and status of the process;
- decision level – where model outputs are analysed with main aim to choose the right decision (beekeeping operation to be performed).

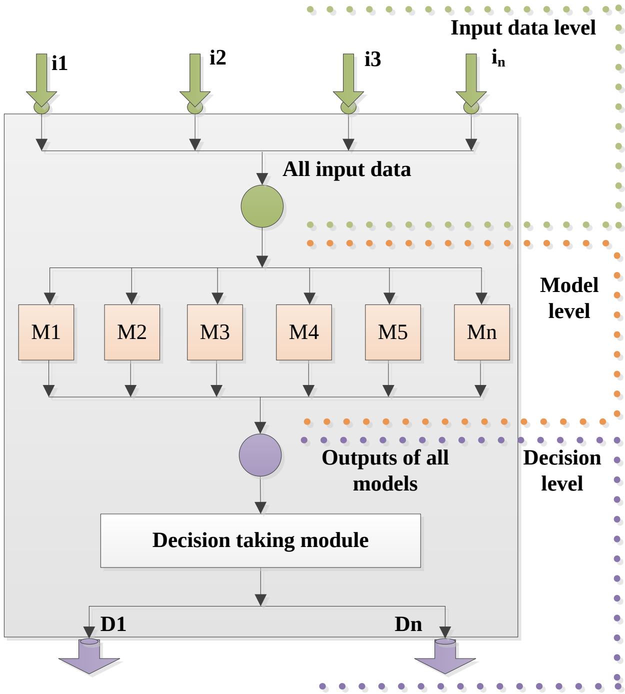

Fig. 3. Three levels of the decision making process (Zacepins, Stalidzans, 2013)

3. Example of implementation of proposed concept

Within the research a model based, real time, distributed, adaptive control of the bee wintering process is developed and experimentally tested. Bee wintering process is a biological process, since biological organisms are involved. Monitoring and control of such process is a rather complicated nontrivial task, because it is hard to predict biological system reaction to human intervention.

The developed system can be divided in several logical blocs, where each of them is independent and has its own functionality. The developed system is based on the proposed architecture of biological object control, which is demonstrated in Figure 1.

Practical experimental work of the research took place in the bee wintering building while monitoring and controlling bee colony wintering process. During the practical work several tasks were completed. Experimental measurements were taken during two wintering periods (2 years). The first period took place in winter 2010 – 2011, the second one in winter 2011 – 2012. If in the first year strict requirements were not defined, then in the second year exact object groups and their distinctive features were defined (Zacepins, 2013).

Microclimate control system was used in bee wintering building for control of ambient temperature on needed level. Additionally wired temperature sensor network was used for individual monitoring of bee colony temperature. Separate information system was developed for data collecting and saving processes. Decision taking about bee colony states was based on different dimension models while real object data was compared to historical data. Detailed description of example of implementation of proposed concept and architecture can be found in author scientific publications (Zacepins, 2012; Zacepins, Karasha, 2013; Zacepins et al., 2011).

4. Conclusions

To implement on individual object monitoring and observations based Precision computer control it is necessary to sequentially complete three phases – data collecting, data analysis and application of control action.

Adaptive control systems are widely used for solving the biological process control tasks, because the result of implementing control actions is not easily predictable. This can be proved by the fact, that the biological process has no linear dynamic, and there is limited knowledge about biosystems and dynamic parameters of the processes. The main feature of the adaptive principle is its adaptability to previously unknown changes of the controlled object, which allows providing high working quality of the system in the variable working environment.

The model based, remote, automatized control system architecture developed by the author for biological object control allows unifying system development process by taking into account similar features of the biological objects.

Application of models in control system is needed to evaluate process progress and predict its development for precise implementation of control action. Control system should be a remote system to allow centralised control of the geographically disseminated local biological systems. To control a complicated biological system the computer control system should be automatized not automatic, to allow the branch specialist to approve or deny the proposed solution of the decision support system.

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