Jakub Pośpiech

Summary of the doctoral dissertation

Title**: Examining of feasibility and usefulness of agent-based control systems for controlling biotechnological processes.**

This dissertation presents results of author's research focused on evaluating usefulness and feasibility of applications based on agent-based systems in biotechnological process control.

Initial analysis of the scientific literature in the area of multi-agent systems and their adoption in process control has shown, that biotechnological processes are considered to have large potential for adoption of agent-based control systems. However, in practice, in comparison with other branches of industry as well as other types of continuous processes, multi-agent systems dedicated to biotechnological systems are scarcely found.

More in-depth literature review, together with author's own analysis allowed to describe the main factors that impede a wider adoption of multi-agent system in biotechnological systems control. The main challenges regarding adaptation of multi-agent solutions is their lack of standardization and common knowledge about the development of agent-based systems. In author's opinion, these factors negatively influence view of agent-based development. Because of that, introduction of multi-agent systems might be considered difficult, and time demanding, which in turn negatively influences system's reliability. In case of biotechnological processes, one of the most important features of control system candidates is their reliability and redundancy. In the biotechnological process control, similarly to other types of continuous processes, a potential downtime should be reduced to minimum. As a result, system's reliability is one of the deciding factors for multi-agent systems introduction.

As a result of this analysis the thesis is proposed **that using an agent-based system, which is built based on a set of development rules for biotechnological processes, enables development of a control system with a reconfigurable structure which is able to adjust to conditions in controlled processes to achieve satisfactory control quality, improving MAS feasibility and proving its usability.**

Agent-based systems presented in this dissertation were developed using JADE (Java Agent Development Framework) framework. For a verification purposes, two types of biotechnological processes were prepared. The first one is biological wastewater treatment reactor, and the second one is the lactic acid fermentation process. Tools used for multi-agent systems development are presented in the chapter 2 of the dissertation and description of verification processes is presented in chapter 3.

Research conducted for the doctoral dissertation is divided into phases. Initial phase was focused on preparation of MAS that would be able to control dissolved oxygen concentration during removal of organic waste in a well-mixed bioreactor inside a laboratory environment. The main objective for this phase was to gather observations that would allow to describe the main difficulties in adoption of agent-based systems for biotechnological processes control. These difficulties were then addressed in the following chapters. After diagnosing key points of interest, research focus was moved to issues causing difficulties in the design and development of multi-agent systems – agents architecture design and the communication between agents. Next phase presents the set of guidelines for developing MAS for a continuous process control that should provide generic advices regarding the most important parts in MAS development. In the last phase, prepared guidelines were verified during a development of multi-agent systems that use complex control algorithms. Described research can be found in chapters 4-8 of the dissertation.

Chapter 4 presents characteristics of the development of multi-agent systems based on the example of agent-based control system dedicated to control dissolved oxygen concentration in biological reactor. The multi-agent system was using conventional ON-OFF controller and its modified versioned that enabled simple adaptation of the controller according to fluctuating process load. MAS design process encountered many difficulties regarding role assignments of specific agents, their relations with each other, communication methods and form of exchanged messages. This issue confirms statements from previous chapters that development of multi agent control systems lacks a set of common good practices, rules and hints making this process more difficult and time demanding. Providing methods to simplify design of MAS is essential for wider adoption of agent based control systems.

Described difficulties were addressed in chapters 5 and 6, where guidelines for systemic architecture and communication rules were presented. Additionally, in chapter 6 a generic ontology schema designed for multi-agent systems for process control, especially for biotechnological processes is presented. Proposed rules, architecture and communication designs were then verified in control of simulation of the dissolved oxygen concentration control inside the biological reactor.

In chapter 7, proposed rules were further verified. In this chapter presented guidelines were used to develop agent-based control system dedicated to control of a real, laboratory biological reactor. The system uses multiple actuators to control one process value. For control purposes predictive control algorithms were used. Multi-agent system prepared according to the proposed ontology structure and the architecture layout was successfully applied in control of the complex biotechnological process. Agent-based architecture layout proved its usability and the previously prepared base implementation of ontology significantly reduced time needed for preparation of system's knowledge base. Multi-agent system by itself was able to effectively control the aeration process outperforming a complex, conventional control algorithm, and display self-diagnostic and

reconfigurability behaviors. This proves that with enough knowledge and preparation agent-based solution might be a competitive alternative to conventionally built systems.

Chapter 8 is focused on an application of the multi-agent system developed according to prepared rules for the lactic acid fermentation control in a two tank reactor setup. Main conclusions from this experiment in the context of this dissertation is the fact that the agent-based system prepared according to the proposed ontology structure and architecture layout can be successfully applied in control of other types of biotechnological processes It is also important to point out that the prepared ontology schema proved its reusability. During this experiment, the ontology implementation from the previous project was reused, even though a different process was controlled this time. Only minor adjustments to the ontology structure were required. This greatly reduced time and effort needed to develop the multi-agent system for this experiment.

The last chapter is a summary of previously described research. Based on performed research projects and available literature, author says, that agent-based system developed accordingly to proposed guidelines reduces effort needed to implement a functional multi-agent system. Which proves the thesis proposed in the introduction chapter.