Multi-Agent Approach for Monitoring and Control of Biotechnological Processes

Ivanka Valova

***Abstract*—**This paper is aimed at using a multi-agent approach to monitor and diagnose a biotechnological system in order to validate certain control actions depending on the process development and the operating conditions. A multi-agent system is defined as a network of interacting software modules that collectively solve complex tasks. Remote monitoring and control of biotechnological processes is a necessity when automated and reliable systems operating with no interruption of certain activities are required. The advantage of our approach is in its flexibility, modularity and the possibility of improving by acquiring functionalities through the integration of artificial intelligence.

***Keywords*—**Multi-agent approach, artificial intelligence, biotechnological processes, anaerobic biodegradation.

I. Introduction

MANY industries use multi-agent systems for real-time monitoring and control. These systems range from small manufacturing facilities to large-scale distributed systems [1], [2], [4], [5].

In [1] authors have designed multi-agent system and Wireless Sensors Network to build virtual organizations of agents that can communicate each other while monitoring crops. The monitoring focuses on several parameters: the temperature, solar radiation, humidity, soil pH, and wind. They propose an architecture in which each agent supports a parameter to be controlled.

In [3] authors proposed a model of intelligent agents to assist the operator in analysing the level of water in a Dam. The presented model improves the water control process of various dams.

The application of multi-agent technologies for sensor networks has received increasing research attention [6]. Practical issues in deploying mobile agents to explore a sensor-instrumented environment are investigated in [7]

In [8] is proposed the use of a real-time system for the monitoring of the power network based on Internet communication protocols. This technological evolution has several implications for data communication systems, which facilitates the implementation of real-time algorithms.

With the development of new technologies, it is possible to use artificial intelligence-based techniques to automate the diagnostics of various biotechnological processes. The availability of large-scale databases can be used to detect and find solutions to many of the problems that arise. We need to provide a communication link between the biotechnological system and the existing vast knowledge libraries.

The application of reliable monitoring techniques to these systems has the objective of investigating the flow of a process and designing optimal solutions. Based on the measurements made and the algorithms proposed for designing biosensors or calculating software sensors, software tools for real-time monitoring and control have been developed.

This article addresses the monitoring and control of biotechnological processes, and in particular, anaerobic biodegradation of organic wastes. The process is known for its instability due to the complex interactions among the different species of microorganisms involved and the complex transformations of the contaminating organics, the complexity and variability of the substrates, etc. Important process parameters are: temperature, pH in the bioreactor, yields and composition of the biogas produced, etc. The presence of immeasurable variables has given rise to the design of mathematical model-based software sensors. The complexity of the processes is reflected in the architecture of the proposed multi-agent system.

An architecture is proposed that uses an agent structure: Data acquisition agent for acquiring data, a monitoring agent that documents the process flow, a tracing agent that creates a simulation model, a diagnostic agent that is able to identify and predict deviations from the parameters set, and a control agent that prescribes measures for maintaining or restoring the optimal state of the biotechnological process. The use of an intelligent broker that serves as a communication node among the individual agents and a database is proposed.

II. Description of the Proposed Multi-Agent Architecture

Data acquisition agent_1 receives real-time data from hardware sensors: temperature (to), pressure in the bioreactor, flow rate of biogas Q, percentage of methane (CH_4), carbon dioxide (CO_2) content and pH in the bioreactor.

The addition of a certain amount of acetate and its effect on the process flow will be investigated.

Data acquisition agent_2 – acquires data calculated using software sensors: growth rates and biomass concentrations of acidogenic and methanogenic bacteria. The use of a microbial fuel cell-based (MFC) biosensor for monitoring the anaerobic degradation process is recommended [9].

Due to its novel transform mechanism, MFC has received considerable interests and a number of potential applications based on its concept have been proposed, particularly in environmental and energy field [10]-[13].

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MFC based biosensor was first reported in 1977 [14], where pure culture *Clostridium butyricum* was positioned as sensing element to transfer electrons using hydrogen as electron acceptor. Biodegradable organic matters, such as acetate could be directly converted to electricity via MFC. It will be of great interest to apply the MFC sensor to the monitoring of the AD system.

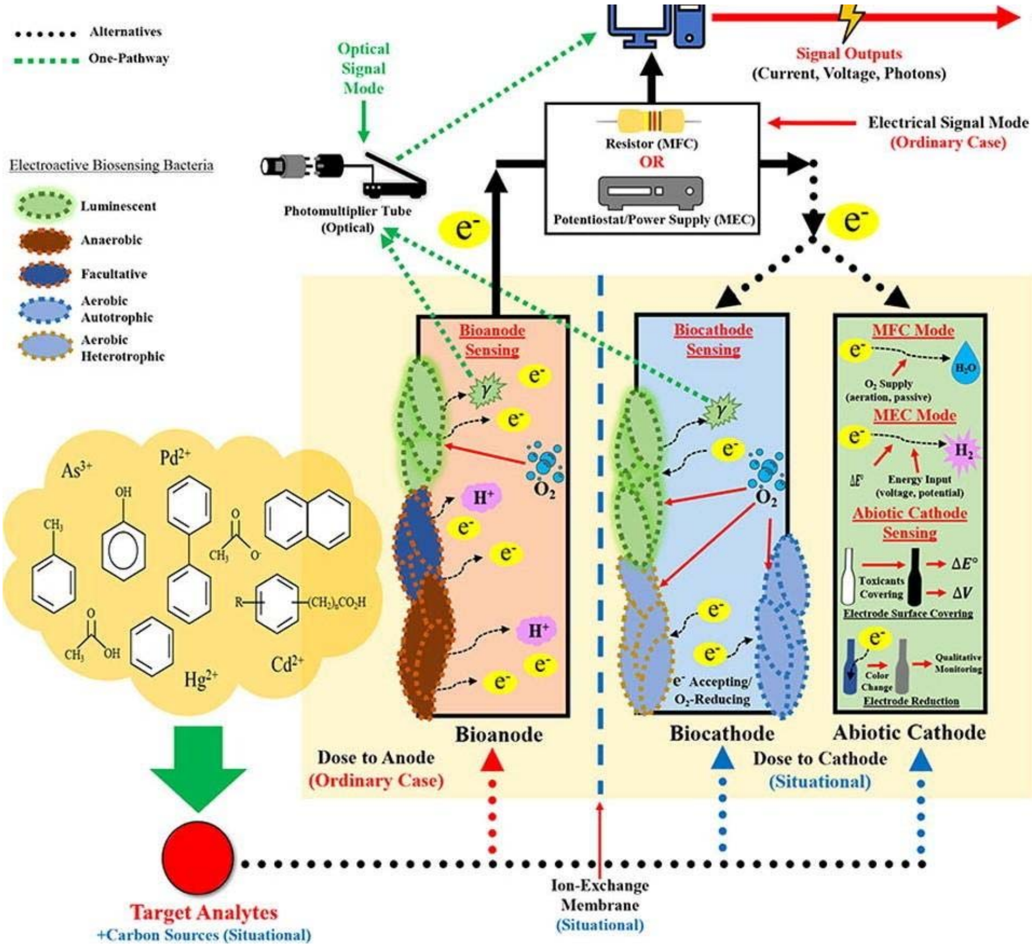

Fig. 1 Structure of biosensor [9]

The data are entered, processed (using filters of different order at the user's request), and visualized (numerically and graphically). Data are recommended to be recorded on a platform that is online and accessible at any time.

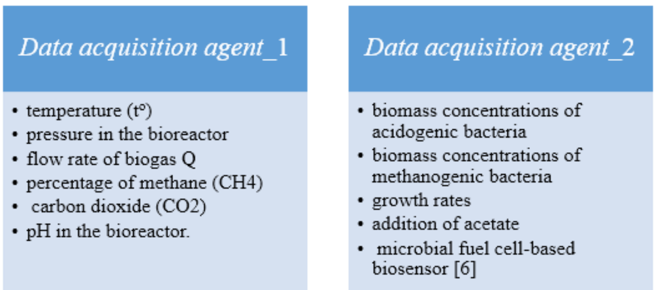

Fig. 2 Data acquisition agents

Based on the acquired data, a simulation model is created. It contains information on how the process should proceed. The monitoring agent analyses the values, then creates a description of the system behaviour.

In [15], the use of X1, X2 monitors of the concentrations of two major groups of microorganisms (acidic and methanogenic) and R1 growth rate evaluator is recommended. These data can be compared with the measurements obtained from the biosensors. The purpose is to verify and compare the results obtained from both methods, for greater accuracy of the trials.

The tracing agent continuously updates the data links between the multi-agent system and the actual system state. Based on the real-time data, a simulation model of the process is created. It contains simulated values of how the system should operate at any time. The tracing agent then transfers the process model via IKB to the monitoring agent, which draws conclusions from the available information and returns a set of symbolic descriptions about the system state to the diagnostic agent. The diagnostic agent generates a high-quality cause-and-effect explanation that will be useful to the process operators. The diagnostic agent is in standby mode, but when it receives information from the monitoring agent, it starts its diagnosis process. The information is sent to the knowledge broker.

A comparison is made with the available information and in case of deviations from the expectations set, information is sent to the control agent, which determines the amount and the need for acetate addition. The pH value in the bioreactor is also monitored.

III. Intelligent Knowledge Broker Layer

The intelligent broker serves as a communication node between the individual agents and the Dynamic Knowledge Data Base. An intelligent broker is a computer program which has a behaviour that can be reasonably called intelligent, including ability to communicate intelligently. Communication takes place by brokers sending data to agents and DKDB.

In the context of a broker in a decision-making process, the terms of data, information and knowledge may be defined like this: Knowledge is learned information – information incorporated in a broker's reasoning resources, and made ready for active use within a decision making process; it is the output of a learning process. In light of this we choose to understand the "communication of knowledge" as the process by which each agent formulates its knowledge into information and sends it as data to DKDB. On this basis we choose to concentrate on the type of broker described by the following normative definition: A knowledge broker is a type of intelligent broker that deals in knowledge, in the way of keeping, querying, distributing it or communicating it.

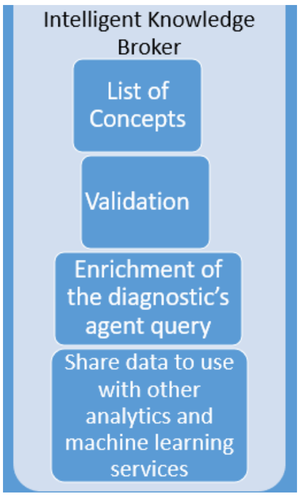

Fig. 3 Architecture of IKB

It has to do with the method of storing and searching for knowledge and with its dissemination. This layer uses several submodules: a searching subsystem, a validating subsystem, and a subsystem for retrieving user information. The user subsystem receives queries and performs many tasks, creates queries using the diagnostic information, returns the information when needed, enriches the queries using concepts that are present in the database.

The searching subsystem reviews data sources by querying existing search engines or a specialized database that contains detailed information about biotechnological processes. The validating subsystem allows an expert to validate the solutions that are identified and appropriate for the query. The necessary terms and concepts are retrieved from the received validated pages and passed to the appropriate agents also for populating the database. The retrieved data can also be structured as an XML file.

In advanced mode IKB layer works by collecting, organizing, aggregating, and analysing data. Data can be stored in an OLAP cube. OLAP tools may be used to query and generate reports from multidimensional data.

IV. Dynamic Knowledge Data Base Layer

The Dynamic Knowledge Data Base (DKDB) layer stores knowledge acquired by all agents and the knowledge broker. Whenever an agent needs to access DKDB, IKB uses distributed method calls to retrieve shared knowledge from DKDB [16]. Data are processed and analysed with view to gaining new knowledge about the anaerobic degradation processes of different organic wastes, mathematical modelling of these processes and development of new technologies.

All process states and measured parameters are archived in the database. It is desirable to make the latter accessible to the interested parties and to provide for a possibility to add additional results. This functionality is necessary so that the resulting process knowledge may be used in similar situations. The knowledge will be enriched on a regular basis and will serve as the basis for development of artificial intelligence-based software that will provide solutions to arising processes. The presence of a human is mandatory and the human is assigned the rights of an administrator of the system so as to make the final decisions.

The database is designed to store a vast amount of information about the state and for evaluation of the parameters in an anaerobic degradation process for methane production. In [15], the addition of acetate was shown to improve biogas production when pH was within the acceptable limits. Two measurable process variables were used to design growth rate evaluators and concentration monitors for both major groups of microorganisms (acidic and methanogenic). Two X1, X2 monitors and one R1 evaluator are created based on a non-linear model of the AD process, with the addition of a control input that reflects the addition of a stimulant (acetate).

Our idea is to design a system having intelligent interactions. Software programs will become smarter after reading the contents of the network and will react by making and executing decisions about the sequence of actions to be executed, as well as will create command interfaces. The designed system will be like a middleware between the human and the bioreactor, i.e. it will be a network of highly intelligent interactions. The multi-agent system is being developed towards using artificial intelligence so as to become an intelligent network.

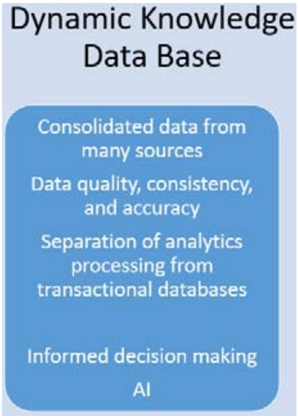

Fig. 4 Architecture of DKDB

The AI module includes machine-learning (ML) algorithms, such as learning using neural networks, which allows the software models to self-learn based on historical data. Learning can be supervised, unsupervised and reinforcement learning. Data are structured and semi-structured. HTML, xlsx, CSV files and MATLAB formats may need to be used.

Machine-learning works on an algorithm that learns using historical biotechnology data. It only works for predefined domains. For example, if we create a machine-learning model for the most important groups of bacteria involved in anaerobic degradation processes, it will produce results only for those processes.

It is important to distinguish between independent and dependent variables in the dataset. Software sensors that calculate data based on mathematical models provide dynamic relationships between measurable variables and some unmeasurable or hardly-measurable variables (growth rates, biomass and substrate concentrations) for the most important groups of bacteria involved in the process. There are three dependent variables in our dataset, which are observers X1, X2 of concentrations of two main groups of microorganisms (acidic and methanogenic) and an estimate of the growth rate R1.

The collection and preparation of the dataset are important stages in the creation of ML/AI models. Data (numerical, graphical or visual) are classified according to the problems and the ultimate tasks of machine-learning - classification, grouping, etc. Pre-processing of data and making it suitable for a ML model is necessary, as it will increase the accuracy and efficiency of the machine-learning model. Knowledge extraction from data is performed using appropriate ML algorithms. The machine-learning model allows a computer system to make predictions.

Procedures for data collection and analysis are extremely important. All data obtained (numerical, graphical, video) will be stored in DKDB. If necessary, additional datasets will be requested from related companies or interested institutions. The implementation of the multi-agent system needs to be consistent with the available techniques and technologies related to anaerobic degradation processes.

V. Conclusion

In the proposed framework, agents work collectively to perform tasks according to the roles assigned. Intelligent agents are used now a days in every field of life to solve complex problems. Agents are a software program that takes action in different states to attain design objectives. In multi-agent approach each agent performs specific tasks according to the role assigned.

A conceptual model of a multi-agent system for real-time monitoring, diagnosis and control is presented. The system is modelled as a collection of agents that collaborate to perform monitoring, evaluation, and control of biotechnological processes.

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