Implementation of a Multiagent Prototype for WWTP Management

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Abstract: The control and management of a Wastewater Treatment Plant (WWTP) is a complex task that requires the supervision of human experts. To ease this task, Multiagent Systems provide a framework for a more efficiently control in environmental processes. A prototype of multiagent system has been designed for WWTP management. Two subgroups of agents are identified: the interface and the intelligent agents. The first subgroup is designed to interact with the plant and the final users. This group contains the monitoring agent, which is used to store and manage all the sensor data incomes, the actuator agent which acts on the plant regulators, and the user agents which allow users to interact with the multiagent system. There are two intelligent agents: the modeling and the predictive agents. The modeling agent induces the models of the plant that users need. There are two methods to make the models. The first one creates rule-based systems to predict abnormal situations, and the second one identifies states of the plant and creates state-transition diagrams to represent the possible evolutions. The user can choose whether the model is incorporated to the set of interesting models. The modeling agent selects the most accurate model and proposes control actions on the plant. The Predictive agent works with the active model to answer the questions about the plant that are asked by the user. A prototype of the multiagent system has been implemented in Jade, a Java-based platform. In the paper, the agent functionalities are identified as agent behaviors, the communication protocols between agents are displayed, and the performance of the whole system is analyzed with actual data from a WWTP located in Catalonia.

Keywords: Integrated Water Assessment, Application of Agent-Based Modeling and Simulation to Environmental Systems, Wastewater Treatment Plants, Multiagent Intelligent Systems.

1. INTRODUCTION

Environmental systems are described as frameworks that are distributed, dynamic, complex, random, periodic and heterogeneous [Rizoli and Young, 1997]. Therefore, any computer system designed as an Environmental Decision Support System (EDSS) must be ready to deal with these features.

Particularly, systems that are designed to control and supervise the processes of a urban wastewater treatment are EDSS that must support the above features. These are systems that are related to Wastewater Treatment Plants (WWTP) where a bio-chemical procedure, as the *activated sludge process* [Horan, 1990], is applied. These procedures are applied on a continuous water flow where the contaminants and the concentration of microorganisms evolve dynamically. Many of the involved actuation and the cause-effect reactions are complex or they are not completely solved. Moreover, there is a hazardous component since the treatment depends on uncontrolled factors as the water contamination degree at each moment, the rain and other weather agents, the unexpected chemical and biological reactions (foaming), the uncontrolled disnitrification at the secondary settlers (rising), and the increment of filamentous bacteria (bulking). Finally, there are several workers interacting with the system, each one with particular functions and goals that make the control process multidisciplinary and heterogeneous.

Within the framework described, the direct use of theoretical models to control a WWTP is senseless, and decisions are taking according to adapted models or, more often, according to the experience of the workers in the plant. When a WWTP is supplied with sensors connected to a computer system a new tool can be available to help in the control and the supervision of the daily activity.

Multiagent systems define adaptable and open computer platforms that, on the one hand satisfy the above features, and on the other hand are suitable to construct an EDSS. Multiagent systems are based on the integration of intelligent agents that are specialized in different tasks (e.g. modeling, prediction, simulation, data management, knowledge elicitation, etc.), and that cooperate efficiently to achieve a global purpose (e.g. WWTP control and supervision).

Here, we describe a prototype of a multiagent system with five agents that perform some alarm control and WWTP knowledge management. The user can define alarm situations about the sensor values. When any alarm situation is reached the system evaluates whether an information message is raised or an actuation proposed to the plant workers. The system is also able to make and remember multiple models of the plant, according to the user needs, and use these models to predict future situations of the plant, and also to simulate hypothetical descriptions.

Section 2 introduces the multiagent system. Section 3 shows some of the models that the system generated for a real WWTP. Conclusions are in section 4.

2. THE MULTIAGENT SYSTEM ARCHITECTURE

2. 1 Introduction

Previous work and experience in the development of EDSS [Riaño et al., 2000] [Riaño et al., 2001], as well as the knowledge acquired from a particular WWTP located in Catalonia [R.-Roda et al., 2001] has been taken into account. The WWTP modeled has several sensors and control points through the water treatment process, where some water samples are periodically analyzed in the laboratory. In the WWTP, at any time, there are 179 available data describing the operational state of the WWTP. Currently, the multiagent system only takes into account 33 on-line data, because the human experts have decided it. With all these daily information, the system performs the following tasks: (a) collecting sensor data, (b) managing several kinds of alarm, (c) proposing different possible actuations over the plant, (d) interacting between the system and the plant operators, (e) modeling the WWTP operation, and (f) forecasting possible future operating situations. The prototype system has been designed in order to implement all the above mentioned tasks. There are three interface agents performing the first four tasks: the monitoring agent, the actuator agent, and the user agent. To carry out the last two tasks, there are two intelligent agents: the modeling agent and the predictive agent. Figure 1 shows the interaction between these agents.

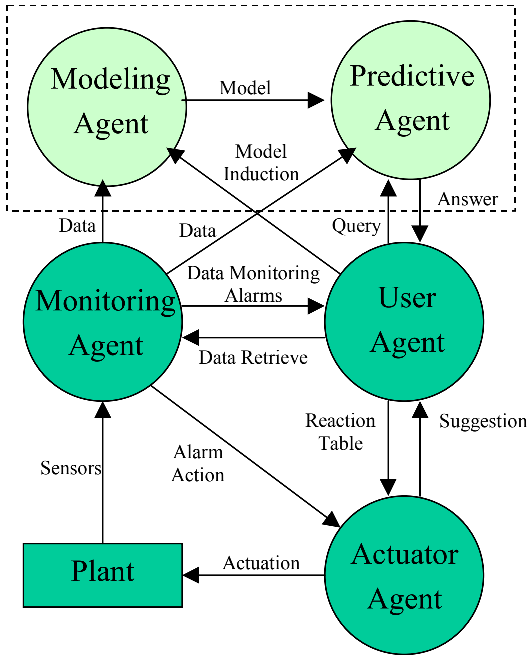

Figure 1. Prototype Multiagent System.

2.2 Interface Agents

The Multiagent System has the monitoring agent to manage the data of the sensors of the WWTP. Also, there is an actuator agent and a user agent to interact with the plant and the plant workers, respectively. A description of these three interface agents is followed.

The *Monitoring Agent* captures the data that comes from the sensors of the plant. These data are stored in a database that the rest of the agents can use. When the monitoring agent obtains a new sensor value it is checked out whether there is an alarm defined for this value. If so, an alarm is raised. The user agent or the actuator agent, according to the alarm definition attends the raised alarms. The monitoring agent is able to deal with three different alarms: soft, hard and hard-hard. *Soft* *alarms* are advising alarms, *hard alarms* have a direct actuation on the plant, and *hard-hard alarms* are hard alarms that have to be solved immediately. For example, when the mass loading rate is low, the operator is informed with a soft alarm:

> *"Loading rate is low. Make a microscopic examination to determine excessive filamentous micro-organisms prolife-ration, i.e. bulking problems"*

But, if the amount of wastewater applied to the process is bigger than 1300 m^3/day, a hard alarm is raised to adjust the flow control devices from the primary settler to laminate flow to aeration tank, and whenever the flow is bigger than 1500 m^3/day a hard-hard alarm is raised to bypass the remaining wastewater.

The agent acts as an information agent [Brenner et alt., 1998] that retrieves information from the plant sensors, decides the relevance of the data and stores the data that is relevant for the control system.

The *Actuator Agent* performs some predefined actions on the plant actuators. For instance, increase or decrease the air inflow according to the oxygen demand (OD1 and OD2 values), open or close the waste activated sludge valve (WAS value) and the recirculated activated sludge valve (RAS value), or purge the primary settler. These actions depend on both the instructions received from the user agent and the alarms received from the monitoring agent.

This agent has been implemented following an architecture similar to *subsumption* [Brooks, 1986] where the response levels are defined by the sort of alarm, representing hard-hard alarms the most reactive level. For each alarm received, the actuator agent looks its type in a *reaction table*. If it is *hard* or *hard-hard* the related action is sent to the actuator agent which transforms it into a task. If it is a *soft* alarm, the actuator agent sends an advice message to the *user agent*.

The *User Agent* is used by the plant workers to interact with the system. It also permits the workers to define, to modify and to remove the alarms that the monitoring agent stores, and the reaction table that the actuation agent has. The user agent is also used to retrieve information about the plant sensor values, to order the modeling agent to construct models of the plant and the predictive agent to use some model to predict future situations or to suggest actuation measures.

All these interactions between the multiagent system and the plant workers are available by means of the windows interface at figure 2.

2.3 Intelligent Agents

The multiagent system has two intelligent agents, the modeling agent and the predictive agent, that are related to the processes of making and using models of the evolution of the plant.

The *Modeling Agent* receives instructions to generate intelligent models from the user agent. These models can be rule-based models [Riaño, 1999] (see table 2) or state-transition models [Gimeno et al., 1998] (see figure 3). In sections 2.4 and 2.5 these models and the way they are automatically made are described in detail. The models can be tested, accepted or rejected by the user agent who decides if the model is incorporated to the library of models in the modeling agent. Among all the models in the library, the modeling agent distinguishes which is the active model.

The *Predictive Agent* main task is to use the active model in the modeling agent to answer the questions that the user agent asks about the possible evolution of the plant and also about the possible actions on the plant actuators. That is to say, it uses a reasoning procedure when the active model is a rule-based model, and an state-input identification procedure when the active model is a state-transition model.

Although, actually the predictive agent is implemented as an intelligent server of the user agent, in the next versions of the system a BDI [Müller, 1996] architecture will be proposed in order to anticipate predictions and make the agent more autonomous.

2.4 Rule-based model

The modeling agent is able to generate a rule-based model of the behavior of the plant in a time interval that is proposed by the user agent for this model. Once the model has been made, it can be stored and tested with new real or hypothetical situations in order either to predict the immediate evolution of the plant or to propose the best actuation according to the plant past experiences.

The modeling process starts with the selection of both, the explanation variables and the variables that are to be explained. If these variables are state variables the generated model is a WWTP evolution model, if the variables are actuation variables, it is an actuation model.

Once the variables has been selected, the CN2 algorithm [Clark and Nibblett, 1987] is applied to each individual variable to be explained together with all the explanation variables. A model of the former variables in terms of the latter ones is then obtained. See table 2.

2.5 State-transition model

Sometimes, the interpretation of a model is easier if it can be represented as a state transition diagram, as the one depicted in figure 3. In the proposed system, nodes stand for the states of the plant, and arcs represent plant state transitions that occur when some new situation is detected in the plant (according to the analysis of the sensor values). Attached to the transitions there can be also the control action that is recommended.

A *k-means* clustering algorithm [Bradley and Fayyad, 1998] has been incorporated to the multiagent system. This algorithm is applied to obtain three classifications that represent the plant states, situations, and actions, respectively. Once these classifications are obtained, each state class is converted into a state node of the diagram. The WWTP data about the daily description of the plant (e.g. water flows, pH, oxygen demand, etc.) is used to introduce the state transitions in the diagram. A situation class that represents a change in the state of the plant, and an actuation class that represents a control action on the plant are attached to the each transition according to a weighted evaluation of the daily evolution of the plant in the time interval indicated by the user agent. This way, only the most frequent past evolutions of the plant are reflected in the final state transition diagram.

2.6 Agent cooperation

Cooperation between the five agents is one of the main features of the multiagent system proposed. Figure 1 shows some of the most relevant agent interactions. In this section we will concentrate in the agent cooperation for the tasks of alarm control and model management.

Alarm control is divided into two stages: alarm definition and alarm raising. Alarms are defined in the user agent who asks the monitoring agent to be on alert for possible abnormal situations detected in the sensor data. In such case, the monitoring agent raises an alarm in the user agent who acts according to the reaction table. If an immediate action on the plant is required (e.g. open the wastewater bypass valve when the flow is bigger than 1500 m3/day), an order is sent to the actuator agent.

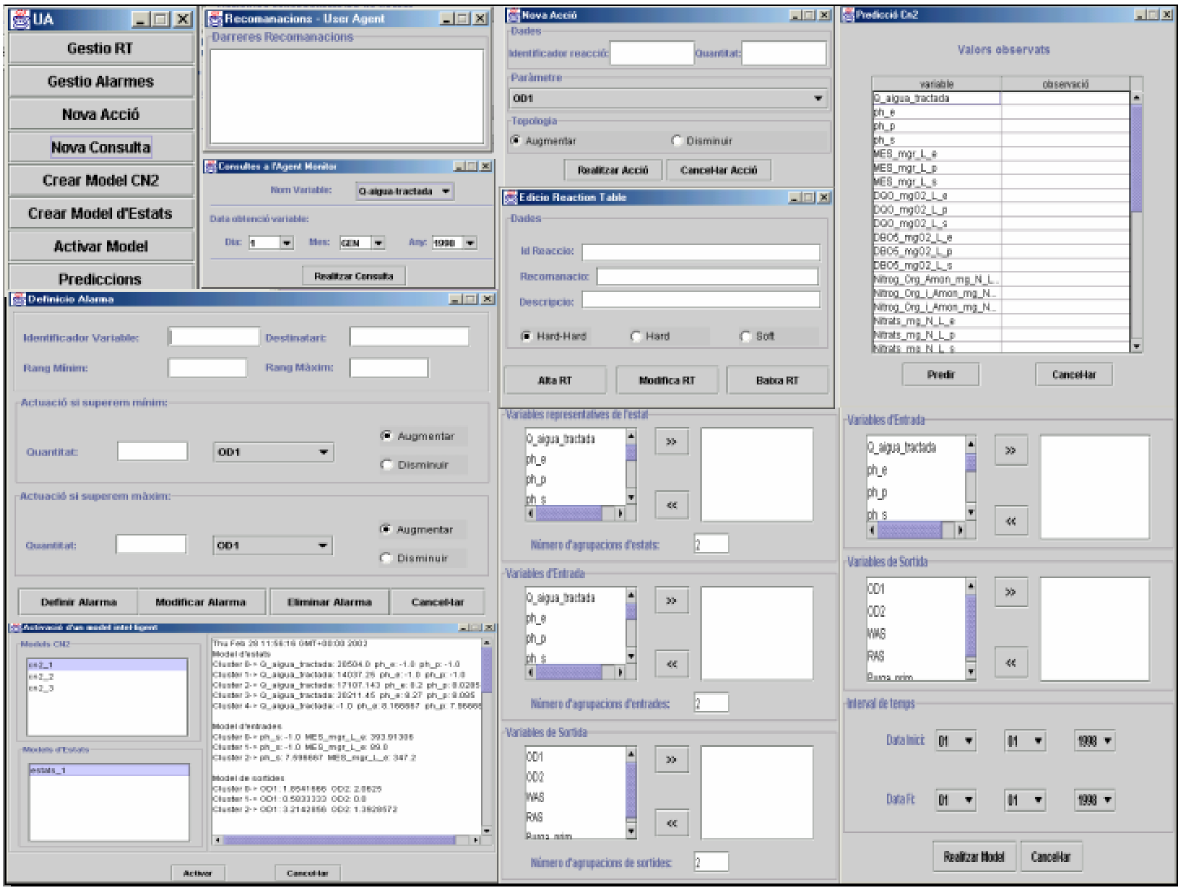

Figure 2. Multiagent System Interface.

Model management concerns the user agent, the monitoring agent and the intelligent agents. The user agent proposes a time interval, a set of explanation variables, a set of explained variables, and a model type (rule-based or state-transition) and passes this framework to the modeling agent who makes a model. This model can be tested by the user agent through the predictive agent and stored in by the modeling agent if appropriate to the user agent. The use of the models depends on the user. There are two WWTP operation modes: user-directed and automatic. In the user-directed mode, the user agent proposes an active model to the modeling agent. This model is applied by the predictive agent on the on-line sensor data supplied by the monitoring agent. Actuation suggestions are sent to the user agent who informs the user or actions the actuator agent.

In the automatic mode, the modeling agent and the predictive agent are continuously evaluating the predictive capacity of all the stored models. At any moment, the most predictive model is selected to be the active model which is used by the predictive agent to suggest control actions to the user agent.

3. TEST CASES

The multiagent system has been tested with a WWTP in Granollers (Spain). Here, we present the results of applying the procedures described in sections 2.4 and 2.5 to the plant in an interval of 4 months. For this time the variables DO1, DO2, WAS, RAS, and primary purge act as control actions in the way that table 1 indicates.

Table 1. Control action variables.

data value	meaning	action
OD* < 0,5	low OD*	↓ air inflow*
OD* > 3,5	high OD*	↑ air inflow*
WAS < 600	low WAS	close WASvalve
WAS >1200	high WAS	open WAS valve
RAS < 600	low RAS	close RAS valve
RAS >1500	high RAS	open RAS valve

Two set of variables were used to describe the above control actions in a rule-based model: one with the biologic oxygen demand at three different points in the plant (BODe, BODp, BODs), and other one replacing these variables with the chemical oxygen demand at the same three points (CODe, CODp, CODs). The rest of variables are the amount of water treated (Q), MESe, MESp, and MES-s. Some of the most representative rules obtained for the first case are shown in table 2.

Tests are completed with the construction of the state-transition model that figure 3 shows. The user agent defined PHp, PHs, MESp, MESs, CODp, CODs, BODp, BODs, CONDp, CONDs, and turbidity (Tp and Ts), the variables that define the state of the plant; Q, PHe, MESe, CODe, BODe, CONDe, and Te, the variables that define the situation of the plant at a particular time; and DO1, DO2, WAS, RAS, and primary purge, the actuation variables. Four states were generated by the multiagent system that the workers of the plant identified as "*risk of secondary settler bad performance*" (node 0), "*effluent turbidity*" (node 1), *high performance*" (node 2), and "*normal*" (node 3). Three situation classes where generated with the meaning "*normal*", "*overloading*", and "*underloading with industrial waste with potential inhibitory effect*". The actuation classes were tree: close all valves to "*minimize the energy consume*" (i.e. ↓ air inflow1, ↓ air inflow2, and close WAS, RAS, and purge valves), close primary valves (i.e. close RAS and purge valves), close sludge valves to "*increase the sludge retention time*" (i.e. close WAS, RAS, and purge valves), and purge by reducing the primary settler sludge retention time to "*avoid sludge septicity*" (close RAS valve and open purge valve).

Table 2. Representative rule-based model of the OD1, WAS, RAS variables based on 4-month WWTP experience.

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If (MESe < 218) and (MESp > 177) and (MESs < 10.5) Then OD1 HIGH
If (18501.5 < Q < 21233.5) and (230 < MESe < 271) and (MESp > 84) and (MESs < 42.5) and (8 < BODs < 13) Then OD1 HIGH
If (269 < MESe < 520) and (67 < MESp < 117) Then OD1 NORMAL
If (Q < 22565.5) and (87 < MESp < 173) and (MESs < 20.5) Then OD1 NORMAL
If (MESe > 271) and (370 < BODe < 580) and (118 < MESp < 210) and (MESs < 35) and (BODs < 23) Then OD1  NORMAL
If (156 < MESe < 238) and (MESs > 27.5) Then WAS HIGH
If (Q < 20904) and (MESe > 358) and (MESp<67) and (MESs <32.5) Then WAS HIGH
if (MESe > 262) and (602 < DQOe < 644) then WAS NORMAL
if (MESe > 500) and (DQOe < 1330) and (MESp > 97) then WAS LOW
If (Q > 21843) and (MESe > 454) and (MESp > 91) Then WAS LOW
If (16378 < Q < 21679.5 ) and ( MESe > 378 ) and ( MESp > 203 ) Then WAS LOW
If (Q > 22161) and (148 < MESp < 175) and (MESs < 32.5) Then RAS HIGH
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The analysis of the state-transition model in figure 3 shows that the central state is the normal state. That is to say, the WWTP is usually returning to a normal situation. The ideal state of high performance (node 2) is only reachable from the normality (node 3), with either a control action 2 or 3 (i.e. normal o increase SRT), to cope with an overloading input. When the plant moves away of the high performance to other states it is always passing though the normal state (node 3). In this state, if there is a normal input, the actuation is normal (0/2) and the plant stays normal or moves towards a effluent turbidity (node 1), whereas if there is an overloading input and we act to increase the cellular age (1/3), it can be either that the plant stays in a normal state or that the plant moves to a risky secondary settler bad performance (node 0) which is difficult to leave.

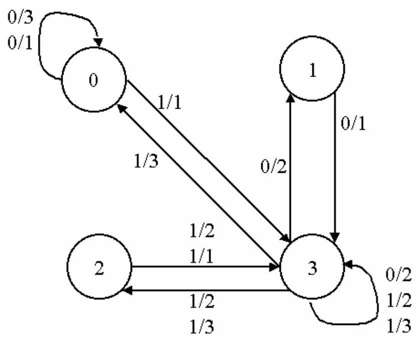

Figure 3. State-transition model.

4. CONCLUSIONS

A prototype of a multiagent system for wastewater treatment plant operation management has been designed and implemented. Five collaborative agents have been implemented in a Jade platform: the actuator agent, the monitoring agent, the user agent, the modeling agent and the predictive agent. In this paper, the design and the implementation of the multiagent system have been described. This prototype has initially validated with some test cases, such as inducing several rule-based models and some predictive state-transition models either to predict the next future evolution of the plant, or to propose and apply actuations. All the models have been tested against the experts opinion with a preliminary positive feedback.

Future work will be oriented to complete the multiagent system architecture, developing new foreseen agents, and carrying out more validation experiments to ensure the real-time reliability of the approach in front of on-line demands.

5. ACKNOWLEDGEMENTS

This work has been partially supported by the Spanish CICyT project TIC2000-1011, and the EU project A-TEAM (IST-1999-10176).

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