Knowledge-based supervision and control of WWTP: a real-time implementation

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KEYWORDS

Activated Sludge Processes; Expert System; Knowledge-Based Expert System (KBES); Real-time System; Wastewater Treatment.

INTRODUCTION

The real-time control of wastewater treatment plants constitutes a quite complex problem due to the lack of reliable on-line instrumentation and simplicity of models used to describe the microbiological processes that take place in the bioreactors (Serra *et al.*, 1993). The use of knowledge-based techniques has been widely proposed to improve the actual situation of these systems (Gall and Patry, 1989; Barnett *et al*., 1992; Ozgur and Stenstrom, 1994). This paper presents the hardware architecture and the software development and implementation of a knowledge-based distributed control system for the supervision of a wastewater treatment pilot plant (WWTPP) with biological removal of organic matter, nitrogen and phosphorous. In previous works, the main prominence was oriented to the knowledge structure development (Serra et al., 1993; Sànchez et al., 1996; Serra et al., 1997) and control strategies (Moreno et al., 1992). The real-time implementation of the data knowledge structure is the main essence of the current work.

In this development, as the main tendency in the actual real-time control and supervision of processes, all the possible knowledge and the top autonomous decision capacity at every subsystem of the process is applied. In this supervisory control outline, every element supervises elements situated hierarchically under its control. This increases the system complexity, but obtaining important advantages, as the increased control of process failure and the possibility of using the top-level control to work in the system supervision. In our case, this top-level control is occupied by an Knowledge-Based Expert System (KBES) designed in G2 (Gensym, 1995) a development environment for creating intelligent, knowledge-based, real-time applications.

METHODS

The process under study is a biological wastewater treatment based on A^2/O multistage configuration with nitrification-denitrification. Figure 1 shows a schematic diagram of the pilot scale facility, which consists of an anaerobic selector (9 litres), three identical aeration tanks (28 litres) and a settler (60 litres). Please note that the oxic state of these three tanks may be easy configured from the expert system. The first tank usually is used as an anoxic reactor, but an aerobic operation mode is also possible. The feed to the anaerobic selector is a mixture of the inlet wastewater and return sludge. The presence of this anaerobic stage is used to improve phosphorous removal. The inlet wastewater is a synthetic influent made by mixing two concentrated complex sources of carbon and nitrogen diluted with tap water.

Different concentrations and flows are automatically assigned and scheduled to simulate real situations.

The hardware architecture contains different supervision levels, including two autonomous process computers (plant control and analysers control) and a PLC. In the PLC program, the operation failure detection and the possible corrective actions have been included. The software for the computer, which controls the plant, is developed in C language, and includes graphic monitoring, data backup, PLC supervision, and control of key process parameters (DO, flow-rates, stirring rates, etc). This computer permits the control of the WWTPP with a set of prefixed setpoints, the usual level of control we can find in a WWTP. Another computer controls two on-line automatic analysers for nitrate-nitrite (Gabriel et al., 1998) and ammonia, and an automatic sampling system. Both process computers are linked via Ethernet to a data server executed in a Sun Sparcstation running Solaris operating system. This gateway is based on TCP/IP communication, and it allows the maintenance of a real time database with the information generated in every subsystem.

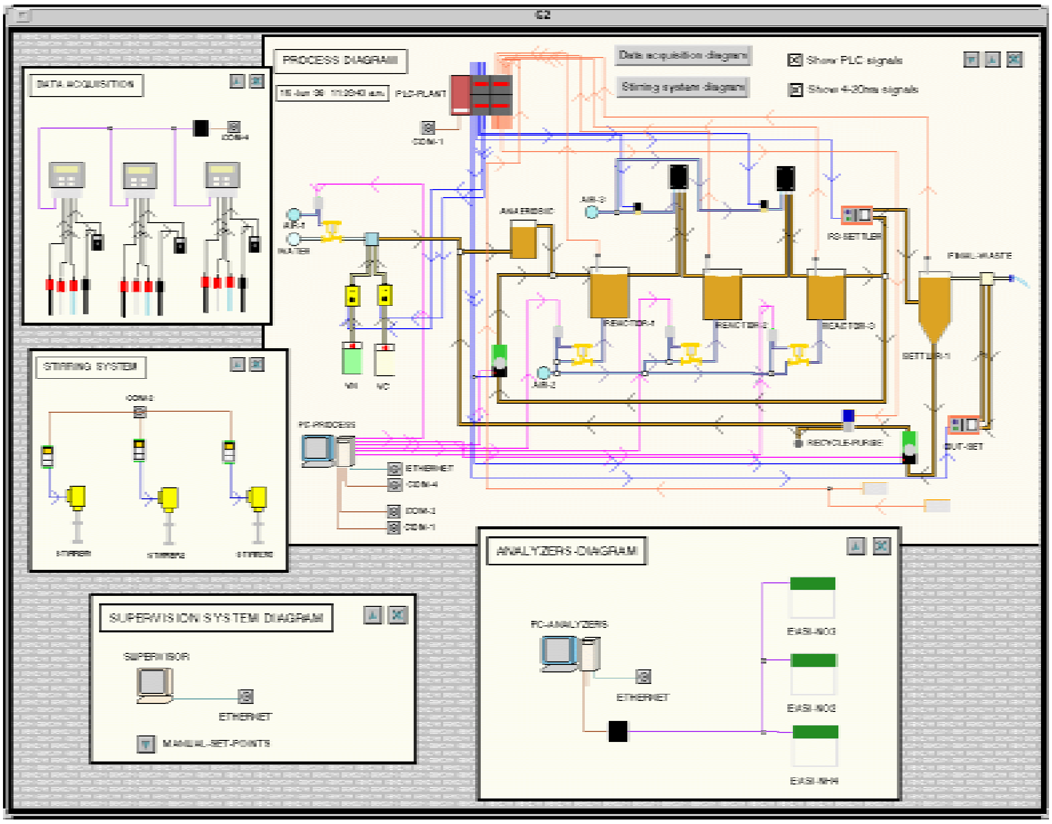

Figure 1. Process diagrams workspaces

The KBES developed in G2 4.0 running in the Sun workstation is on the top of the system architecture. It systematises the knowledge about the process, which is based on the existing scientific knowledge and the practice acquired in our particular system. The ES acts as the master in a supervisory setpoint control (SSC) scheme. It is based on a distributed architecture integrated by a supervisor. The knowledge is organised in several modules, representing the available knowledge for every sub-process. The ES is fed with in-line data (pH, T, DO, ORP, aeration and flows) and on-line data (NO_3^-, NO_2^- and NH_4^+) generated by the plant using the data server. Qualitative data (odours, colours, microbiological observations data) and discrete data from off-line analyses (PO_4^{3-}, COD, SST, SSV, TKN, and SVI) can be sent to the KBES. Both last tasks are accomplished using the Internet as a vehicle. Each specialised operator can send specific data from any computer using a form page in WWW. HTML code generates an e-mail formatted message using the PERL script language. The KBES is able to read these messages, and to use this symbolic and numeric knowledge to update object's attributes. Using rules based on the available data, the expert system continuously decides the optimum control to achieve the required nitrogen and organic matter removal. Finally, control actions are transmitted to the process computers that actuate on each element of the plant. The definitive scheme is outlined in Figure 2.

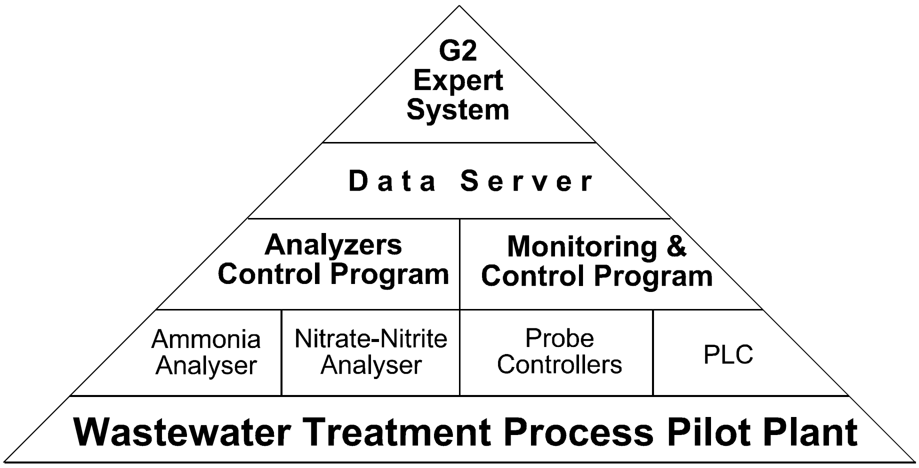

Figure 2. Outline of the distributed system for supervision and control

RESULTS AND DISCUSSION

All the KBES knowledge is structured trough a whole of rules and procedures for each subsystem of the WWTPP. Knowledge representation in G2 is maintained and extended through classes. Classes have attributes, which define the inherited and locally defined properties of the class. Main classes considered include process units (14 definitions), instrumentation (38 definitions), connections (27 definitions), sludge and microorganisms (84 definitions), and computers (4 definitions). Every object is an instance of a class, which is defined through an object definition. Figure 1 - the process diagrams workspaces - presents several objects with their icons and connection stubs. The workspaces are the blank pages upon which G2 permits the creation of objects. A knowledge base (a container in which a set of knowledge about real or virtual entities is collected and organised) can contain one or many workspaces. Logical hierarchy of objects and workspaces to group and organise rules and objects can be created. In our prototype, the workspaces Definitions, Process Parameters, Modules, Plant Diagrams, and Graphical Monitoring were considered as main workspaces, although the total amount was more than 200.

In the KBES, a set of rules (319) and procedures (45) to help fault detection, plant maintenance, and nitrification - denitrification cycle operation was implemented and validated at pilot scale. In these rules and procedures, every measure is checked using different criteria. The measures should be into a predefined band, the rate of change should not be too fast or too slow and the measures should not be in contradiction with other measures. If the data is considered not reliable, the KBES can deactivate local control loops and establish constant actuation, based on normal values. Other features are the minimisation of energy consumption, adapting the setpoints of flows, stirring and oxygen to the load detected in the plant. It is also capable of detecting operation problems in the different elements (pumps, air services, leaking problems...).

CONCLUSIONS

The main achievement of this prototype is a versatile framework able to deal with different plant configurations, based on the object-oriented paradigm and on rule-based reasoning. The on-line feature is an important innovation of this system, particularly for data monitoring and supervisor control. In our system, different control strategies can be implemented for activated sludge control of carbon, nitrogen, and phosphorus removal with different plant configurations. In addition, the developed KBES can be adapted to a new plant in a short time because of object-oriented design. Finally, this system is running continuously during more than 800 days. The supervisory KBES shows an excellent performance to manage the WWTPP. The developed system detects and controls wrong and special operations, as for example: pump failure, feeding problems, probes malfunction, equipment maintenance, analysers control and maintenance, etc.

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