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A KNOWLEDGE-BASED DISTRIBUTED SYSTEM FOR SUPERVISION AND CONTROL OF WASTEWATER TREATMENT PROCESSES

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ABSTRACT

This paper presents the hardware architecture and the software development of a real-time knowledge-based distributed control system for the supervision of a wastewater treatment pilot plant with biological removal of organic matter and nitrogen. A continuous monitoring of plant and controls data is used by an expert system developed in G2, a development environment based on object-oriented paradigm. A set of rules and procedures to help fault detection, plant maintenance, and nitrification - denitrification cycle operation was implemented and validated at pilot scale. The hardware architecture includes different supervision levels, including two autonomous process computers (plant control and analysers control).

KEYWORDS

Activated Sludge Processes; Expert Systems; Knowledge-based Systems; Real-time Systems; 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). Activated sludge is, nowadays, the most extensively used system to clean wastewater. Barnett *et al*. (1992) presents an extensive literature review on application of Knowledge-Based Expert Systems (KBES) for the activated sludge process. Most of systems here summarised are off-line KBES mainly diagnostic and advising tools to help operators (Gall and Patry, 1989; Ozgur and Stenstrom, 1994). Some KBES have been designed with the main purpose of online supervision (Verheijen *et al*., 1997) though the emphasis on real-time supervisor control is usually absent.

This paper considers the hardware architecture and the software development of an intelligent distributed control system for the supervision of a wastewater treatment pilot plant with biological removal of organic matter and nitrogen. In previous works, the main prominence was oriented to the development of the knowledge structure (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 our 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 is a way to increase the system complexity, but with this complexity, the system obtains some important advantages. One advantage is the increased control of process failure to assure the system's security. With this architecture is easy to obtain a fault tolerant system. Another important advantage is the possibility of using the top-level control to work in system's supervision. The top-level control is occupied by an Expert System (ES) designed in G2 (*Gensym*, 1995) a development environment for creating intelligent, knowledge-based, real-time applications. G2 development is based on object-oriented design.

METHODOLOGY

The Pilot Plant

The process under study is a biological wastewater treatment based on A^2/O multistage configuration (*Manual*, 1993) with nitrification-denitrification. Nitrogen removal in a fully automated pilot plant treating 500 litres per day of a synthetic influent is currently our main goal. 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 due to a possible utilisation for phosphorous removal (not considered in this study). 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 can be automatically assigned and scheduled to simulate real situations.

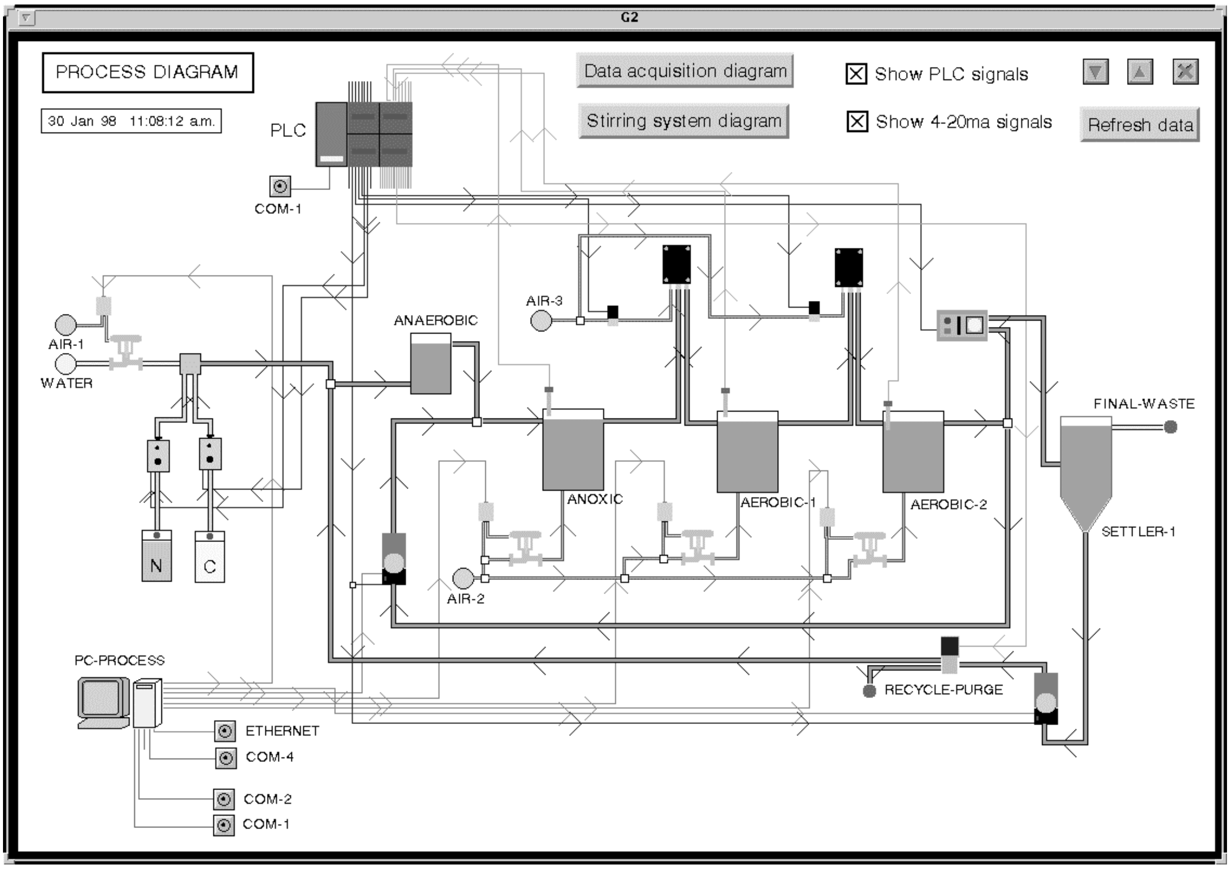

Figure 1. Process diagram workspace

Each mechanical unit of the plant (pumps, level detectors, nipping valves...) is controlled by a PLC, that allows to automate all those elements. In the PLC's program the operation failure detection and the possible corrective actions have been included. Every reactor of the pilot plant has in-line sensors (dissolved oxygen tension, pH, ORP, temperature) connected to probe controllers. At the same level of the supervisor's scheme, two on-line automatic analysers for nitrate-nitrite (Gabriel *et al.*, in press) and ammonia are used. Both analysers are controlled by a computer. A control and monitoring computer supervises the PLC (via RS-232). The computer also acquires data from the probe controllers (via RS-485) and it controls the dissolved oxygen (DO) through the manipulation of the pneumatic control valves of every reactor (via 4-20 mA loop). The software developed in C language includes graphic monitoring, data backup, and control of key process parameters (flow-rates, DO, stirring rate...). The analysers control computer sees about controlling a sampling system trough a number of nipping valves. Also, it actuates each module of the analysers (via RS-485), and the software developed allows graphic monitoring and data backup. The two process computers (Pentium processors) are linked via Ethernet to a data server executed in a Sun Sparcstation running Solaris operating system. This gateway is developed in C language for TCP/IP communication with the monitoring programs, allowing the maintenance of a real time database with the information generated in the system.

The Expert System

The expert system developed in G2 (version 4.0) running in the Sun workstation is on the top of the system's architecture. The ES systematises the knowledge about the process being based on the existing scientific knowledge and the practice acquired in our particular system. All this knowledge is structured trough a whole of rules and procedures for each subsystem of the pilot plant. G2 calls the blank pages upon which we create and maintain objects workspaces. 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. The objects upon workspaces are capable of having their own subsidiary workspaces. Thus, logical hierarchy of objects and workspaces to group and organise data can be created. In our prototype definitions, rules and procedures, plant diagrams, and graphical monitoring were considered as main workspaces. Knowledge representation in G2 is maintained and extended through classes. Classes have attributes; these define the inherited and locally defined properties of the class. G2 maintains class attributes within attribute tables. Main classes considered include process units (14 object definitions), instrumentation (38 object definitions), connections (27 object definitions), sludge and microorganisms (84 object definitions), and computers (4 object definitions). Every object is an instance of a class, which is defined through an object definition. Figure 1 - the process diagram workspace - presents several objects with their icons and connection stubs. For the sake of readability, the objects of data acquisition and stirring systems diagrams are separated from the process diagram workspace. In addition, the PLC signal stubs and 4-20 mA signal stubs may be hidden from the process diagram.

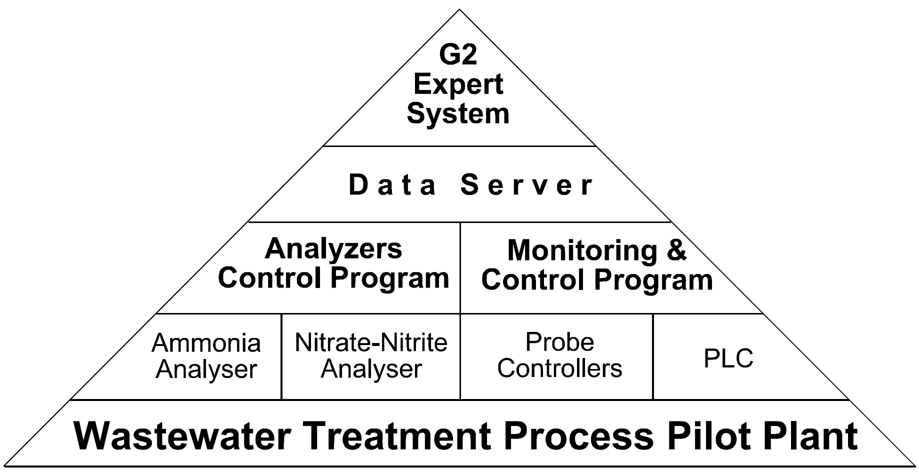

Figure 2. Outline of the distributed system for supervision and control

The ES is fed with online data generated by the plant using the data server. Qualitative data (odours, colours, microbiological observations data) and discrete data from off-line analyses (COD, SST, SSV, TKN, and SVI) are also sent to the ES. 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 ES 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.

RESULTS AND CONCLUSIONS

A set of rules and procedures to help fault detection, plant maintenance, and nitrification - denitrification cycle operation was implemented and validated at pilot scale. 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 online feature is an important innovation of this system, particularly for data monitoring and supervisor control. Recently, some papers appeared showing the promising potential for implementing online monitoring and control (Balslev *et al.*, 1996; Nielsen and Önnerth, 1996), though their knowledge integration is not as formal and versatile as KBES would require. 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, our KBES can be adapted to a new plant in a short time because of object-oriented design.

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