An overview of the posters presented at Watermatex 2000. II. Sensor/monitoring, control and decision support systems

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Abstract This paper gives an overview of the poster sessions on sensor/monitoring, control and decision support systems, as they have been presented during the Watermatex 2000 conference. The COST benchmark for the comparison of different control strategies has been analysed. Two different teams have performed research on the control of sewers to decrease combined sewer overflows. Extended methods for gauge monitoring accuracy are proposed. The use of adaptive controllers for improving control performance under varying process conditions is demonstrated in two applications. More advanced techniques for monitoring and control are also discussed. Applications are situated in the field of fault detection and control. Three posters on decision support systems have presented the methodology and architecture of specific applications. Rewarded posters are mentioned and have been selected for full paper publication in this issue of *Wat. Sci. Tech*.

Keywords Control; sensors; monitoring; decision support systems

Benchmark study

The COST 624 wastewater treatment benchmark is a simulation protocol defining a plant layout, simulation model, influent data, test procedures and evaluating criteria, allowing fair comparison of different control strategies.

Vrečko *et al.* (2000) (rewarded full paper publication) have performed a steady state analysis of the influences of influent and potential manipulated variables on the control performance. Steady state optimisation under different constant influents has resulted in an appropriate suggestion for manipulated variables, controlled variables and control strategies. Optimisation with typical dynamical influent data has revealed that quite good results can be achieved by setting the manipulated variables to constant optimal values.

Sewer systems

Gauge accuracy monitoring

Many calibrated models for sewer systems are largely dependent on gauge data. The output of these models is the basis for future network extension planning. Considering the large capital costs involved in the construction and extension of sewer networks, it is essential that the accuracy of the gauges and the models is consistent with the proposed expenditure. In order to ensure this accuracy, gauging contractors are submitted to audits several times a year. Up till now they have to comply with simple criteria: the data of the auditor is compared to the gauge data and the difference should not exceed a critical magnitude. This methodology is insufficient to distinguish between errors due to bias and errors due to lack of precision.

Within this scope Sparks and Kasmarik (2000) have described statistical tools, which have proven to be useful in improving gauge accuracy and to assess the competence of gauging contractors. They have used a linear regression model to fit the gauge data versus the data from the auditor: the regression line, an estimation of the standard deviation and the 95% prediction bands have been calculated. As a criterion for precision an upper bound

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for the standard deviation has been set, while bias can be expected when the 95% prediction interval does not contain the first bisector.

Control of combined sewers

Two teams have demonstrated the control of sewers to decrease combined sewer overflows (CSO). Campisano *et al.* (2000) have performed an optimisation study on the combined WWTP-sewer system at Trondheim-Høvringen, Norway. The aim to minimise CSO-discharge into the receiving water has been achieved introducing, upstream to the treatment plant, moveable regulators in the main intercepting tunnel, in order to activate in-line storage capacity. Duchesne *et al.* (2000) have found that total overflow volumes can be significantly decreased by allowing surcharged flow in the sewer. The optimisation strategy has been applied to the interceptor of the city of Laval, Canada.

There is clearly a need of specific models for control applications. In their present study, Campisano *et al.* (2000) have left the integrated SIMBA® sewer model, in which the De Saint Venant equations are approximated by a diffusive wave, zero order spatial discretisation and flow momentum and internal friction are not taken into account, and have replaced it by the fully dynamic FLUSS model. Comparison between the two models has shown differences when local and convective accelerations become significant due to energy transformation phenomena. Duchesne *et al.* have developed a simple hydraulic model to simulate all possible flow regimes in sewers, including backwater effects. Integration of this model into their operational control model SWIFT has led to the modification of the optimisation algorithm to allow surcharged flows in some parts of the controlled sewer, as long as constraints on maximum piezometric heads are respected. This model, which has a fast computational speed allowing its application in real time, has been integrated in a global predictive control strategy, considering actual and future states of the system to be controlled.

Adaptive controllers

Control of carbon dosing for denitrification

In order to perform efficient and economical carbon dosing to maximise nitrogen removal from a domestic wastewater through denitrification, Marsili-Libelli and Manzini (2000) have performed a study on the design of an adaptive controller. Two different kinds of controller structures have been considered: PI and Generalised-Minimum-Variance. Their performance has been tested through numerical simulations, for an enhanced ASM2 model with two-step nitrification and denitrification. The whole process has been approximated around the operating conditions by a linear time-invariant model, that is adapted as process conditions vary. Benchmark input files have been used. The rationale behind adaptive control in this case was not so much tracking precision as carbon saving and discharge limits compliance.

Control of DO-concentration in aeration basins

Adaptive control strategies seem well suited to overcome the problems in controlling the DO-concentration in a WWTP aeration basin. Yoo *et al.* (2000) (rewarded full paper publication) have presented an autotuning method for PID controllers, as this type of controller is simple and familiar to process operators. Closed-loop identification of the DO dynamics results in a high order model. This model is consequently reduced to a first or second order model plus delay that can be used for PID controller tuning. The procedure has been applied successfully to a full-scale coke WWTP.

Advanced techniques for monitoring and control

Wastewater treatment plants are complex MIMO systems, exhibiting a wide range of dynamic behaviours. Only a few and unreliable on-line analysers are currently available.

As a result, identification of abnormal process behaviour and consequent undertaking of suitable actions is often very difficult or even impossible with traditional techniques.

Detection of accidental perturbations in a wastewater treatment plant

Recently new methods have been introduced which are based on the data analysis of available online measurements. Polit *et al.* have studied four types of expert supervisory systems for the detection of faults in a WWTP.

A rule based expert system using qualitative representation of a set of reduced input measurements has been developed in order to deduce the situation for the plant and, if needed, to propose corrective actions. The response time of the expert system has appeared to be short enough for an automatic detection of accidental situations and is, consequently, a possible solution for implementing an automatic supervisor.

In a *data mining approach*, the LAMBDA classification technique has been applied. From a set of measured data, a set of classes is obtained by unsupervised learning. Then, the expert must map the set of classes to a set of physical states. When all data are classified in known states, all possible state sequencing paths are identified and supervised learning is applied to data on transitions, in order to obtain its transition function.

Using a multilayered feedforward *neural network* for diagnosis of the faults, it has been found that suitable signal processing becomes as essential for proper operation as the classifier itself. Indeed, performance has been enhanced by a principal component analysis stage before the classifier and subsequent postprocessing for false alarm rejection.

The identification of different scenarios from the data available on a wastewater treatment plant has also been approached as a dynamical classification problem, for which *learning machines* are a suitable methodology. Support vector machines have been chosen as an appropriate paradigm.

All four methods developed have been found able to detect most of the faults in the wastewater treatment plant and consequently form possible solutions for implementing an automatic supervisor.

Software sensors in anaerobic wastewater treatment

The inhibition of methanogenic bacteria is one of the main problems in the operation of anaerobic wastewater treatment plants. For wastewaters with considerable fluctuations in organic loadings and/or composition, process stability is a bottleneck for the application of anaerobic treatment. Aubrun *et al.* (2000) and Von Sachs *et al.* (2000) have developed software sensors for the detection and anticipation of fluctuating influents in anaerobic wastewater treatment. This type of sensor uses available on-line measurements, combined in state estimation techniques to estimate the unmeasured states.

Within this scope Von Sachs *et al.* have proposed a control strategy for a two stage anaerobic process which is favourable for the digestion of surfactants. In the first stage, the main organic loading and acidification proceed. Methanogenesis takes place in the second stage. Due to this separation, the VFA concentration can be easily measured by titration. The methane production has been forecast on the basis of the stoichiometry of the methanogenesis. Comparison between the actual and expected methane production can be used as an indication for the presence of inhibitory substances. The reactor has been controlled by a PI algorithm which uses the relative specific methane production rate as control variable and the dilution rate as manipulated variable. The control algorithm can manage both sharply falling and rising influent concentrations and inhibition by sodium . The controller adapts the dilution rate until the input loading rate re-equals the degradation rate of the organisms. When the addition of sodium stops, the reactor returns to the dilution rate applied before the presence of inhibitory substances. This approach can be a possible way

to handle wastewater containing inhibitory substances, e.g. detergents from textile industry for which the authors have planned future experiments.

Aubrun *et al.* (2000) (rewarded full paper publication) have designed a sensor for COD estimation in an anaerobic fluidised bed reactor. The aim of the software sensor has been set to predict a variation of the influent organic concentration around its nominal value, assuming no knowledge about this variation. Flow rate, pH and temperature have been used as measured input variables, and the methane production and pH as measured output variables in order to predict the substrate concentration in the influent. The reconstruction filter has exhibited good performance and the estimation error has remained within acceptable limits. Consequently, this software sensor can be incorporated within monitoring and supervision systems.

Controlling an anaerobic fermentation system

One of the main advantages of techniques such as neural networks is that they do not require any prior knowledge about the structure of the relationships existing between key variables and can thus also be used when classical mathematical modelling is impossible or only after strong simplification. Holubar *et al.* have demonstrated that the anaerobic digestion of surplus sludge can be effectively modelled by means of a hierarchical system of neural networks. With this model, the gas production and composition can be made several time-steps in advance to predict and avoid shock-load. The trained networks have been used in an optimisation algorithm to find out which is the best loading rate pattern for the next time steps.

Decision support systems

Decision support systems are computer-based tools, an organised system of people, procedures, software, databases and devices, to support human decision-making. Decision support systems are being developed in a broad field of applications. During the poster session on decision support systems three applications were presented. Some important features of the different decision support systems are outlined for the different applications. The required integrated approach to the problem, system analysis, model development and methodology is presented.

Identification of sustainable treatment options for domestic wastewater

Balkema *et al.* (2000) (rewarded full paper publication) have introduced a model based decision support tool for the identification of sustainable treatment options for domestic wastewater. In order to enable decision makers to select sustainable wastewater treatment systems, insight into the sustainability of a wide variety of systems has to be provided in a transparent way, leaving room for adaptation and interpretation according to the local situation. A structured methodology for the comparison of a wide variety of wastewater systems using a multi-disciplinary set of sustainability indicators, including technical, economic, environmental and socio-cultural aspects, has been defined. The poster describes the goal and scope of the research (setting the system boundaries and selecting the sustainability indicators), the outlines of the inventory analysis (defining the superstructure that forms the modelling framework) and the optimisation (integer programming using the weighted sum of the sustainability indicators as objective function).

Integrated river quality management

Cianchi *et al.* (2000) have presented the use of internet technologies for integrated river quality management. The co-ordinated approach which imposes river stream – rather than discharge – standards requires the availability of an integrated information system through

which all the different authorities can co-operate. This is not a simple problem. The solution which is envisaged in this paper is based on a new internet-based information system where models and control modules can be shared among several users. The poster shows how this information system is organised in order to cater for the needs of all possible management levels.

In addition to a user-friendly graphical interface for developing the required configuration the system can have different features for different types of users depending on their function in the administration of the river system and the controlled discharges. The interaction with the system is through a normal webbrowser. The proposed system provides a knowledge-based core system where models can be defined and assembled using a components palette. The models can include the main components of a typical WWTP and a number of ancillary functions (measuring points and actuators). The system functions are performed by agents, specialised software modules which can migrate over the network and activate the tasks for which they are designed. The system is conceived to operate as a comprehensive water quality management tool, with tasks ranging form database management to system modelling and control design, in order to provide a full decision support system. The graphical user interface assists in defining the system structure, depending on the application, and the agent-based structure decomposes, interprets and executes the resulting commands.

Integral approach to watershed management

Knezic *et al.* (2000) have shown how integrated approach, system analysis and multicriteria decision making help stakeholders and politicians to evaluate management strategies for watershed management. The objective of water resources management is to harness all resources in the best possible way in order to achieve the best results. The complex environmental, social and economic conditions demand that the problem is solved considering a larger number of alternative solutions with different technical and technological characteristics, as well as socio-economic and environmental impacts. The methodology for solving this complex watershed management problem relies on the paradigm "Pressure – State – Impact – Response". The recognition of the functions and processes that define pressure, state, impact and response should be done in a systematic and comprehensive way to ensure that nothing is missed.

Objective definition, alternative and criteria evaluation are very important facilities for the process of strategy management planning and strong attention has to be paid to include all stakeholders in the decision making process. All these facilities are assembled by multicriteria decision making. The presented decision support tools has shown the ability to tackle such complex problems.

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