# EUNITE Case Studies

EUNITE, the **Eu**ropean **N**etwork on **I**ntelligent **Te**chnologies for *Smart Adaptive Systems* started January 1st, 2001. Its targets were to join forces within the area of Intelligent Technologies for better understanding of the potential of hybrid systems and to provide guidelines for exploiting their practical implementations and particularly, to foster synergies that contribute towards building *Smart Adaptive Systems* implemented in industry as well as in other sectors of the economy.

The Roadmap work in EUNITE started by collecting several Case Studies from its Committees. Following materials can be downloaded here:

**WDS Case Study by Bogdan Gabrys, 18.07.2002**

**Adaptive Fuzzy Control of a Rotary Dryer by K. Leiviska, 26.06.2001**

**Fuzzy Quality Control of a TMP Plant by K. Leiviska, 26.06.2001**

**Intelligent Control of a Rotary Kiln by K. Leiviska, 26.06.2001**

**Econometric and fuzzy models for the forecast of demand in the airport of Rhodes by J. Z. Hernández, 27.11.2001**

**Installation and experiences of field testing a fuzzy signal controller by J. Z. Hernández, 27.11.2001**

**Opportunistic planning for a fleet of transportation robots by J. Z. Hernández, 27.11.2001**

**Reflective knowledge models to support an advanced HCI for decision management by J. Z. Hernández, 27.11.2001**

**Using a multi-agent approach to optimise the train coupling and sharing system by J. Z. Hernández, 27.11.2001**

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**Genetic Optimisation of Adaptive and Intelligent Controllers by D A Linkens et al., 29.11.2001**

**Hierarchical Intelligent Control of Unconsciousness by D A Linkens et al., 29.11.2002**

**Smart Adaptive Control of Muscle Relaxation by D A Linkens et al., 29.11.2001**

**Supervisory Self-Organising Control of Relaxant Anaesthesia by D A Linkens et al., 29.11.2001**

**Industry Foresight with Scenario and Scanning Agents by Christer Carlsson**

**Taming the Bullwhip Effect with Fuzzy Optimisation Methods by Christer Carlsson**

**Real Options Theory and the Handling of Giga-investments by Christer Carlsson**

**Fuzzy Real Options Theory and the Handling of Giga-investments by Christer Carlsson**

**Advanced Vendor Evaluation by Martin Nelke**

**An Intelligent Adaptive Controller for Bioreactors by Robert Babuska, 11.12.2001**

**Fuzzy Supervised PID Control of a Flow Rate Process by Mariagrazia Dotoli, 30.11.2001**

# Neuro-fuzzy approach to diagnosis of leakages and other operational faults in water distribution networks.

*Submitted by Bogdan Gabrys* 18.07.2002, IM

## Problem

A lot of time, effort and resources is dedicated to purifying water but surprisingly high percentage of treated water is wasted through leakages in the water distribution networks (WDN) before even reaching customers. The occurrence of other operational faults like blocked pipes or erroneous states of valves etc. can also cause serious disruption in the services which need to be avoided. It is therefore very important that the state of the distribution system is continuously monitored. Unfortunately, due to financial constraints, it is not practical to measure all variables of interest and limited number of measurements are used together with WDN topology information to calculate the state of the WDN through state estimation procedures. Due to the scale of distribution systems an interpretation of the state can be quite a difficult task even for experienced system operators. Additionally if the so called topological error (e.g. leakage) occurs, the state estimation procedure usually results in a set of errors scattered across the network, making the diagnosis of the cause of the errors even more difficult. Though sequential analysis of precise numerical results of state estimation is useful, it also tends to ignore the greater picture of the overall system state which is something that experienced human operators primarily focus their attention on before analysing the detail. Therefore a neuro-fuzzy approach, thought to be mimicking the information processing and abstraction forming by human operators, has been proposed as a solution to this problem.

## Solution

A neuro-fuzzy pattern recognition approach to fault detection and identification based on the examination of patterns of state estimates has been proposed to solve the problem. A General Fuzzy Min-Max (GFMM) neural network for clustering and classification has been used as a main building block in the developed recognition system. This hyperbox fuzzy sets based method has been designed to be able to process inputs in a form of confidence (real value) intervals, learn on-line, grow to meet the demands of the problem and include new information without need for retraining of the whole system, and cope with labelled and unlabelled data reflecting the fact that some of the network states are known (i.e. normal operating state etc.) while others are not. To improve the efficiency of the learning process and adaptability, the diagnostic system has been designed as a two-level hierarchical system. The first level consists of a GFMM neural network which selects one of the n second level "experts" (implemented using GFMM NN as well). In terms of water distribution systems the purpose of the first level of this recognition system is to distinguish different typical behaviour of the water system (i.e. night load, peak load etc.) while the second level components are responsible for the detection of anomalies for some characteristic load patterns. The second level can be, therefore, viewed as a collection of "load-pattern-experts".

## Status and results

The system has been implemented in Matlab and extensive simulation study have been conducted in which the two-level neuro-fuzzy recognition system has been trained and tested using data covering a 24-h period of operation of a realistic water distribution network. A set of 9144 training set representing 39 categories have been initially used. The 39 categories represented a normal operating state and leakages in 38 pipes of the network.The results have been tested on a separate testing set consisting of 91440 representing a mixture of normal operation and leakages (ranging from 0.002 to 0.029m^3/s) in all pipes of the network. The ability of GFMM to produce a graded response has been found invaluable in the process of restricting the area where the fault occurred if not enough accurate measurements are available to pinpoint the location of the leakage to a single pipe.The system has been also successfully tested for its ability to include information about new types of faults while in operation. The system which has been trained to recognise one type of anomaly (i.e. leakages) has been able to include new classes of operational faults (i.e. representing wrong status of valves and pipe blockages) utilising the GFMM ability to grow and adapt while in operation.

## Adaptivity and portability

The adaptivity is an essential feature of the developed system. It can expand to include new information, has ability to adapt the parameters (hyperbox fuzzy sets) on-line and the hierarchical representation makes the approach even more flexible. Within the proposed two-level framework, distinctive variations in typical water network behaviour for different days of the week or seasons of the year can be quite easily accommodated by adding (removing) of the second layer experts and expanding (shrinking) the first layer network accordingly. Since the GFMM has been developed as a general purpose pattern classification/clustering approach it can be (and has been) applied to a number of different problems from different domains without any need for modifications making it also quite portable.

## More information

Gabrys B. and Bargiela A., Neural Networks Based Decision Support in Presence of Uncertainties, ASCE J. of Water Resources Planning and Management, Vol. 125, No. 5, pp. 272-280, 1999.

Gabrys B. and Bargiela A., General Fuzzy Min-Max Neural Network for Clustering and Classification, IEEE Transactions on Neural Networks, Vol. 11, No. 3, pp. 769-783, 2000.

Gabrys, B., "Agglomerative Learning Algorithms for General Fuzzy Min-Max Neural Network", a special issue of the Journal of VLSI Signal Processing Systems entitled "Advances in Neural Networks for Signal Processing", Vol. 32, No. 1/2, pp. 67-82., August-September 2002

Gabrys, B., "Neuro-Fuzzy Approach to Processing Inputs with Missing Values in Pattern Recognition Problems", International Journal of Approximate Reasoning, in press, 2002

# Adaptive Fuzzy Control of a Rotary Dryer

*Submitted by K. Leiviska,* 26.06.2001, IBA A

## Problem

To control a rotary dryer is difficult due to the long, and also varying, time delays involved. Accidental variations in the input variables as in the moisture content, temperature or flow of the solids will disturb the process for long periods of time, until they are observed in the output variables, especially in the output moisture content. Therefore, pure feedback control is inadequate for keeping the most important variable to be controlled, the output moisture content of the solids, at its target value with acceptable variations. Also the development of model-based control systems has proved difficult and time consuming due to the complexity of the process. Increasing demands for uniform product quality and for economic and environmental aspects have necessitated improvements in dryer control. Interest has been shown in recent years in intelligent control systems based on expert systems, fuzzy logic or neural nets for eliminating process disturbances at an early stage. These systems add another dimension to the control of a drying process, the human element.

## Solution

In Control Engineering Laboratory, University of Oulu, several methods for the rotary dryer control have been studied: conventional PI control, model-based cascade control, fuzzy control, and neural network control. Also two types of hybrid controllers where fuzzy logic and neural nets have been connected with PI control have been introduced.

Lately, three different fuzzy adaptive controllers methods were tested for the dryer control. The first method was based on the previously applied hydrid PI-FLC controller with a simple gain adjusting approach. The output scaling factor is adjusted based on the experimentally defined rule base and membership functions. Good results were achieved and the controller performance was clearly improved. The second method introduced a fuzzy PI-controller and adjusting all scaling factors; for both inputs and the output. Results were not so encouraging, probably because of the fact that both the controller and the tuning part utilised rule bases and membership functions taken from the literature. The third approach was a simple procedure for tuning normal PI-controller with a fuzzy tuner. Once again, the adaptive controller performed better than the original one.

## Status and results

Hybrid methods have been tested in the pilot-scale rotary dryer and adaptive controllers by simulation in Matlab environment. Adaptive methods improve the controller performance from some percents up to 50%, as measured by IEA and ITAE indices.

## Adaptivity and portability

Tested controllers are adaptive fuzzy type. The are no commercial applications, so portability cannot be discussed.

## More information

Leena Yliniemi, Adaptive Fuzzy Control of a Rotary Dryer, In: Industrial Applications of Soft Computing (K. Leiviska, Ed.). Studies in Fuzziness and Soft Computing, Vol. 71, Springer Verlag, 2001.

# Fuzzy Quality Control of a TMP Plant

*Submitted by K. Leiviska,* 26.06.2001, IBA A

## Problem

The quality control in a TMP plant (maintaining freeness and fibre length at optimum levels) has to cope with two different kinds of disturbances: slowly proceeding wearing of refiner plates and faster variations in raw material quality. Information about the pulp quality is usually obtained from laboratory testing of pulp or finished paper samples, so this information is a few hours old and therefore of no use for real-time control. Also, delays in on-line freeness and fibre length measurements have limited the use of automatic on-line quality control.

Generally, refiner control systems are based on the principle that freeness is directly related to specific energy consumption in the process. Motor load usually controls this. The strategy presented here is based on the fact that the refining consistency is another key variable in the TMP-plant control because it affects on how energy is transferred to fibres. When the consistency and motor load are stabilised there exists a good basis for the actual quality control of the TMP-plant. In this case it is done using conventional adaptive controllers.

## Solution

The fuzzy quality control is based on on-line measurements of freeness, fibre length and consistency. The fuzzy quality controller works as a master controller adjusting the set points of the motor loads and primary stage consistency. Inputs are the difference between the freeness set point and measurement, consistency set point and mean fibre length measurement. The consistency set point is used as a control input instead of the measurement, because the actual consistency always includes short-term fluctuations around the set point and therefore may cause some unnecessary output changes.

The fuzzy quality controller has been implemented in the mill's automation system using standard fuzzy controller toolbox available in the system. Minimum-maximum method was used in inference and singletons were used for outputs. The controller has been tuned based on experience and also a test simulator was used. The controller has been tuned so that the main control variable is the fibre length. Therefore, the freeness level is allowed to increase, when the motor load control opens the plate position more than the consistency controller requests.

## Status and results

The fuzzy quality controller was implemented as a part of AutoTMP control system at four refiner lines at Holmen Paper, Hallstavik mill in Sweden. The control system features the TCA consistency measurement in the blow line. Based on it, the refining consistency and motor load are controlled using adaptive control methods. The fuzzy control strategy maintains the fibre length at an acceptable level and the freeness is controlled to be on a target level.

Operator confidence in the control system has been very high; 95-100 % uptime for the consistency and motor load controls and over 90 % uptime for the fuzzy quality controls have been experienced. The six months follow-up period proved a 20-50 % decrease in the standard deviations of the key quality and process variables.

## Adaptivity and portability

The quality controller is an intelligent supervisory controller without adaptive features. It is a part of a commercial control system and using it in another application requires usual fuzzy controller tuning.

## More information

Jaakko Myllyneva, Lennart Karlsson, Ismo Joensuu, Fuzzy Quality Control of a TMP Plant. In: Industrial Applications of Soft Computing (K. Leiviska, Ed.). Studies in Fuzziness and Soft Computing, Vol. 71, Springer Verlag, 2001.

# Intelligent Control of a Rotary Kiln

*Submitted by K. Leiviska,* 26.06.2001, IBA A

## Problem

The lime kiln process is inherently difficult to operate efficiently because of complex dynamics and multi-variable process with non-linear reaction kinetics, and long time delays. During its operation many interconnected variables must be considered and control actions must be designed to meet multiple and sometimes conflicting objects, and changing operating conditions. Some measurements are unreliable, and the kiln characteristics may change during a long run. The operation may also be upset by disturbances such as changes in the composition and/or properties of the lime mud. In addition, certain process variables must be maintained within predefined constraints in order to assure the safe operation.

## Solution

The kiln process has been extensively studied at the Wisaforest mill. A kiln control system based on fuzzy logic was developed already during 1993. Encouraged by good results, the research was continued with the main emphasis on applying a novel linguistic-equation approach for fuzzy modelling and simulation of the kiln process. The original knowledge-based fuzzy system was modified in order to take into account supervisory control and adaptation to changing operating conditions.

The LECont concept was implemented in G2. The compact system corresponds to a three-level cascaded controller:

- The basic PI type LE controller handles the normal operation with symmetrical membership definitions.
- The operation condition controller changes the control surface of the basic LE controller by modifying the membership definitions for the change of control variable $\Delta$ u.
- The predictive LE controller changes the membership definitions for the derivative of the error $\Delta$ e. This level contains both the braking and asymmetrical actions.

Neural networks are used in defining the set points for the control loops.

## Status and results

The system has been in continuous operation since the beginning of 1999. According to the statistics, the mean value of excess oxygen has been reduced by about 15% and the quartile range has been reduced by more than 20%. The mean value of the hot-end temperature has been reduced by nearly 40°C and the quartile range and the standard deviation have declined by nearly 50% and more than 30%, respectively. The mean of the specific heat energy consumption (5.5 GJ/$t_{CaO}$) was nearly 7% lower than the respective value during manual operation and a decrease of over 10% in total reduced sulphur (TRS) emissions and a reduction of about 50% in the proportion of high emission periods were recorded.

## Adaptivity and portability

A basic linguistic equation controller corresponds to a normal FLC. The strength of actions is

controlled by working point models, which could be considered as gain scheduling algorithms using a specific LE structure. The braking and asymmetrical actions correspond to predictive switching control. The use of the system in other kilns requires the tuning of models and controllers.

## More information

E. Juuso, M. Jarvensivu, O. Ahava, 2001,Intelligent Supervisory Control of an Industrial Rotary Kiln. In: Industrial Applications of Soft Computing (K. Leiviska, Ed.). Studies in Fuzziness and Soft Computing, Vol. 71, Springer Verlag,.

# Econometric and fuzzy models for the forecast of demand in the airport of Rhodes

*Submitted by Josefa Z. Hernández* 27.11.2001, IBA B

## Problem

A civil aviation authority requires demand forecasts at many levels for planning and other purposes. At the strategic level, forecasts are required for long-term planning over time periods of 10-20 years. More detailed forecast, but over a similar time span, are required for mayor investment projects such as the expansions of terminals and runways. By contrast, the medium-range analysis, 3-10 years ahead, is needed for the annual planning of the aviation authority. The most difficult part is the selection of the relevant causal variables to be taken into account in forecasting and the specification of the type of functional relationship existing between the dependent and independent variables.

## Solution

At the Section of Transportation, in the Democritus Thrace University (Greece), a fuzzy regression analysis for the forecasting of the airport demand has been used. Instead of probability functions of other forecasting methods, the function of the relationship between the variables can be seen as possibility functions. The fuzzy linear regression model becomes a possibilistic one, that can be used in the context of possibilistic theory to provide a new methodology for capturing the vague and incomplete knowledge by means of possibility distributions.

In fuzzy linear regression models, the difference between data and estimated values is assumed to form an ambiguity that is due the system's structure. Moreover, the proposed model seeks to bring the ambiguity of the relationship back to the system coefficients and offers one way to construct an accurate relationship which enters directly in the model through fuzzy coefficients.

## Status and results

This fuzzy method of forecasting airport demand has taken into account the airport of Rhodes as a case study. Moreover it was used conventional regression methods, but this approach, ignores significant changes that may occur in import explanatory variables that drive demand, however the limits of the fuzzy regression depend on the unpredictable events which affect demand. In the case of the airport of Rhodes, such an unpredictable event was de War in the Persian Gulf in 1991, that contained the upward growth of demand at the airport.

The accuracy of prediction proves to be satisfactory. However, it is never possible to fully predict human behaviour.

## Adaptivity and portability

Thanks to the fuzzy techniques the vague and the incomplete knowledge can be captured.

## More information

V.A. Profillidis / Journal of Air Transport Management 6 (2000) 95-100

# Installation and experiences of field testing a fuzzy signal controller

*Submitted by Josefa Z. Hernández* 27.11.2001, IBA B

## Problem

Signal controllers at real intersections of different road or streets have different things to realise: (i) the high volumes of traffic during peak hours, (ii) pedestrian's crossings, (iii) bus traffic, etc. Some of the items of a good controller are: (1) Vehicles don't have to wait a lot of time at the intersection in order to there won't be long queues, (2) Pedestrian's waiting times have to be shorter and (3) Bus's travel times don't have to be increased.

## Solution

At the Helsinki University of Technology, a fuzzy signal controller has been used at a real intersection with two different algorithms: a normal fuzzy (Fu) and a multi-objective fuzzy (Fm). The Fm algorithm was designed for safety and environmental aspects as well as efficient flow, whereas the Fu algorithm only considered the traffic fluency. The fuzzy-control algorithm works at two levels. The upper level classifies the traffic situation in oversaturated, normal or low-demands conditions. The lower level adjusts the green and cycles time.

## Status and results

The fuzzy signal controller was installed in a real intersection. Results were based on simulations and field measurements, and both indicated that the fuzzy controller was very competitive against traditional vehicle-actuated control, if traffic volumes were higher than low-demand. Some of the advantages of the fuzzy-signal controller were: the average delays were approximately 3-8 seconds shorter, the percentages of stops were 2-12% lower, the bus delays were smaller in 8/9 cases, and there were good savings in fuel and emissions. However, the better traffic fluency was only one advantage. Pedestrians can also benefit; because the cycle time was on average 8 seconds shorter.

## Adaptivity and portability

One of the benefits of the fuzzy logic lies in its ability to handle linguistic information by representing its as a fuzzy set. Changing these fuzzy sets and the fuzzy rules this controller can use for different intersection which different traffic conditions.

## More information

J. Niittymäky. European Journal of Operational Research 131 (2001) 273-281

# Opportunistic planning for a fleet of transportation robots

*Submitted by Josefa Z. Hernández* 27.11.2001, IBA B

## Problem

The Dynamic Transportation-Planning Problem (DTPP) embodies a class of real-world applications that involve the reactive routing and scheduling of a fleet of taxi vehicles in an urban road network in response to dynamically changing transportation demands. The complexity associated with dynamic transportation problems is enormous. Therefore there are a lot of constraints such as time windows, deadlines, carrier capacities, trip duration, resource optimisation, and moreover there can be unpredictable events like traffic situations, weather conditions and vehicle breakdowns between others.

## Solution

In the Intelligent Systems Laboratory, at the Nanyang Technological University, an intelligent transportation planning system (ITPS) has been developed using a heuristic solution. This solution is a combination of a constructive method realised by a blackboard system architecture with an iterative method supported by a truth-maintenance system. It comprises both traffic simulation and vehicle locomotion models and various monitoring and problem-solving strategies. In particular, dynamic vehicle assignment and routing strategies are employed to construct and deploy plans in response to changes in the traffic conditions and new passenger request. For the routing strategies include iterative deepening depth-first and A* search algorithms.

## Status and results

It has been developed simulation software only. Experiments using randomly generated road networks and traffic conditions show the effectiveness of the proposed approach, as the dynamic strategy realised performs better than classic approaches in terms of average passenger service rate, waiting time, and travel time. The drawback is an unavoidable increase in computational time due to the implementation complexity of the blackboard approach.

## Adaptivity and portability

For the ITPS to be scalable and thus usable in real-world applications, more efficient dynamic routing algorithms (such as iterative, real-time A* search) must be incorporated. Also, the actual implementation of the ITPS using intelligent electric vehicles will require other issues to be solved efficiently and reliably, especially the navigation and communication aspects of the system.

## More information

M. Pasquier et al. Engineering Applications of Artificial Intelligence 14 (2001) 329-340

# Reflective knowledge models to support an advanced HCI for decision management

*Submitted by Josefa Z. Hernández* 27.11.2001, IBA B

## Problem

A good communication between human and computer is essential in a lot of computer systems. This issue is especially relevant in real-time management scenarios where the system is intended to provide an intelligent support to human operators in the decision-making task. This type of decision support systems should be capable of warning the operators of any undesired evolution of the installation and recommending adequate control decision that maximise the efficiency of the installation behaviour and minimise the negative impact of the observed problems. As the operators have to assume the system recommendation as their own, it is necessary that the decision support system provides a communicative platform close enough the information needs of the operators that explains its proposals using reasoning schemes and concepts operator are familiar with.

## Solution

The Intelligent System Group (ISYS), at the Technical University of Madrid, proposed a new concept of intelligent interface. This intelligent interface is supported by a knowledge-based architecture joined to a user-system dialogue-based interaction model. In a intelligent interface, the way of generating the answer to the user's question responds not only to the criteria regarding the availability of knowledge necessary to reason but also to aspects related to the way of presenting these answers according to characteristics of the user and the interaction context. The central element in the design is the specification of the conversation model to support the user-system communication, that may require the definition of the particular instances of the questions considered according to the characteristics of the problem domain and the requirements of the potential users.

To support this conversational model it has been developed a general architecture with four main components are distinguished: a problem solving medium, composed of a structured collection of basic problem solvers responsible of producing the corresponding answers, a conversation manager, whose goal is to decide the appropriate way to solve problems according to the needs of the conversation, a memory manager, responsible of keeping a consistent set of system beliefs through truth maintenance mechanisms and a presentation manager specialised in the input-output activities of the system.

## Status and results

The approach was developed for an application in the domain of private traffic for the city of Turin. The tool for private traffic management may play the role of an automatic assistant for supervising the state of the traffic network and the operation of the units responsible for automatically and dynamically regulating the traffic lights in the intersections of the traffic network. This application was tested, showing the feasibility of the intelligent interfaces approach to support highly interactive decision support system.

## Adaptivity and portability

Only adding new problem solvers, if its necessary, and changing the conversational model, the system can be used for other application of control decision support in traffic management field.

## More information

J.Z Hernández, J.M. Serrano. Expert Systems with Applications 19 (2000) 289-304.

# Using a multi-agent approach to optimise the train coupling and sharing system

*Submitted by Josefa Z. Hernández* 27.11.2001, IBA B

## Problem

The problem consists of scheduling a given set of transportation tasks in a railway network reducing the cost. Each task is specified as a tuple consisting of the origin and the destination node; the earliest possible departure time, the latest allowable arrival time and an additional time stamp indicating when the task is announced to the system. To reduce the track allocation cost and to increase the capacity of tracks, different modules are coupled together and uncoupled. This allows the joint use of the train paths by the formed module-sets for the track allocation price near by one module.

## Solution

In the Institute of Transport, Railway Construction and Operation, at the University of Hannover, a multi-agent system approach has been used for the innovative train coupling and sharing system (TCS). It has been used an incremental planning approach that takes incomplete task specifications into account and uses the contract-net protocol to obtain a initial plan. Then, a post-optimisation of the initial solution is achieved by means of the simulated trading protocol. The plan execution-monitoring unit of the agent, which dynamically reacts to external events and which can initiate a revision of the actual plan of the agent, draws the link between the agents planning unit and the external world.

The agents in the TCS/MAS-system are based on the architecture for the integration of reactive behaviour and rational planning (InteRRaP), which was developed at the DFKI. The goal of this kind of architecture is the combination of reactive and planned performance. Agent architecture with these kinds of attributes is also called “hybrid architecture”. These kinds of agents can carry out simple actions on demand (reactive behaviour), plan complex actions on the basis of their base knowledge alone (planned behaviour) and co-operate with other agents (co-operative behaviour).

## Status and results

In the current version of the system, an abstracted map of the German railroad network with approximately 250 nodes and 350 links has been used. In the simulation process, the results of three different optimisation levels were compared. The first one, without optimisation (without coupling and sharing process) and then with minimal sharing length requirement (100 and 200 km). The results were better when it was permitted coupled and sharing with the minimal sharing length, since this minimal sharing length prevents same unions to commit them to sharing partners with low cost-saving potential (i.e. with only a short common path) to early. These early commitments, made in the case where the minimal sharing length exits, make impossible for the units to benefit from better sharing peers that occur later within the integration process because they cannot satisfy the additional constraints and thus have to reject route sharing.

## Adaptivity and portability

The main idea of multi-agent system is to generate approximate solutions to very complex problems by distributing then to autonomous problem solvers (agents). These agents would be able to solve local problems by themselves. By integrating the agents in a communication environment, they are able to find a solution for the whole problem in co-operating with each other. These autonomous problem solvers can be used in a lot of problems and can be reused for other problems of scheduling.

## More information

J. Böcker et al. European Journal of Operational Research 134 (2001) 242-252

# Adaptive and Intelligent Control for Multivariable Anaesthesia

*Submitted by D A Linkens with M Mahfouf and M F Abbod,29.11.2001,IBA D*

## Problem

Balanced anaesthesia management in the operating theatre requires regulation of drugs to control depth of anaesthesia (unconsciousness),analgesia (pain relief) and relaxation (muscle paralysis for surgical efficiency and patient benefit).In theatre, pain relief is managed manually via open-loop assessment, since it cannot be measured in an unconscious patient. In contrast, relaxant and hypnotic drug effects can be monitored and their interactions controlled via feedback. Muscle relaxation can be monitored via neuromuscular stimulation at the hand, while unconsciousness can be inferred via blood pressure (particularly when using intravenous propofol).The challenge is to design a multivariable controller which allows for drug interactions and inter and intra-patient variability.

## Solution

Both classical Generalised Predictive Control (GPC) and Self-Organising Fuzzy Logic Control (SOFLC) schemes have been investigated. The simulations have necessitated careful model elicitation (particularly for cross-coupling dynamics) for the combined use of propofol and atracurium. GPC uses an internal model for its control algorithm calculation at each time step, while SOFLC uses exploratory movements in the closed-loop system to refine its rule-base iteratively (ie. adaptively).Clinical trials have been undertaken for the GPC scheme, using a population average model for the internal calculations for control action.

## Status and results

The GPC and SOFLC approaches have been evaluated in a comparative simulation study. Generally, GPC gave a smoother performance with less control actuator activity, but at the expense of having to know considerable detail of the process dynamics. The SOFLC gave more active control signals, and in several cases approached limit cycle conditions. The scaling factors required careful adjustment, while a second experimental run was necessary to refine the rule base. This is not surprising since the rule base was initially set to zero. The steady state performance of GPC tended to be superior to that of SOFLC.

## Adaptivity and portability

The multivariable SOFLC scheme achieves Level 1 adaptivity in the EUNITE definition since it can cater for disturbances in the environment (mostly in the patient in this case) by self-adjustment of its rule base. Potentially, it could achieve Level 2 by commencing on-line control using a rule base for alternative drugs, but this has not been tested. More ambitiously, Level 3 can be attempted via initialisation from a zero rule base, but simulations have shown that this will require cautious and very slow adaptation i.e. long exploratory runs.

## More information

Further details are in:

M Mahfouf and M F Abbod, ”A comparative study of generalised predictive control (GPC) and intelligent self-organising fuzzy logic control (SOFLC) for multivariable anaesthesia”, in “Intelligent Control in Biomedicine”, ed. D A Linkens, Taylor and Francis,1994,pp79-132.

# Decision Support for Artificial Ventilator Management via Adaptive Modelling

*Submitted by D A Linkens with H F Kwok, M Mahfouf and G Mills,29.11.2001,IBA D*

## Problem

In hospital Intensive Care Units (ICU) the management of artificial ventilators is an important and routine requirement which absorbs much anaesthetist and nursing time. A computer-based decision-support system offers potential advantages, and particularly when the patient is being weaned from the ventilator to their own spontaneous breathing. Patient-specific models (either quantitative or qualitative) are necessary for such decision-support tools. The ventilator control variables are the inspired oxygen level, the tidal volume, respiratory rate, peak pressures and the mode of ventilation. The decisions are based on measurements of blood gases (via sampling), pH, and respiratory mechanics (e.g. lung resistance and compliance).

## Solution

A detailed lung model for blood gas dynamics called SOPAVent is the basis for the decision-support advice. It has been validated against clinical data for a range of patient lung abnormalities. To make the model patient-specific requires the on-line estimation of two particular parameters, being dead-space and shunt, since they have both intra and inter patient variability. To provide on-line advice it is necessary to have a method of parameter prediction which is not dependent on blood sampling and subsequent analysis. For shunt estimation it has been shown that there is good correlation between it and a hypoxaemia index, called the respiratory index (RI) which is the ratio of the alveolar-arterial oxygen difference to the arterial oxygen tension. This can be measured on-line. For estimation of the dead-space, a similar index based on carbon dioxide measurements is being investigated.

## Status and results

The shunt estimator has been validated against 9 patients in an ICU database, with 117 sets of blood gas measurement. A similar approach is being used for dead-space estimation. However, there will always be some error between the adapted SPOAVent model and the specific patient. To adjust for this discrepancy, a grey-box model is being constructed which incorporates a black-box dynamic model in parallel with the physiologically-based SOPAVent model. This will be based on population average discrepancy data, thus leaving the adaptivity in the shunt and dead-space on-line adjustment.

## Adaptivity and portability

This system achieves Level 1 adaptivity in the EUNITE definition since it allows for disturbances to patient characteristics and subsequent alterations in the decision-support advice. It may become Level 2 adaptable if the SPOAVent model can be made adjustable to various abnormal lung conditions, such as pneumonia and ARDS (Accute Respiratory Distress Syndrome).

## More information

Further details are given in:

H F Kwok D A Linkens, M Mahfouf and G Mills, ”An adaptive approach to respiratory shunt estimation for decision-support in ICU”,EUNITE 2001,Annual Symposium on “Intelligent Technologies, Hybrid Systems and their Implementation in Smart Adaptive Systems”,Tenerife,13 &14 December 2002.

# Genetic Optimisation of Adaptive and Intelligent Controllers

*Submitted by D A Linkens with M Mahfouf and M F Abbod,29.11.2001,IBA D*

## Problem

All control algorithms have parameters which require adjustment to suit the application. Classical PID control needs tuning of its 3 parameters. More advanced techniques have their own internal parameters which adjust the structures to give suitable oerformance. This is true for classical self-adaptive systems, such as those based on Model Predictive Control (e.g. GPC) and intelligent systems (eg SOFLC due to Procyk and Mamdani).To optimise these parameters manually is a daunting and time-consuming task. Thus, Genetic Algorithms(GA) are proposed as a means to achieve acceptable settings of the internal design parameters.

## Solution

Multi-objective GA techniques have been applied to both GPC and SOFLC internal parameter selection. The GPC parameters are the prediction horizon, the control horizon and the filter polynomial. The SOFLC objective was a reduction in the number of rules commensurate with the reference trajectory properties of the basic PI table. The multi-objectives chosen were a range of performance criteria such as IAE (Integral Absolute Error),ITAE (Integral of Time and Absolute Error) and ICE (Integral Control Effort).Instead of the common Pareto ranking approach, a fuzzy-based ranking technique was employed.

## Status and results

The fuzzy ranking GA achieved satisfactory tuning performance for either the classical adaptive GPC or the intelligent SOFLC scheme. The technique was validated on a challenging anaesthetic problem involving linear pharmacokinetics and highly nonlinear pharmacodynamics.

## Adaptivity and portability

This case study is a hybrid, integrated example which utilises fuzzy reasoning within multi-objective genetic optimisation applied to adaptive, intelligent control. Portability would require an adequate model of the new process being studied.

## More information

Further details are given in:

M Mahfouf, D A Linkens and M F Abbod,(2000),"Multi-objective genetic optimisation of GPC and SOFLC tuning parameters using a fuzzy-based ranking method.", IEE Proc., Control Theory Appl.,127,pp344-353.

# Hierarchical Intelligent Control of Unconsciousness

*Submitted by D A Linkens with J S Shieh,29.11.2002,IBA D*

## Problem

The control of patient unconsciousness during surgical procedures is an extremely challenging task for anaesthetists. Not only is measurement a major problem, but also a rigorous definition of unconsciousness is very difficult. However, human anaesthetists are able to perform this task in routine conditions. The challenge is to produce a computer-based system which will regulate unconsciousness under normal conditions, with the anaesthetist being able to concentrate on the really life-threatening emergency situations which can arise. The system must be capable of utilising a range of inferential measurements (as surrogates for unconsciousness) and be adaptable for a wide range of patient conditions.

## Solution

A multi-layer hierarchical architecture has been developed for either intravenous infusion (using the liquid drug propofol) or inhalational breathing (using a gaseous drug isoflurane).The system uses fuzzy merging of the various measurements which embody 3 types of information:1. brain-related signals via evoked potentials,2. vital signs, such as blood pressure and heart-rate monitoring,3. clinical signs, entered manually via anaesthetist's observations of the patient. A Self-Organising Fuzzy Logic Controller (SOFLC) of the Procyk and Mamdani type discovers necessary rules on-line, either from prior simulation or ab initio in the operating theatre. In particular, the scaling factors for the SOFLC are determined via some a priori knowledge of the patient sensitivity obtained during initial sedation prior to commencement of surgical operation.

## Status and results

The estimation of inter-patient variability has been successfully determined for both propofol (intravenous) and isoflurane (inhalational) drugs. This is achieved by initial bolus administration of propofol or methohexitine in the pre-operation room and assessment of patient sensitivity into three bands of High, Medium and Low. This information is then used to adjust the parameters in the SOFLC. Successful operations have been achieved using this system, with the anaesthetist acting in a supervisory role. They evaluate the system under normal conditions, and take over control during emergency situations.

## Adaptivity and portability

In terms of its multi-layer hierarchy of differing intelligent techniques, the system is hybrid in nature. In terms of adaptivity it achieves Level 1 in the EUNITE definition in that it adjusts to a changing environment. Thus, it uses a form of gain-scheduling to ensure fast stability of the closed-loop control for accommodating the large inter-patient variability of drug sensitivity.

## More information

This is part of extensive PhD studies performed by J S Shieh, as described in his thesis:

J S Shieh"Hierarchical fuzzy logic monitoring and control in anaesthesia", PhD thesis, University of Sheffield,UK,1994

Some details are also available in:

J S Shieh,D A Linkens,and J E Peacock (1999),"Hierarchical rule-based and self-organising fuzzy logic control for depth of anaesthesia",IEEE Trans SMC,Part C,29,pp98-109.

# Smart Adaptive Control of Muscle Relaxation

*Submitted by D A Linkens with S B Hasnain,29.11.2001,IBA D*

## Problem

To provide feedback control of neuromuscular blockade during surgical operations using continuous drug infusion. In this case study the challenge is to provide an adaptive controller which will accommodate a change in the type of drug being infused, without being re-programmed. Measurement signals are available from a Relaxograph (or equivalent monitor) which uses supra-maximal stimulation of the ulnar nerve at the wrist and processed signals from the palm of the hand.

## Solution

The feasibility of automatic control of muscle relaxation had already been established using classical PI algorithms. This had been done using simulation and in clinical trials. This has been shown that there can be 4:1 variability in patient gain sensitivity to a particular drug. Hence, the Self-Organising Fuzzy Logic Control (SOFLC) structure of Procyk and Mamdani has been adopted for this application, so that the controller can adjust its rules to be patient-specific. Basically, the SOFLC is similar to a PI controller with fuzzy rules being elicited via on-line self-exploration. The results of this are described in an accompanying case study.

The SOFLC structure has also been studied for the case of porting the system from the use of one type of drug to another one. In this case, the SOFLC is initiated to suit the pharmacokinetics of one drug (established either via simulation or clinical trials) and then allowed to adapt on-line to the pharmacokinetics of the new drug.

## Status and results

The SOFLC system has been shown to give good control performance ( in terms of stability and settling time)under simulated conditions when switching between infusion of pancuronium (a slow-acting drug) to atracurium (a fast-acting drug).Successful results were also obtained if the SOFLC was initialised with zero rules (ie. no a priori knowledge of drug dynamics),but more cautious control excursions were necessary to ensure stability for all conditions. This can be achieved by adjustment of the scaling factors which are part of the SOFLC architecture.

## Adaptivity and portability

The SOFLC can achieve Level 2 adaptation in the EUNITE definition, in that it can adjust its control to new drug usage. This is via prior initialisation to an alternative drug. It approaches Level 2 adaptivity, in that it can commence from a zero rule base. However, this requires slower adaptation than for Level 2.Also,in this architecture some basic knowledge of the overall system gain and time constants is needed for initial settings of the scaling factors within the SOFLC.

## More information

The work was done as part of a PhD project on the use of parallel computing using self-organising structures. Details are in:

S B Hasnain, ”Self-organising control systems and their transputer implementation”, PhD thesis, University of Sheffield,UK,1989.

# Supervisory Self-Organising Control of Relaxant Anaesthesia

*Submitted by D A Linkens wiith M F Abbod,29.*11.2001,IBA D

## Problem

To provide on-line automation of muscle relaxant drug administration during surgery. The system should cater for possible faults in the equipment, changes in patient dynamics and variability between patients. Apart from catastrophic faults in the Relaxagraph, there are also signal changes caused by movement of electrodes on the skin, and incipient drift caused by sweating etc. Intra-patient variability can be caused by a range of conditions, such as blood loss (giving reduced drug sensitivity ) etc.

## Solution

A supervisory layer has been added to the Self-Organising Fuzzy Logic Control (SOFLC) structure of Procyk and Mamdani. This provides for fault surveillance and monitoring of gradual changes in the environment and patient conditions. In particular, controller initialisation from the supervisory level determines the approximate time delay in the overall system, the SOFLC scaling factors, and the selection of an initial rule base. Also,a gain scheduler estimates the patient sensitivity via prior knowledge of the chosen drug pharmacokinetics and pre-operation room bolus drug responses. Three categories of sensitivity are defined, being Low, Medium and High. The supervisory layer monitors the system performance during an operation in terms of basic closed-loop behaviour of steady-state, oscillatory, divergent or convergent conditions. It adjusts the system response accordingly.

## Status and results

The system has been developed and validated for management under both catastrophic and incipient measurement (Relaxograph) and actuator faults/changes. It has been demonstrated to cope under simulation conditions with significant changes in intra-patient dynamics via its SOFLC level. Further, the gain schedulig for inter-patient variability has been shown to give satisfactory performance in terms of stability and speed of response.

## Adaptivity and portability

It achieves Level 1 adaptivity in the EUNITE definition, in that it caters for changes in the environment, including alterations in either the process (the patient),the measuring equipment (Relaxograph) or the actuator (drug syringe-driver).It achieves Level 2 adaptivity via gain scheduling, since it incorporates patient-specific information on drug sensitivity elicited in the pre-operation room prior to commencement of surgical procedures.

## More information

Further details can be found in:

M F Abbod, ”Hierachical supervisory fuzzy control for muscle relaxation anaethesia”, in “Intelligent Control in Biomedicine”, ed. D A Linkens, 1994, pp133-173.

# Industry Foresight with Scenario and Scanning Agents

*Submitted by Prof Christer Carlsson, 18.12.2001, IBA E*

## Problem

Strategic management needs planning 3-5 years ahead, sometimes 10-15 years ahead in order to foresee and prepare for changes, which may have a dramatic impact on both the industry and corporate survival and success. Forecasting methods are not up to the task of tracing the origins of and forecasting disruptive changes. Instead, various qualitative methods have been used, which in many cases are not more advanced than educated guesswork. In order for the qualitative methods to work data is needed, and some methods to process and make use of the data in a systematic way, which may be a challenge with qualitative data. Often time is of essence and a thorough analysis carried out over several weeks is not possible.

## Solution

IAMSR has developed a "family" of scanning and scenario agents, which work as a collaborative multi-agent system from a hyperknowledge platform. The system works from both a corporate intranet and from a mobile platform. The multi-agent system works with profiles of the events, which may become milestones in the development of an industry or some customer market, and searches for "weak signals" in (mostly commercial) data sources on the Internet, collects the information and stores it in pre-defined categories in a data warehouse. The system can easily handle hundreds of data sources, it works in the background and can be operated on a 24/7 basis (even if much less frequent runs often are quite sufficient).

## Status and results

The multi-agent system is in operation with several corporate partners in the paper and pulp, the steel, the basic metals and the energy and heat industries. The agents appear to collect profiled information with quite a good success rate, which even is comparable to the material collected by professional market and industry intelligence operations. The added benefits of the multi-agent system is speed and cost: the time spent for collecting comparable material is less than 1% of the time spent by professional intelligence operations, and as the commercial data sources charge for use per time unit, there is a corresponding significant reduction of cost.

## Adaptivity and portability

The foresight system adapts to new material in the data sources, i.e. it does not collect material already retrieved a second time. It also adapts to changes in the updating routines of the data sources. The system is portable to several user environments and recognizes its new environment before starting to operate. In terms of the EUNITE levels of adaptivity the foresight system is of Level I/II.

## More information

Industry Foresight with Intelligent Agents, (with P.Walden and S.Liu), Human Systems Management, Vol 19, 2000, pp 169-180..

# Taming the Bullwhip Effect with Fuzzy Optimisation Methods

*Submitted by Prof Christer Carlsson, 18.12.2001, IBA E*

## Problem

The logistical chain between producer and customer is highly integrated in the fine papers market. Information about the true demand of the end-customer market is collected routinely and is then passed up the supply chain by the actors step-by-step. This is, however, not a pure information transition as the actors also take note of and both plan and act on the basis of the information they handle. The actors are rational agents and try to make optimal decisions. There is some friction in the information transition, which causes the actors to take precautions and build buffer inventories against unforeseen demand changes. This will induce variations in the demand estimates, which will grow as the information works its way up the supply chain. This is called the *bullwhip effect* and causes annual costs of 50-60 M€ for a paper mill with an annual production capacity of 300 000 ton.

## Solution

IAMSR proved that the bullwhip effect is caused by (i) the assumption of rational actors, (ii) optimisation methods building on rational actions, and (iii) the assumption that stochastic models are suited for handling imprecise information. Thus the classical methods used for dealing with the bullwhip effect do not work properly, they may even contribute to the problem. The stochastic elements of the bullwhip models were replaced with fuzzy parameters and new solution methods were worked out and proved to converge to optimal solutions. Then the methods were implemented as models on a hyperknowledge platform and introduced in a corporate intranet.

## Status and results

The fuzzy bullwhip models worked surprisingly well. The method introduced a new ordering policy for the fine paper markets, which the paper mills accepted after some trials. IAMSR also worked out a new policy for the actors of the supply chain to share information over secure inter-/intranet links. This policy was quickly abandoned and later on effectively sabotaged by the whole-sellers, which found out that their possibilities to build good negotiation positions were reduced by the information sharing. The fuzzy bullwhip models are now further developed for the steel industry.

## Adaptivity and portability

The fuzzy bullwhip system (a system of 4 interactive models) adapts to changing market conditions and to changes in the variance of demand. In terms of the EUNITE levels of adaptivity the fuzzy bullwhip system is of Level I.

## More information

Reducing the Bullwhip Effect by Means of Intelligent Soft Computing Methods, (with R.Fullér), HICSS-34 Proceedings, 2001,

A Fuzzy Approach to Taming the Bullwhip Effect, (with R.Fullér), Proceedings, International Symposium of Hungarian Researchers on Computational Intelligence, Budapest 2000, pp 69-77

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# Real Options Theory and the Handling of Giga-Investments

*Submitted by Prof Christer Carlsson, 18.12.2001, IBA E*

## Problem

Very large investments, often called giga-investments, require a budget of 0.2-0.5 B€ and will typically have a life cycle of 15-25 years. The classical approach for decision support is to estimate the future cash inflows of the products (or services) produced through the investment, the future cash outflows caused by the investment and related operations and then to calculate the net present value (NPV) of these cash flows. If the NPV is significantly positive the investment decision is made and senior management will have to live with this decision for the life cycle of the giga-investment. In many cases this have been problematic, in some cases catastrophic.

## Solution

The Black-Scholes formula for setting the optimal price of an option in the financial market won a Nobel Prize in 1990s. Less known is the version of the formula, which was developed by Merton for real assets in the 1970s. The *real options* model offers a way to handle large investments with risky outcomes in a more flexible way than the NPV method. There is an *option* for senior management to invest capital or to wait for more and better information, and then commit capital. This works out as a decision tree spanning most of the life cycle of the giga-investment and which makes it possible to make decisions on investment as milestones in future markets are passed. The flexibility offered has been shown to save significant costs and to reduce the possibility of building (a very expensive) catastrophe.

## Status and results

The real options models have been tested on fours historic cases and been evaluated and compared with the results produced with the NPV methods. In all four cases the costs, which could have been saved with the real options methods were significant and it was possible to show that some bad decisions could have been avoided. The models were implemented with MS Excel and run in simple client-server environments at very low cost.

## Adaptivity and portability

The real options methods adapt to changing market conditions if the decision tree is made dynamic, i.e. it is allowed to change its structure on the basis of new information. In our case this information was produced with the Industry Foresight method. In terms of the EUNITE levels of adaptivity the real options model is of Level I.

## More information

Triegeorgis, Lenos (ed.) *Real Options in Capital Investment. Models, Strategies and Applications*, Prager Publishers, Westport CT 1995

# Fuzzy Real Options Theory and the Handling of Giga-Investments

*Submitted by Christer Carlsson, 18.12.2001, IBA E*

## Problem

Very large investments, often called giga-investments, require a budget of 0.2-0.5 B€ and will typically have a life cycle of 15-25 years. The classical approach for decision support is to estimate the future cash inflows of the products (or services) produced through the investment, the future cash outflows caused by the investment and related operations and then to calculate the net present value (NPV) of these cash flows. If the NPV is significantly positive the investment decision is made and senior management will have to live with this decision for the life cycle of the giga-investment. In many cases this have been problematic, in some cases catastrophic.

## Solution

The *real options* model offers a way to handle large investments with risky outcomes in a more flexible way than the NPV method. There is an *option* for senior management to invest capital or to wait for more and better information, and then commit capital. The classical real options model builds on the questionable assumption that an efficient market will discount the effect of the giga-investment by putting a realistic market value on the shares offered through the stock exchange. This is then used to estimate the market risk and to build a stochastic real options model. The assumption is questionable due to the very long life cycle involved. A better approach had to be found..

## Status and results

The real options model was enhanced and developed with fuzzy numbers, which were used to replace the stochastic elements. Then it was possible to show that the Black-Scholes formula can be proved also with fuzzy numbers and that there is an options price for the added flexibility introduced with the fuzzy numbers. The fuzzy numbers were also used to update the dynamic decision tree, which now became more adaptive to changing market conditions. The fuzzy real options models were compared to the classical real options models and proved to be more general. The results when compared with the NPV models were significantly better.

## Adaptivity and portability

The fuzzy real options methods adapt to changing market conditions if the decision tree is made dynamic and adaptive to changes in fuzzy numbers, i.e. it is allowed to change its structure on the basis of new information. In our case this information was produced with the Industry Foresight method. In terms of the EUNITE levels of adaptivity the real options model is of Level I.

## More information

On Possibilistic Mean Value and Variance of Fuzzy Numbers, (with R.Fullér), Fuzzy Sets and Systems, Vol. 122, No.2, 315-326

Project Selection with Fuzzy Real Options, (with R. Fullér, P. Majlender), Proceedings Computational Intelligence, Budapest 2001, 81-87.

# Advanced Vendor Evaluation

*Submitted by Martin Nelke,* 08.01.2002, IBA-E

## Problem

Vendor evaluation can be defined as a permanent and objective monitoring and evaluation process of a vendor's performance regarding specific criteria as quality or timeliness. The main objective of any vendor evaluation is to ensure a company's product and service quality. This objective is highly correlated with constraints such as permanent cost reduction and maintenance of competitive advantage. It can be supported by the vendor controlling based on information gathered from the company's own experience with the vendor as the most reliable source to carefully manage and improve existing vendor relations.

Knowledge Discovery (KD) is an extraction process of implicit, unknown, potentially useful and understandable information from large data sets using data mining technologies. The goal of the described approach was the development of an integrated software solution to assist in extracting knowledge by data mining technologies from data for vendor evaluation to improve organisational and operational decision-making.

## Solution

The system is based on a distributed system architecture. It consists of three main components: a data base with flexible interfaces to enterprise resource planning (ERP) system (SAP R/3®) and to other databases, a data mining tool ("DataEngine"), and a web-based end user environment supporting an easy access through the browser of the SAP R/3® client or other applications. To obtain the data that is going to be used by data mining technologies, the product platform includes an interface to the SAP R/3® system.

Different analyses are available for vendor evaluation: Statistical reports e.g. for return delivery analysis, delivery date analysis and trade volume analysis. Based on a pre-defined, hierarchical key measure system, score values can be calculated for each vendor’s performance with a fuzzy rule base. An important feature is the possibility to analyse different time periods. The evaluation can easily be performed on either an ad-hoc or regular basis. Key figures are derived by transforming and aggregating base table fields. Each key figure can be allocated a weight factor which allows user specific priorities. Vendor categorization that is based on a segmentation using (Fuzzy C-Means) of the whole vendor portfolio helps to identify intra-segment similarities and inter-segment dissimilarities. This, in turn, helps to get a deeper understanding the vendor portfolio structure, and to optimise this portfolio according to the company's business strategy. Based on pre-defined cluster models, each vendor will be assigned a membership value for each of the classes known

## Status and results

The main characteristics of the VendorAnalyzer are the increased software architecture’s adaptivity and modularity in order to be transferable in other business areas or sites, the adaptation of different data mining technologies to the vendor evaluation task, and the interactive and user-friendly graphical interface to enable users to carry out their daily analyses.

The vendor evaluation information is derived form the raw data stored in different tables of the ERP system and will be explored by different data mining technologies like fuzzy logic, cluster algorithms and neural networks as well as statistical concepts and models to support generation of statistical reports, development and application of advanced data mining models, ad-hoc modification of existing models, additional user specific data acquisition and trend analysis for time series data.

An interactive and user-friendly graphical interface has been designed and developed to enable easy access to the vendor evaluation data analysis results for business end-users.

## Adaptivity and portability

By addressing different business applications with this approach, the system architecture and technologies for the interfaces can be re-used widely, whereas the models itself and the user interface will differ (based on the different data in the different companies).That means an increasing need of consultancy and customisation by transferring the results to other applications.

One of the general characteristics (and advantages) of data mining is the development of models based on data representing the real world situation. That means even in same business cases at different companies or locations, models will not always be the same and a re-modelling has to be carried out anyway. Regarding the other aspects except modelling, the effort for adaptation of the web user interface, the database and the pre-processing is minimized by the selected technology and implementation.

The system architecture has been adapted also to the business case of delivery analysis based on customer order data in steel industry.

## More information

Grimmer, Udo; Poloni, Marco: “VendorAnalyzer: A real life vendor profiling tool - Data mining on top of mySAP.com” , European SAP-Microsoft Congress 2001, February / March 2001, Berlin; Germany

i2: “Supplier Relationship Management (SRM) - Powering the Bottom Line through Strategic Supplier Relationships”, WP-6709 (02/01), January 2001

Nelke, Martin; Klotz, Uwe; Poloni, Marco: “A new Vendor Evaluation Product for SAP R/3 ® Systems”, Session “Knowledge Discovery in Enterprise Information Management SAP R/3 Systems” of European Symposium on Intelligent Techniques, September 14-15, 2000, Aachen, Germany

Nelke, Martin: “Supplier Relationship Management: Advanced Vendor Evaluation for Enterprise Resource Planning Systems”, Proceedings of Eunite2001, December 13-14 2001, Tenerife, Spain

Contact:

Mr. Martin Nelke

MIT – Management Intelligenter Technologien GmbH

Pascalstrasse 69, D-52076 Aachen Germany

Phone: +49-2408-94580, Fax: +49-2408-94582

email: martin.nelke@mitgmbh.de

# An Intelligent Adaptive Controller for Bioreactors

*Submitted by Robert Babuska, 11-12-2001*, TE

## Problem

Bioreactors are widely used in food and pharmaceutical industries to cultivate microorganisms. To ensure an optimal environment for the microorganisms, the pH value, temperature and dissolved oxygen concentration in the reactor must be controlled within tight bounds. Ideally, one controller should be able to ensure the required performance for a whole variety of processes (different microorganisms, batch, fed-batch or continuous operation), different scales (volumes ranging from 1 liter to 10,000 liters) and throughout the entire process run. The main control challenges are the dependence of the process parameters on the process type and scale, and the time-varying nature of the dynamics due to gradual changes of operating conditions. Industrial experience shows that controllers with fixed parameters cannot fulfill the requirements. Adaptive control has therefore been chosen as an alternative approach.

## Solution

A model-based adaptive control scheme has been implemented. An important requirement is the robustness of the entire system in order to ensure safe and stable operation under all circumstances. This is achieved by combining well-proven linear identification and control design methods with a fuzzy expert system that supervises the entire process and initiates appropriate actions whenever needed (such as the identification of a new model, re-tuning of the controller, etc.). The control system consists of two levels: feedback loops at the real-time control level and the fuzzy expert system at the supervisory level. The low-level loops are based on standard digital PID controllers whose parameters can be adjusted on line. At request, a test signal is added to the reference or to the control input, in order to ensure proper excitation for model identification. In order to minimize the disturbance of normal process operation, the test signal is adaptively (re-)designed and is only injected when strictly needed. The process input-output data are continuously being collected for performance monitoring purposes.

## Status and results

In order to validate the self-tuning scheme, extensive simulations were first done under Matlab/Simulink, using models identified from real-time process data. Then, a large number of fermentations were run in a 20 l glass bioreactor controlled by the Applikon ADI 1065. Currently, a prototype of the control system is implemented in standard computer hardware. The low-level control loops run on a personal computer under the TwinCAT real-time extension of Windows NT. The supervisory system runs on another personal computer under Matlab/Simulink/Stateflow. These two computers communicate via network, using an Active X server. Temperature, pH and dissolved oxygen control loops were tested in several settings. The experimental results proved that even with a poorly tuned initial controller, good performance can be achieved after two or three system identification and controller tuning iterations. The adaptive control scheme is also able to keep track of changes in process operating conditions, such as an increased or decreased feed. It clearly outperforms standard fixed-parameter controller algorithms that are currently used in commercial biocontrollers.

## Adaptivity and portability

Adaptivity is an essential feature of the developed system, using a combination of well-proven linear methods and a knowledge-based supervisory system. The implementation of the supervisor as a fuzzy rule-based system proved useful. It is transparent, easy to manage, adjust and extend for the different control lops within the considered process and even for other applications.

## More information

This research project has been a cooperation between Applikon Dependable Instruments B.V., Schiedam, Faculty of Electrical Engineering, Eindhoven University of Technology and Faculty of Information Technology and Systems and Kluyver Laboratory for Biotechnology, both at Delft University of Technology. The project was in part sponsored by Senter, project number BTS98083. For more information, please, contact Robert Babuska (R.Babuska@ITS.TUDelft.NL).

# Fuzzy Supervised PID Control of a Flow Rate Process

*Submitted by Mariagrazia Dotoli, 30.11.2001, TE*

## Problem

A flow rate process exhibits several nonlinear features: the flowmeter is linear in a limited range, the electrovalve exhibits hysteresis and the actuator is affected by saturation. Thus the task of controlling the flow-rate is strongly dependent on the operating condition and, in particular, on the setpoint. It is relatively easy to tune a PID controller when the system works at a specific condition, i.e. when the reference input matches the designed value. On the contrary, if such a PID is employed in a condition different from the designed one, the system performances deteriorate. The purpose of this investigation is to make the PID controller adaptive, i.e. capable of controlling the flow-rate at every operating condition. Since PID controllers are widely used in industry, the problem addressed is of interest for several other applications.

## Solution

In order to make the PID controller adaptive, we employ a hierarchical control strategy, consisting of a fuzzy supervisor and of the PID controller itself: the fuzzy supervisor modifies the PID tuning on-line, according to rules with three inputs, the reference, the error and the control action. The first input affects extensively the PID controlled system, while the two additional inputs provide information about the system steady state precision and response speed. Clearly, the supervisor outputs are the PID parameters: the proportional gain, the integral time constant and the derivative time constant.

The fuzzy supervisor is designed as follows. Using the Ziegler-Nichols technique, several optimal configurations of the PID parameters are obtained, each corresponding to a particular operating condition. A tuning table recording the PID parameters is thus produced. On the basis of such a table, a simplified fuzzy supervisor with the set point as a single input is designed. Afterwards, the fuzzy rule base is modified taking into account additional information from the two further inputs. The resulting set of rules is subsequently refined performing some experiments and comparing several system performance indices, namely rise, delay and settling time, integral time absolute error and overshoot.

## Status and results

The proposed schema guarantees a good performance in any operating condition. Specifically, the unsupervised and supervised configurations resulted in similar dynamics for all values of the set point. It is to be remarked that the fuzzy supervisor was tuned automatically and compared to a traditional unsupervised PID previously optimized.

## Adaptivity and portability

Advantages of the proposed method are the fuzzy-supervised PID adaptivity to different operating conditions, the ability to provide smooth transitions from an operating region to another, the preservation of the performance standards and the linguistic approach to the supervision. The main disadvantage is tuning the supervisor parameters, which is not straightforward and requires considerable process knowledge from the designer. Thus, the developed strategy can be reused, but the process knowledge required is extensive.

## More information

Further details are given in:

M. Dotoli, B. Maione and B. Turchiano, " Fuzzy-Supervised PID Control: Experimental Results", EUNITE 2001, Annual Symposium on "Intelligent Technologies, Hybrid Systems and their Implementation in Smart Adaptive Systems", Tenerife, 13-14 December 2002.

# Literature Categorization Through Conceptual Associative Spatial Graphs

*Submitted by J. van den Berg, 28.02.2002, IBA-E*

## Problem

Scientific and technical literature is often fragmented, which implies that answers to queries often require combining information from various sources. Professionals regularly perform literature searches to determine articles relevant to a question and related to the topic searched. Categorization of available literature is a means to guide the search and increase its efficiency. Currently, literature is typically categorized by assigning the articles to one of the standard categories. However, categorization based on actual associations amongst published material is much more effective and can help professionals to better focus on the relevant material and topics. Intelligent computer assistance for automatically building databases of such associations is thus a valuable service.

## Solution

Erasmus University Rotterdam has developed a new methodology to find associations between related concepts in scientific texts. To construct the representation, first all concepts in the articles are identified. Each concept is assigned to a vertex in a graph. Arcs are added to the graph if two concepts co-occur in an article in order to trace related concepts. Furthermore, weights of relevancy for related concepts (based on the number of co-occurrence) are represented in an associative conceptual space (ACS). The combined combination of a graph and the ACS is called a conceptual associative spatial graph (CASG). After training, the distribution of the concepts reflects co-occurrence: concepts that appear together in the articles frequently are located close to one another in the space. Hence, CASG is an example of a self-organizing system, to a certain extent similar to the self-organizing maps. The distance between the concepts in ACS is used as weights of the graph. The CASG allows its users to find paths between concepts, provided that these concepts are linked via other concepts in the literature.

## Status and results

The methodology has been implemented in a prototype system. and the algorithms have been tested for constructing CASG. Simulations using artificially constructed test sets have shown convergence to a configuration reflecting co-occurrence of concepts: clusters of frequently co-occurring concepts are always separated from each other. Paths linking arbitrary concepts can be found instantly. The methodology is also tested on a set of articles published in Nature Genetics for over four years. The training was efficient (it was completed within 3 hours) after which searching was possible. Currently, efforts for performance comparison of the method developed to other competing methods are planned. Definitions of precision and recall for paths are needed for this purpose.

## Adaptivity and portability

In the current situation, literature categorization is made based on pre-defined categories in the library cataloguing systems. Categorization through an intelligent system such as CASG implies that it is adaptive to the actual relations as perceived and used by the contributors to the literature. CASG itself, however, is not adaptive in the EUNITE sense. In the future, adaptation of CASG to newly available data is bound to become more important, since the generation of literature is a dynamic and ever-changing process. Another interesting question to investigate is how to adapt a categorization system that is trained with data from a particular field to one that can also function within the scope of another field.

## More information

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# Fuzzy Exception Learning to Detect Noise Trading

*Submitted by Uzay Kaymak, 23.01.2002, IBA-E*

## Problem

Noise trading is known in financial literature as agents' market activities that are not rationally based on the arrival of new information about asset values. Technical traders, who forecast financial price movements based on past prices and volumes are likely candidates for noise traders. Technical traders bid up prices in a bullish market and bid down prices in a bearish market, resulting in shorter or longer periods of serial correlation in returns. Timely detection of the occurrence of these incidental periods offers extra arbitrage (trade) opportunities to traders. Hence, these exceptional situations need to be detected before they can be acted upon in trading decisions.

## Solution

Periods where noise trading has significant influence on price formation are exceptional. They have unequal lengths and appear at irregular moments, often with gradual (i.e., fuzzy) regime transitions, which make them difficult to detect by conventional statistical analysis. Erasmus University Rotterdam has developed a method based on fuzzy set theory for detecting the gradual regime transitions. Gradual regime transitions can be described naturally within the framework of fuzzy set theory, amongst other by using linguistic rules that can be verified by experts. The fuzzy exception learning method developed observes the average behavior of system outputs and tracks deviations from this average behavior. These deviations are then correlated to regions within the system's input space. The result is a set of fuzzy rules that describe the regimes, which lead to deviations from the average system behavior. Temporary deviations from the average system behavior due to noise trading can thus be detected.

## Status and results

A prototype system is available. The method has been applied to both real and simulated financial data, and it has been found to detect regime shifts with sufficient accuracy for simple financial products. Some of these regime shifts could be attributed to noise trading. However, the influence of the detection method on actual trading decisions is unknown at the moment. Recently, it has also been shown that the fuzzy exception learning algorithm can be explained in terms of probabilistic fuzzy systems. In the future, the link to other probability-based methods will be investigated.

## Adaptivity and portability

The training algorithm for fuzzy exception learning can be both incremental and batch. The system demonstrates type-I adaptation in the former case, since the rules are modified as new data comes in. However, this is a very simple form of adaptation. Once

the regime shifts are detected, the trading decisions can be made adaptive to the dominant regime at that moment. This is again typically type-I adaptation. Note that it is possible to have a mixture of regimes, some of which are coming up gradually while others fade away, which warrants the gradual transition from one regime to the other. It is also possible to model abrupt transitions between regimes. The solution is not portable at the moment. It could be a future research project to study how the model for the regime shifts for one product can be extended to predict the regime shifts for another product. There should be sufficient possibilities in this direction, since the price developments of different financial products are related to one another's through the market mechanism.

## More information

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# Quality control for household appliances by on-line evaluation of Mechanical Defects

*Submitted by G. Tselentis date* 05.07.2001, Service Center

## Problem

A European manufacturing company of washing machines and dishwashers requires an automatic on-line inspection system to accurately monitor the mechanical characteristic of all their products. Present on-line inspection methods are scarcely effective because they are human operator dependent and not sufficiently reliable. Thus, the main objective is twofold:
a) to have diagnostics of mechanical defects by means of vibrations analysis, thus allowing the percentage of faulty products to decrease
b) to assure and improve the products quality as regards to the emitted noise/ vibrations level. This will happen because the knowledge of defects permits a continuous improvement of the production process.
The system is meant to provide a non-operator dependent evaluation of the machine vibroacoustic quality. It has to be reliable and effective in identifying faulty products and classifying the defects at the end of the production line, with a confidence level more than 99%. The maximum time required for every test should be less than 2 minutes in order to be acceptable by industry. The prototype test station will embody and rely on two main technological developments.

## Solution

A prototype test station for house-hold appliance on-line inspection is constructed, capable to give a global evaluation of the vibroacoustic quality of the machine under test, classifying it into two classes, product complying or not to specifications, according to a pass or fail quality control strategy. With the aid of a non-invasive optical sensor network (laser inteferometers) for multi-point vibration measurement the prototype can measure accurately vibrations on the surface of the appliance in a range of frequencies from 0 to 10 kHz, with peak velocity up to 0.2 m/s and resolution less than 1 micron. A diagnostic expert system is capable to identify the typical mechanical defects of house-hold appliances by vibration analysis performed by means of intelligent techniques like fuzzy logic and neural networks.

## Status and results

The prototype achieved very high (~98%) classification results. The appliances are mounted easily on the measuring palette and procedure can be accomplished in the predefined 2 minutes lag by setting the appliance to work on the centrifuge mode.

## Adaptivity and portability

The system needs new training even if small changes (new materials in parts) occur in the production chain as vibration signatures can be influenced by small relocation of mass distribution of the appliance. Retraining in a new model is a tedious and time consuming task. Cumulating new training data for the data base can be achieved only after a quite large number of tests. Failures in this case have to be artificially produced in order to have a statistically acceptable number of samples. The system cannot easily be relocated and work in new environment without tuning but this tuning refers more to the sensor setup.

## More information

MEDEA project, SMT4952016 (search CORDIS page www.cordis.lu)

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# Odorous quality control in food packaging

*Submitted by G. Tselentis,* 28.06.2001, Service Center

## Problem

One of the problems in food packaging quality control is to detect when the packaging material can chemically interact with other substances (like ink for labelling) and emit bad odours that could degrade food quality. In this case even if there is no evidence of health hazard the negative impact in the credibility and market value of the product is of high importance.

Odorous quality control in industry is typically performed by human operators. In some cases reference substances and human olfactory panels are used for better assessment. Olfactory devices (e-noses) emerged in the market and used for automating olfactory control, showing encouraging results. In this problem an e-nose is used for distinguishing malodorous packages used in a production site of pasta. The performance vs. typical classification techniques and the ability of the system to operate in acceptable limits while sensors might degrade from poisoning (i.e. sensor surface get saturated from chemical substances and the signal degrades) should be investigated.

## Solution

Intelligent Techniques are investigated as they can provide soft thresholds for reject-accept similar to human operators. During the project a European consortium aimed to develop a prototype that can classify odours based on chemical sensor data. Data produced as sensors' conductivity varies according to the volatile substance that contacts their surface. Partners experimented with Conducting Polymer (CP) sensors and concluded the last validation phase with Metal Oxide (MO) sensors. The aim was to investigate the power of uncertainty modelling techniques like fuzzy logic, neural networks and machine learning on chemical sensors data, as it is difficult to model the electrochemical interactions that take place on the surface of the sensor. Three parallel classification modules were developed using fuzzy sets, linguistic description and neural networks. Each module considered and treated data in a different way in order to provide greater system robustness. Classification results can be either merged or considered separately.

## Status and results

The prototype is able to distinguish malodorous packages with a success ratio of ~80%. The prototype can be connected directly to a sampler and perform detection in short time (within minutes). The problem of sensor poisoning is the main factor for lowering the performance of the classifier.

## Adaptivity and portability

The training of the classifiers with new data from the production line is in some cases time consuming and can take several hours when using machines with typical computing power. Sensor poisoning is confronted with a calibration procedure using a reference odorous substance. The classifiers use this reference to readjust the classes and thus the problem of adapting the quality control system is based on this calibration procedure. The system can be transferred in a new site with minimal adjustments but the classifiers should be retrained.

## More information

For more search INTESA project (ESPRIT 25254) at www.cordis.lu

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