SYNERGIES WITH TECHNOLOGIES

DRINKING & WASTE WATER

The most important technologies in the context of ANCS are sensor technologies, particularly sensors that use different types of communication systems (such as fieldbus or OPC). They are necessary for implementing ANCS, but they can also be improved by the technology of ANN. Virtual analysers, a device that calculates virtual signals based on simple and robust measurements and can thus substitute laboratory measurements, are particularly interesting for signals that are expensive to produce via analytics such as the biological or chemical oxygen demand (BOD/COD). From substitute signals that correlate (non-linearly) with the needed signal, estimations can be calculated within the ANN that are often more precise than the laboratory analytics.

CASE STUDIES

OPTIMISATION OF THE BIOLOGICAL TREATMENT STEP FOR THE WASTE WATER TREATMENT PLANT (WWTP) COLOGNE, STAMMHEIM

The WWTP Cologne Stammheim is one of the largest sewage treatment plants in Germany with a capacity of 1.3mn population equivalents. The plant treats a mixture of urban and industrial sewage. The biological treatment stage consists of high-load sludge activation, intermediate clarifiers, low-load aeration and biological treatment. The nitrogen removal is carried out via the pre-denitrification method in the low-load activation by pressure ventilation. Light load activation and biological treatment are situated in basins each with different boundary conditions.

The optimisation task

Low-load activation and final sedimentation were selected for optimisation. The optimisation strategy targets the control variables, including air, re-circulation volume flow, and precipitant agent dosage. The operating condition should be attuned such that the minimal use of the respective resources (energy, chemicals) is achieved. For this task, an ANCS was implemented aligned to the local conditions. As a special function, a simulator was programmed to test "what-if" scenarios with the possibility to manually enter values for the mentioned control variables.

Results

The optimisation yielded 15% energy savings for the WWTP under dry weather conditions. Under stormy weather conditions, the optimisation strategy was switched to complying with limiting values (regardless of energy consumption).

IWaNET – INTELLIGENT WATER NETWORK: LEAKAGE DETECTION IN THE WATER SUPPLY NETWORK IN BELM, GERMANY

The municipal utilities (Gemeindewerke) Belm operate a comparatively small distribution network for drinking water. The total length of the network is 110 km, stretching over 10 x 8km with the annual water supply at about 0.72mn m^3. 3,600 households with about 14,000 inhabitants are supplied by the system. Central water supply systems have complex requirements for operational monitoring and optimised operation control as they need to ensure:

- the supply of high quality drinking water with sufficient pressure and amount at each sampling point
- the energetically optimal operation of the entire system, and
- the control of incidents to ensure high customer satisfaction with high customer confidence. Monitoring the entire system at all times is currently impossible, and thus requires a new approach.

The optimization task

The reaction of the system at several sampling points can be used as a basis for approximating the behaviour of the whole system. Therefore, the implemented ANCS uses monitoring data of few sampling points for the simulation of and optimisation recommendations for the operation of the water supply network.

Results

The IWaNet system is able to indicate, which incidents and failures are likely to occur. When applied first, the system was able to detect a leakage and to localise it within few hundred meters with limited information on pressure and throughput. The system warns the user before user-set thresholds will be exceeded. It is possible to achieve optimisation of the processes with regards to energy consumption.

http://demeau-fp7.eu/

BARRIERS AND SOLUTIONS

OPPORTUNITIES FOR UPTAKE

- **Upscaling**: Membrane filtration processes show very reproducible behaviour. Therefore, experiences derived from research projects such as DEMEAU support the application of the ANN approach to a diverse range of sizes of (drinking) water treatment plants.
- **Process optimisation**: The implementation of ANN in established membrane filtration processes can enhance process productivity between 4–15%. Among existing membrane filtration plants in Europe, there is a large potential to achieve increased environmental and economic sustainability.
- **Flexibility**: As ANN are applicable to many different technology set-ups, the opportunities for uptake are diverse.

BARRIERS TO UPTAKE

- **Legal and/or regulatory barriers**: Drinking water companies must comply with the Drinking Water Directive by ensuring that the water quality of the treated drinking water fulfils the requirements of the directive. The ANN technology supports company compliance with standards, as the system continuously monitors and steers the process based on current environmental data provided.
- **Economic barriers**: The size of the plant for ANN application determines the return on investment; larger plants are hence more cost efficient than smaller plants. The potential impact of ANN application can be estimated accurately and cases for a reasonable investment (e.g. with regards to the projected payback period) can be determined in advance.
- **Maintenance**: Optimisation is a long-term task and models tend to become outdated, particularly when living (biological) systems are involved. Therefore, maintenance is an important aspect to consider as part of ANN implementation. The systems require so called "re-trainings". Re-trainings can be pursued either by aquatune, the operator or automatically by the system itself. The solution applied depends on several technical and economic parameters. aquatune offers attractive service level agreements that cover all possible options for ensuring ongoing maintenance.

WW Roetgen with the worldwide largest two-stage UF: 1st stage for drinking water production (X-Flow, 7,000 m^3/h)

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DEMEAU

DEMONSTRATION OF PROMISING TECHNOLOGIES TO ADDRESS EMERGING POLLUTANTS IN WATER AND WASTE WATER

ANCS

AUTOMATIC NEURAL NET CONTROL SYSTEMS

WW Roetgen with the worldwide largest two-stage UF: 2nd stage: backwash water treatment (Multibore®, 630 m^3/h)

Artificial Neural Networks and Genetic Algorithms can make a significant contribution to energy and economic optimization of operating water treatment plants. According to the current state of the art, control and regulation of plants is based mostly on simple concepts such as switches with a fixed time interval or based on the achievement of set limits (e.g. pressure values). The energy costs caused by the operation may be significantly higher than necessary.

PREDICTING TARGETS WITH ARTIFICIAL NEURAL NETWORKS

Many process variables, such as the permeability of a membrane for the treatment of drinking water, depend in a complex manner on many different parameters. The Artificial Neural Networks (ANN) technology allows the prediction of such process variables. Based on those predictions, procedurally and economically optimal settings of the process can be determined.

CALCULATION OF OPTIMAL SETTINGS FOR PROCESS VARIABLES WITH GENETIC ALGORITHMS

The search for an optimum solution is extremely complex due to the high number of effects that simultaneously affect process quality and efficiency. For such situations, genetic algorithms, which were developed based on natural functionalities, have proven their effectiveness. The DEMEAU project, financed within the 7th Framework Programme for Research and Technological Development of the European Union (FP7), demonstrated possibilities for savings in the operation of a membrane water treatment plant.

ecologic WAG aquatune IWW

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INTRODUCTION

Artificial Neural Networks (ANN), a technology based on observations of the human brain, has become increasingly important in the operation of drinking water plants or waste water treatment facilities. Over the last sixty years, scientists have advanced simple mathematical models to powerful software tools that cannot only "learn from data" but also deal with nonlinearity. The greatest advantage of ANN is precisely its ability to learn and therefore develop on solutions to problems. ANN works in combination with an algorithm that seeks the best process configuration. The two components together are called Automatic Neural Net Control Systems (ANCS).

AUTOMATED NEURAL NET CONTROL SYSTEMS TO OPTIMISE WATER TREATMENT PLANTS

Primarily, ANCS is a computer-based system searching for process optimisation that is fed with input signals from a technical process, such as for example the sensor-data of a drinking water plant. In this way, the ANCS uses input information to determine the optimal performance of the process. In the case of a drinking water plant, such a process could be a membrane filtration process, where the system aims to optimise its target parameters. Parameters can include permeability, energy consumption, or cost efficiency, for example. The ANN, which effectively consists of calculation patterns, describes how input signals derived from a sensor are transformed into output data (Figure 1). During the learning phase, the output data is compared with measured output values to calibrate the ANN. The technology connects causes to effects using its algorithm-changes in input signals cause therefore changes in the output (target) signals, mapped by the ANN. Once the system is mature, its predictions are used within an optimisation algorithm to find optimal settings for the process parameters. ANCS was developed during the EU LIFE funded project "Purifast".

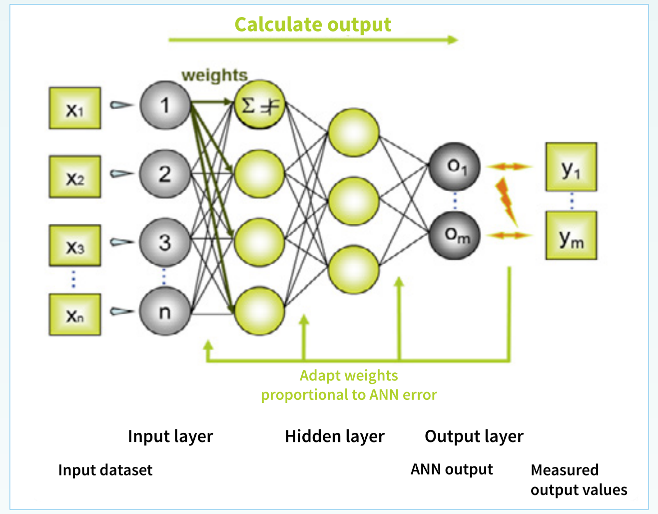


Figure 1: *ANN-Structure: Mapping of input data (e.g. flux, temperature, pH) to target data (permeability, efficiency)*

AUTOMATED NEURAL NET CONTROL SYSTEMS APPLIED TO FILTRATION PROCESSES

The membrane filtration process consists of altering periods of filtration and backwashing. The overall process performance is dependent upon the quality of the raw water and the various settings of operating parameters. Process data obtained from a completed filtration cycle is utilised to identify the optimal operative settings for the subsequent cycle.

Membrane permeability represents as the only parameter the effectiveness of the filtration and backwash cycle. Constantly high membrane permeability indicates high yield conditions as well as the absence of irreversible membrane fouling. For both filtration and backwashing, operational conditions and physicochemical processes are essentially different. Therefore, two specialized ANN-models are necessary to reproduce and predict the filtration process effectively. Those individually trained models are recombined to build a composite model, which can be considered as a single ANN structure that still provides two output parameters.

By applying ANCS membrane filtration, process performance stability is maintained by applying optimally adjusted operation parameters. The optimisation is based on the assumption that the raw water quality encountered during a filtration cycle also applies to the next filtration cycle with significant accuracy.

- Filtration and backwash flux, in addition to filtration and backwash duration, are common parameters to describe the operating status of the filtration plant.
- Water quality parameters that can be used to define the physiochemical raw water composition include: temperature, pH, redox-potential, conductivity and turbidity. The latter may differ from site to site, depending on which type of measurement is provided.

OPTIMISING A TECHNICAL PROCESS FOLLOWING THE RULES OF EVOLUTION: THE GENETIC ALGORITHMS

DEMEAU, a project funded under the 7th Framework Programme for Research and Technological Development of the EU (FP7), is currently working to demonstrate optimisation algorithms, Genetic Algorithms (GA). Genetic Algorithms are inspired by Darwin's evolution theory, in particular by his theory on the survival of the fittest. GA is an efficient way to find an operable solution, which would be a time consuming task when determined conventionally. GA provide solutions for optimisation problems with several variables approximate to mathematically optimal solutions. Possible process settings like throughput or temperature are coded and act within the algorithm as chromosomes.

The GA searches the fittest solution of the optimisation problem within a defined number of generations (rounds of comparison). Chromosomes survive a generation if the setting that they represent delivers better results in the ANN, which represents the system to be optimised, than the respective other chromosome. Throughout the process, the chromosomes are inherited by the next generation or drop out of the process. The functions of mutation and crossover simulate non-linear thinking, adding an additional level of complexity to the selection process. The functions add new features to the process and make GA more efficient. During the optimisation process, many possible operating points can be tested in a very short time to determine the fittest chromosome, and thereby also the optimal system settings within a given parameter range. A diagram of the process is shown in Figure 2.

Using ANN together with a genetic optimisation algorithm, the input parameters are divided into two types of variables, constants (or disturbance) and manipulable, and are then optimised for the problem at hand. For optimisation, a target function is defined and includes the manipulable variables. The manipulable variables can be altered in a fixed range. Therefore, the data range should be selected to lie within the area of training parameters, assuring that no extrapolation is possible. Consideration of logical or operational barriers should be included as barriers for the search area. Each time a greater fitness is generated, the chromosomes are decoded back to the original process settings.

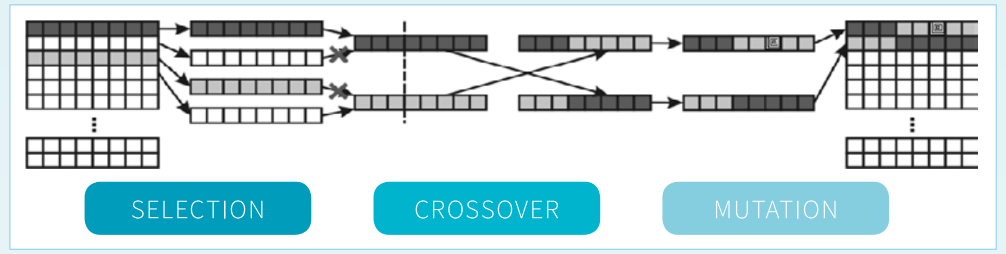
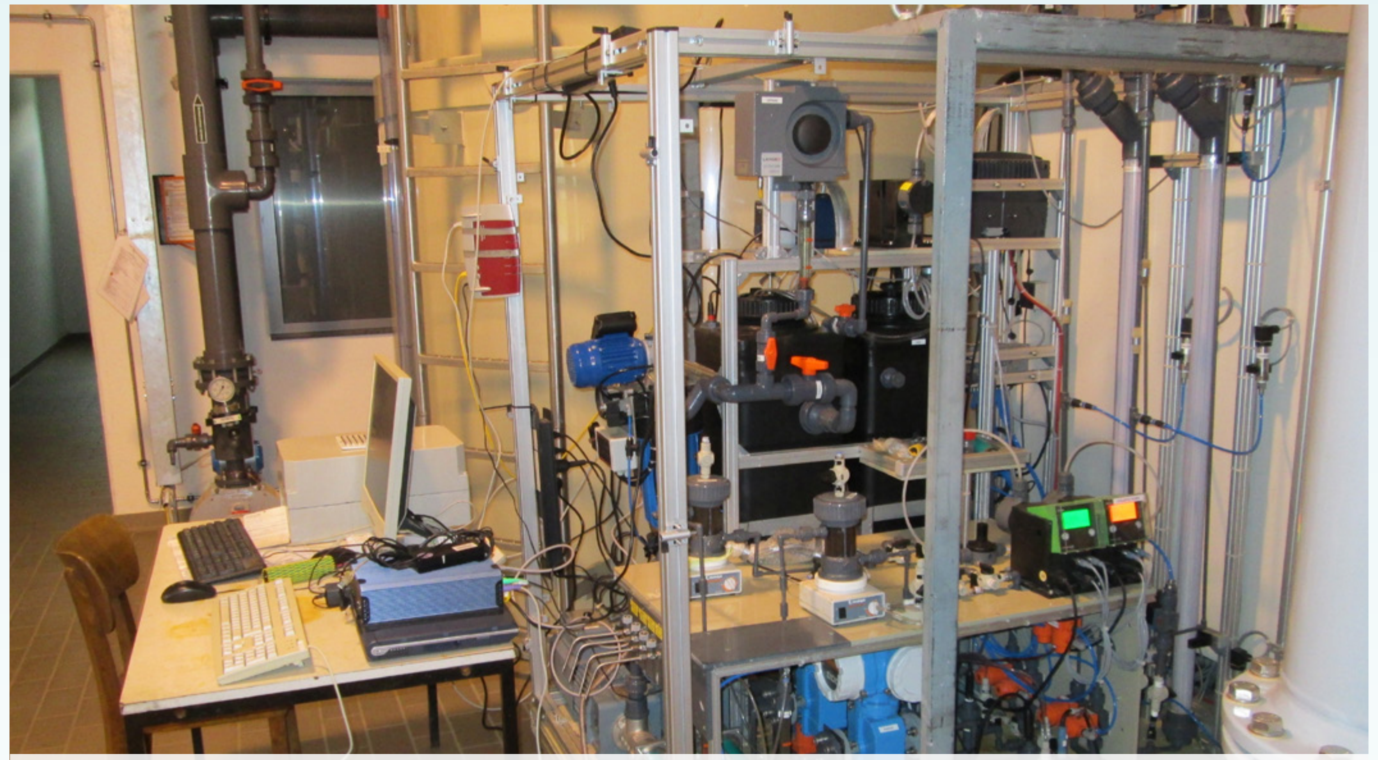


Figure 2: *Adoption of Darwin´s principle of "survival of the fittest" for the search of values for optimal parameter settings (Genetic Algorithms).*



Piloting the backwash water process (Sep. 2014–Feb. 2015) with two treatment lines, UF-modules Lab 1.5 MB 1.0 (Multibore®), membrane area 1m² (small area/full length), capillaries per fiber 7, inner diameter 1.5mm, outer diameter 6.0mm, pore size ca. 0.02µm, material: PESM

ANCS IN PRACTICE

REQUISITE CONDITIONS FOR APPLICATION

- To cost efficiently apply ANN, the process to be controlled or optimised should possess a certain degree of complexity. Processes for which ANN can be applied include the activated sludge reactors of municipal wastewater treatment plants or the purification processes in waterworks. In addition, a minimum production volume needs to be considered. For the average waste water treatment plant, the minimum size is roughly 30.000 population equivalents.
- The advantages of the technology increase with the complexity of the processes controlled and/or optimised. Availability of data is a necessary requisite. However, as modern automation systems require sensor data for correct operation, data availability is usually not a barrier.
- ANCS can be combined with many different systems of measurement as well as control technologies, and thus is very adaptable.

SCALABILITY

- Generally, ANCS can be applied to systems of all sizes. However, the size of the system influences the economic viability as time for the return of investment, shorter for bigger systems, is an important consideration for such an investment.
- The scalability depends on the process and the design of the solution in which ANN are deployed. Processes in wastewater treatment plants are dependent on the functioning of the microorganism colony. As microorganisms show usually a very individual behaviour, every model has to be custom designed. Despite this, it is still possible to scale the overall design principals.
- The filtration process as demonstrated in the DEMEAU project functions with membrane modules whose behaviour is reproducible. Therefore scaling up the results from a pilot plant to the full scale operating plant does not present any major problems. For scaling up, the formulation of the signals used as input and outputs of the model needs to be size-independent.

EXAMPLES FOR URBAN APPLICATION

- Drinking water processing (e.g. dosage of flocculating agents, filtration)
- Drinking water supply (e.g. management of storage tanks, energy recovery with turbines, consumption forecasts, leak detection)
- Control of urban drainage systems
- Waste water treatment (e.g. activated sludge plants, anaerobic reactors, process water treatment)
- Management of digestion towers, biogas plants, dosage of co-substrates

IMPACT

- ANN can be used for multi-parameter control, an important advantage over conventional control algorithms.
- ANN have the ability to tackle non-linear signals. Conventional control and statistics systems are linear systems. This limits their performance in many non-linearly behaving environmental processes.
- ANN can be "trained" on historical process data. This is cost efficient compared to engineered solutions, as training is a machine automated process. As such, ANN offer cost and time savings compared to conventional model based control systems.
- Genetic Algorithms are very efficient in finding solutions, when the search space is very large. This is already the case when the number of controlled variables in the process exceeds 3. For example, for filtration processes, the parameters throughput, filtration time, backwash volume and backwash time need to be optimised in order to minimise the total energy consumption and maintain productivity at 95%.
- Applied in conventional processes, the application of ANN can achieve high cost savings through reduced maintenance costs and lower environmental impact due to savings related to cleansing chemicals. With regards to filtration processes, ANN can decrease the backwash frequency, while simultaneously increasing the productivity of the plant and decreasing the use of chemicals for the backwash process.