Multiobjective Evolution of a Fuzzy Controller in a Sewage Treatment Plant

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ABSTRACT

This paper describes the use of a multi-objective evolution strategy in tuning a fuzzy controller which is used in sewage treatment plants. The controller adjusts the oxygenation in the aeration tank to support biological processes, which reduce nutrients. Globally optimal settings are unknown and up to now the settings are made by a specialist equipped with a large amount of background knowledge. We successfully approximated the pareto-optimal set of solutions considering given constraints and three objectives using a wastewater simulation software. Evolution was able to find the settings proposed by a human expert as well as an interesting parameter niche, the so called simultaneous intermittent denitrification, which promises energy savings.

Categories and Subject Descriptors

G.1.6 [**Numerical Analysis**]: Optimization—*constrained optimization, global optimization*; I.6.3 [**Simulation and Modeling**]: Applications

General Terms

algorithms, experimentation

Keywords

evolution strategies, multi-objective optimization, fuzzy controller, sewage treatment plant optimization

1. INTRODUCTION

In several sewage treatment plants the oxygenation in the aeration tank is controlled using a fuzzy controller. One such controller, the Aqualogic Fuzzy Controller, developed by Passavant Intech, tries to improve the purifying capacity of the plant. The controller adjusts the power of the blower via a set of fuzzy rules and several settings (e.g. the *oxygen set point* for the aeration phase). The oxygenation supports the reduction of nutrients (i.e. ammonium, nitrate and phosphate). Depending on the type of wastewater treatment plant, different settings are required. Note that we optimize these settings and not the fuzzy rules. There are conflicting goals, e.g. low concentration of different harmful chemicals or low energy consumption. Therefore, we have a multi-objective search problem and we search for pareto-optimal solutions. We use a simulation software for sewage treatment (Simba) which is connected to the fuzzy controller to evaluate specific controller settings. The evaluation of one individual takes about one hour due to the complexity of the simulation and we are only able to work with small populations and few generations. We consider the concentrations of three nutrients and the corresponding constraints (see Table 1). A top-level view of our experimental setup can be seen in Figure 1.

Table 1: Fitness components

Objective	Constraint	
Ammonium	NH_4-N mg/l	< 6 mg/l
Nitrate	NO_3-N mg/l	< 10 mg/l
Phosphate	PO_4-P mg/l	< 3 mg/l

SPEA2, the successor of the popular Strength Pareto approach of Zitzler and Thiele [2] has been shown to work quite well for multi-objective search problems. Since the parameters are real values, we prefer an evolution strategy and adapted the selection and elitism technique of SPEA2 for use with an evolution strategy. Additionally we make use of step size self adaption and reduce noise effects by resampling of individuals, which survived several selection phases. Note that the MO-CMA [1] was not yet published at the beginning of our project and the high evaluation time prevented a comparison.

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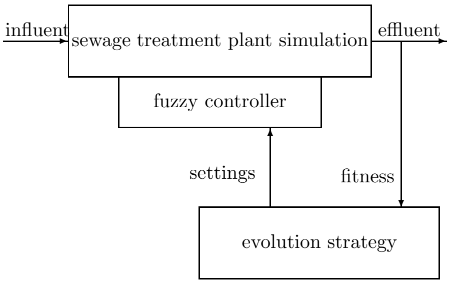

Figure 1: Evaluation of an individual. The evolution strategy forwards the parameter settings to the fuzzy controller. After a certain delay the effluent values are measured to determine the fitness.

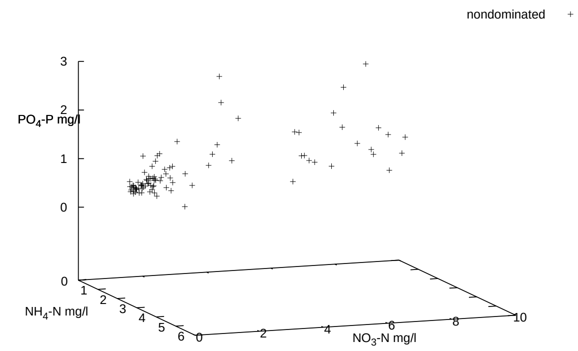

Figure 2: Side view of all non-dominated individuals which were found during the run.

2. EXPERIMENTAL RESULTS

We used an (4/2+20) strategy and evolved 30 generations (i.e. 600 individuals) and the entire run took about four weeks to complete. The fitness of the nondominated solutions found during the run can be seen in Figures 2 and 3. Since the parameter space consists of ten dimensions, the connections between parameters and fitness are hard to understand and we omit confusing plots.

The solutions found by the evolution are convincing and contain the settings, which were proposed by a human expert. Due to the conflictive relationship of the objectives (e.g. ammonium is oxidised into nitrate) the surface is convex. The phosphate elimination is very sensitive to parameter changes compared to ammonium and nitrate, which yields a steep surface regarding the phosphate concentration. This seems to be a simulation specific problem, since real sewage plants don't show such a behavior.

One subset of solutions near the origin of the objective space is especially interesting: a low oxygen set point combined with long aerobic and short anaerobic phases. The so called *simultaneous intermittent denitrification* is a mixture of the simultaneous denitrification and the intermittent denitrification. Intermittent denitrification denotes the sequential reduction of ammonium (high oxygenation), nitrate and phosphate (blower off) while simultaneous denitrification means simultaneous reduction of the nutrients with a continuous low oxygenation. Note that the controller is designed for intermittent denitrification only, but a low oxygen set point could lead to a behavior, which is comparable to the simultaneous denitrification. The low oxygen set point leads to energy savings and the concentrations of ammonium, nitrate and phosphate are low, too. Unfortunately, practical experiences show that the simultaneous denitrification can worsen sludge properties (e.g. sedimentation behavior), but the simulation does not include such properties. Future experiments on real wastewater treatment plants with the new *simultaneous intermittent denitrification* setting will reveal advantages and disadvantages.

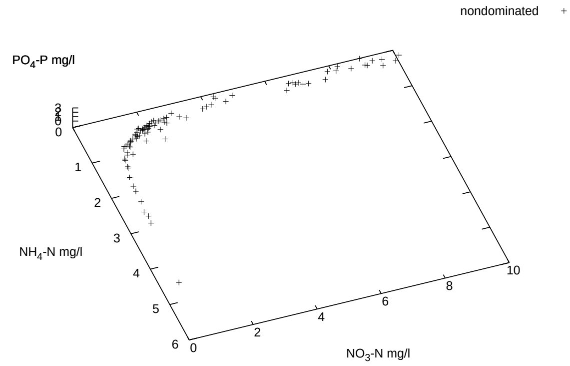

Figure 3: Top view of all non-dominated individuals.

3. CONCLUSION

We successfully created an experimental environment for the evolution of settings for a fuzzy controller, which is embedded into sewage treatment plants. The evolved settings are suitable for use with real wastewater treatment plants and contain the solutions which are proposed by a specialist with the necessary background knowledge of the controller. The evolution was also able to find a special niche of the parameter space, the so called simultaneous intermittent denitrification.

Future work will include evolution starting from default settings instead of random ones in order to reduce the number of fitness evaluations. For an automatic adaptation without (or at least with little) human interaction we need to decide which pareto-optimal solution should be chosen. This could be determined by a minimum distance measure to a given goal in the objective space. If these problems are solved the experimental environment can be used to automatically find a suitable controller setting for a real wastewater treatment plant. Investigations covering these topics are on the way.

4. REFERENCES

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