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SMART-ONLINE^{WDN}: A FRANCO-GERMAN PROJECT FOR THE ONLINE SECURITY MANAGEMENT OF WATER DISTRIBUTION NETWORKS

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The SMaRT-OnlineWDN project´s main objective is to develop an early warning system and a decision support toolkit for emergencies and the deliberate contamination of water distribution networks. There are four parts in this Project. One is to find an optimal sensor network as a combination of different sensor types e.g.: quality and hydraulic sensors and an optimal sensor placement. Another one is developing an online running model, which is automatically calibrated to the measured sensor data and simulates the current hydraulic status of the WDN. The third part is developing a model with more accurate transport and mixing mechanisms. Once a contamination event has been detected, the source identification tool will locate the contamination source by using the inverse transport model. Then, the spread of contamination is found out by simulating the future hydraulic status and using a forecast on water demand. For validating the models, the methods and the data acquisition, experiments are done at a real world test track. The fourth part of the project is a Risk analysis by studying the likelihood and

impacts of deliberate contamination and how to behave in this case and also how to inform customers. The decision support toolkit is completed by combining all parts together.

INTRODUCTION

Water Distribution Networks (WDNs) are critical infrastructures that are exposed to deliberate or accidental contamination. In particular, the drinking water supply is at potential risk of being a terrorist target and contamination need to be detected in due time. The resource, the treatment plant or the distribution network may be contaminated with a deliberate injection of chemical, biological or radioactive contaminants. Several papers report deliberate contamination of a water distribution networks in the past as summarized in [1].

Until now, no monitoring system is capable to protect a WDN in real time. Powerful online sensor systems are currently developed and the prototypes are able to detect a small change in water quality. In the immediate future, water service utilities will install their networks with water quantity and water quality sensors. For taking appropriate decisions and countermeasures, WDN operators will need to dispose of:

1) a fast and reliable detection of abnormal events in the WDNs;

2) reliable online models both for the hydraulics and water quality predictions;

3) methods for contaminant source identification backtracking from the data history.

Actually, in general none of these issues (1) – (3) are available at the water suppliers. Consequently, the main objective of the project SMaRT-OnlineWDN (see figure 1) is the development of an online security management toolkit for water distribution networks (WDN) that is based on sensor measurements of water quality as well as water quantity. Its main innovations are the detection of abnormal events with a binary classifier of high accuracy and the generation of real-time, reliable (i) flow and pressure values, (ii) water quality parameter values of the whole water network. Detailed information regarding contamination sources (localization and intensity) will be explored by means of the online running model, which is automatically calibrated to the measured sensor data.

Its field of application ranges from detection of deliberate contamination including source identification and decision support for effective countermeasures to improve operation and control of a WDN under normal and abnormal conditions (dual benefit).

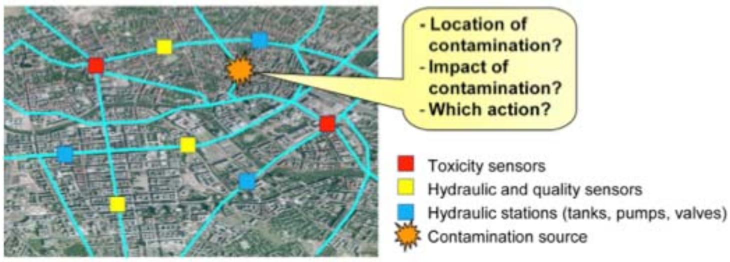

Figure 1. In case of a toxic contamination of the water distribution network, the water suppliers will be supported by the SMaRT-OnlineWDN security management toolkit.

In this project, the technical research work is completed with a sociological, economical and management analysis. SMaRT-OnlineWDN combines applied mathematics, civil and environment engineering, fluid mechanics research and social science and economics in a multidisciplinary approach. The French-German cooperative research project consists of end users (BWB in Germany, CUS Strasbourg and VEDIF - Veolia Eau d’Ile de France), technical and socio-economic research institutions (Fraunhofer IOSB, TZW, Irstea, ENGEES) and industrial partners on both French and German sides (Veolia, 3S Consult).

SYSTEM CONCEPT AND OBJECTIVES

The overall objective of the project SMaRT-Online^{WDN} is the development of an online security management toolkit for WDNs. The general system concept is sketched in Figure 2. The software solution relies on data treatment and assimilation from a sensor network of water quantity values (pressure, flow rate) and water quality values (e.g., chlorine residue, pH, conductivity, turbidity, temperature,). The core of the online security management toolkit consists of a grid of smart sensors in combination with an online simulation model. The boundary conditions of the network model are regularly updated by measurement data guaranteeing the compliance of the model with the observations. In addition, monitoring of water quality parameters supports the detection of biochemical contamination of the drinking water.

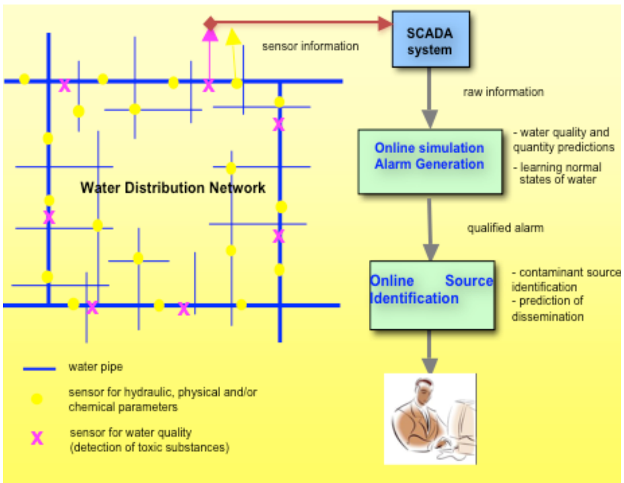

Figure 2. General system concept of SMaRT-Online^{WDN}.

The SMaRT-OnlineWDN modules can be summarized as follows:

1. Event Detection and Alarm Generation: To enable a robust detection of changes in the water quality, a sensor data fusion module evaluates the data of smart sensors. Online simulation model is used for plausibility check of the event detection.

2. Optimal sensor placement. A concept for the optimal placement of a defined number of quality sensors in a real-world network topology and an existing network of usual sensors (hydraulic state, physical/chemical parameters) are developed and implemented as a software tool. It enables the user (e.g.: WDN operators) to find optimal locations for early warning detection system [2,3] and for parameter estimation [4,5].

3. Online Simulation: Generation of real-time, reliable (i) flow and pressure values, (ii) water quality parameter values of the whole water network.

4. Transport model: A detailed experimental and simulation based study of the transport of conservative substances in real-world water drinking networks is performed. A special focus is on the flow and distribution of substances at crosses and Tee-junctions as in most of the actual available WDN simulation software tools (e.g. EPANET) a complete mixing of the substances is assumed. These phenomena are investigated by means of detailed 3D computational fluid dynamics (CFD) models. Later on, a simplified 1D model will be implemented due to the need of a short simulation time in the real-time management toolkit software.

5. Online contaminant source identification and mitigation of risks: A backtracking algorithm that uses the data history of the measurements has to be implemented. The merit of off-line methods (e.g.: [6]) and pseudo real-time ones [7] will be studied compared to the developed online solution method. As a result of water quality sensor alarms, the possible localisations of the intrusion of contaminant can be calculated.

6. Risk analysis and impact assessment: Risk analysis and impact evaluation (real impacts and perceived ones) are performed for the three aspects of sustainability: environmental, social and economical, combined with technical innovation.

SMaRT-OnlineWDN will improve the observability of water quality and quantity in the distribution network in near real-time. It acts as an early warning system as well as decision-support system in case of contamination events. Furthermore, it supports a better understanding of the physical and bio-chemical processes in the pipe systems.

ALARM GENERATION

The system architecture and workflow of the alarm generation module covers the three distinct steps, data preprocessing, novelty detection and plausibility checks.

The algorithm of the data-driven alarm generation module consists of a data pre-processing, the calculation of principal components, the generation of a dynamic alarm threshold and the calculation of an alarm index value for each test sample. A general user interface has been designed which can be used for monitoring the measurement data for events. The alarm generation module has been tested on offline data from Berlin, Strasbourg and the TZW test network. For reduction of false alarm, a first implementation of a fingerprint database has been released. The alarm generation module was successfully interconnected with the Sir 3S OPC server for real-time modelling.

ONLINE SIMULATION

The main difference between online and offline hydraulic simulation is that the boundary conditions (tank water levels, zone inflow, demands, etc.) and operational states of devices (like valve status, pump operations, etc.) of the online model are not predefined by the user, as it is true for the offline case, but derived from (near) real time data originating from the SCADA (Supervisory Control And Data Acquisition) system of the utility. Therefore these data of the online model are always up to date. The simulation based on online data is able to reflect the actual current state of the system much better than the offline model where the proper choice of the boundary conditions is based on historical data or the experience and the knowledge of the modeller.

However, in practice, not all of the model parameters can be measured and transferred online due to financial and technical limitations. This applies in particular to the time varying demands of the customers. As a result, one major issue of online simulation is the proper estimation of the noisy data “user demands”. Therefore an online calibration tool will be developed that calculates (or estimates) the distribution of actual demands within the particular zones by minimizing a least-squares function of calculated and measured values of all available measurements of the zone such as in [8].

Another challenge of online simulation consists in the strong requirements for calculation time and data transfer. The objective is to run the online simulation cycle at least every five minutes including online calibration, data transfer and monitoring. In order to enhance the overall process a method for simplification of large water distribution system networks has been developed, which is based on topological decomposition of the network graph [3, 10]. On the one hand the method shall be used for the enhancement of the solution of the hydraulic calculations by a new method for reordering of the system of equations that has been published recently [11]. On the other hand, graph decomposition can be used as general tool for adaptive modelling in the context of SMaRT-OnlineWDN.

In the context of SMaRT-OnlineWDN the online simulation framework is not used only for the monitoring of the current state of the system but also for the management of mitigation measures in case of an accident. For that purpose the additional simulation modes look-ahead, what-if and reconstruction are required. Look-ahead simulations can be used for predicting the spread of contamination if the location of the source is known. What-If simulations support the fast and efficient development of counter measures like isolation of contaminant and flushing.

From the software point of view, the architecture of the system was designed to make possible the inclusion of new algorithms that could work connected to the online calculations process without making changes in the core of existent software/components.

TRANSPORT MODEL

Existing transport model tools are not adapted for online modelling and ignore some important phenomena that may be dominant when looking at the network in greater detail with an observation time of several minutes. These phenomena are addressed in SMaRT-OnlineWDN. In summary, it is important to consider: 1) Inertia terms to make slow transient predictions of the hydraulic state; 2) The hydrodynamic dispersion and possibly the molecular diffusion to improve the transport along a pipe and at junctions; 3) The imperfect mixing at T- and Cross junctions depending on velocity inlets; 4) The diameter reduction and the wall roughness.

INVESTIGATION OF TURBULENT FLOW AT T-JUNCTIONS

When simulating the behaviour of pollutant at the junctions of pipes it is important to consider the effects of turbulence induced. For this, two turbulence models have been compared: 1) a “large eddy simulation” (LES) model that is more accurate but with large computational burden; and 2) a “Reynolds-Averaged Navier-Stokes” (RANS) model that neglects the small perturbations that are significant in the pollutant streamlines in the tubes. Figure 5 shows the differences between the two methods (RANS k-ε and LES Smagorinski Lilly). The inlet is West side and the two outlets are North and East.

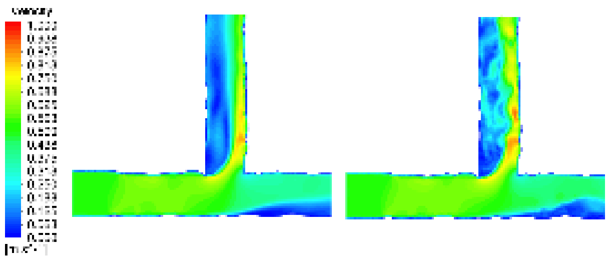

Figure 5. Comparison of turbulence simulation (velocity) using methods RANS (left) and LES (right).

SIMULATING MASS FLOW DISTRIBUTION AT T-JUNCTIONS

Many various configurations of T-junctions were simulated. The configuration in Figure 6 is with one inlet and two outlets. It shows the difference in mass flow distribution of the pollutant at the two outlets. This demonstrates that it is important to simulate imperfect mixing for T-junction configuration.

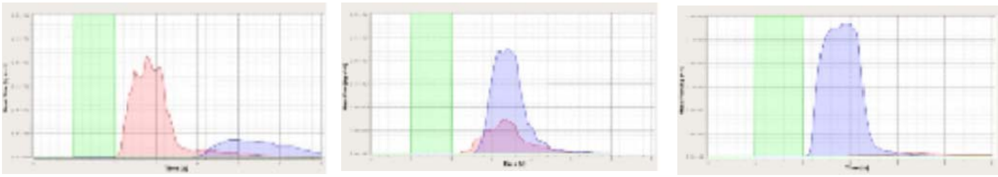

Figure 6. Influence of Mass Flow distribution with three case studies. Green represents the inlet; blue the main outlet and red the secondary outlet. Parameters: v=0.8m/s at the inlet, injection of 306g by constant mass flow.

INFLUENCE OF CURVATURE T-JUNCTIONS

In a first study the influence of the curvature at the joint of a T-junction on the flow are analysed. The diameter of the pipes is D=0.1m and velocity at the inlet is set to v=0.02 m/s, so the problem is laminar. Compared are a junction without curvature (Figure 7, A) to a curved junction with the radius of R=0.1m (Figure 7, B). The inlet is East side and the two outlets are North and West.

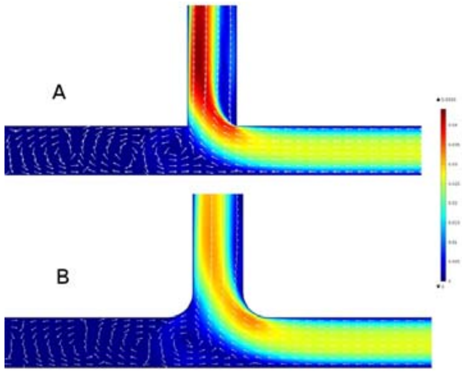

Figure 7. Influence of the curvature radius on the flow at a T-junction.

RESULTS FROM TEST NETWORKS

At the test networks from TZW (Dresden) and BWB (Berlin) the developed SMaRT-Online^{WDN} tools are investigated and tested under practically relevant conditions. A new test platform has been completed at TZW with Online-sensors installed, the alarm generation tested on it and experiments conducted for transport model.

The test field at the BWB Berlin utility (Figure 8) is about 600 m with pipes made of cast iron and size of DN 150 mm. The pipes are about 90 years old and incrusted. Chemicals can be injected in to the pipe by a pump and three multi parameter sensors located at different distances measure hydraulic and quality parameters (Flow, pressure, conductivity pH-Value, oxygen,…) different concentration during the flow. So the Transport phenomena like Advection, dispersion and absorption can be worked out.

First investigations at TZW have been performed applying several color tracers with different densities under laminar and turbulent flow conditions. The experiments were conducted in a straight pipe with velocities in a range of 0.004m/s to 0.5 m/s. The main results under laminar flow conditions are: 1) Dispersion is the main process for spreading and mixing, 2) The behavior (moving up or down) of the tracer depends particularly on the density of the injected liquid, 3) An injected liquid with a higher or lower density than the water moves at the pipe wall with a lower velocity than the water body.

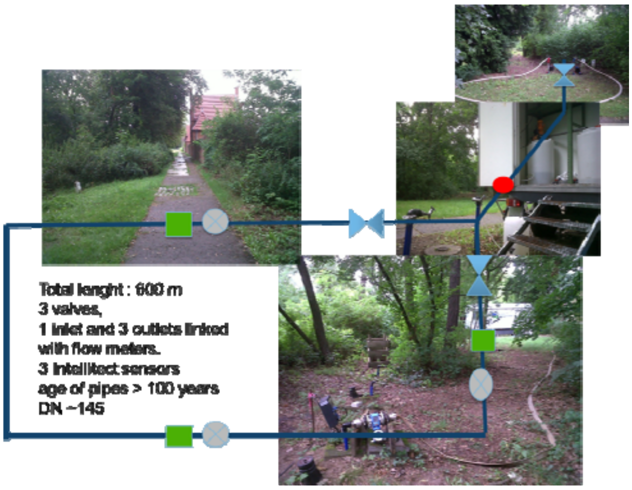

Figure 8. Test field at the Berlin utility.

RESULTS FROM REAL WORLD NETWORKS

Veolia Eau d'Ile de France is the operator of the drinking water network of the Syndicat des Eaux d'Ile de France (SEDIF), the biggest drinking water network of France with more than 8,300 km of pipes that provide water to more than 4 million people all around Paris. Due to the size and the urban environment of the network, the network safety is one of the major concern of the SEDIF and of Veolia Eau d'Ile de France.

The first step of this project was the creation of a pilot on a subnet of the network; on this pilot of 200 km of pipes, 20 water quality sensors were installed, with 10 on the distribution network and the other 10 on connection pipes. The sensors installed are the Kapta sensors that measure active chlorine, absolute pressure, temperature and conductivity every 5 minutes. These measures are sent to the control room of the network. This pilot was the first step of a global deployment of these water quality sensors all over the network in 2013 and 2014: by the end of 2014, 200 sensors have to be installed.

As an end user of the SMaRT-OnlineWDN project, Veolia Eau d'Ile de France scheduled to implement the different methods defined in this project to:

a) Optimize the deployment of the water quality sensors

b) Define alarming rules to treat the huge quantity of data sent by the Kapta sensors to detect water quality failures

At this stage of the SMaRT-OnlineWDN project, Veolia Eau d'Ile de France is currently working on the adaptation of the optimization placement method developed in the project. Indeed, the operation tools used by all the end users are different; a specific work has to be done to adapt the developed tools to the one used on site. All the data necessary for the sensors placement have been collected that is: location of sensitive clients, density of connections, and hydraulics of the network. This work has implied to match the GIS system with the hydraulic model. The preliminary calculations of random contamination injection (start time and duration) are undergoing. This step of the method is very time-consuming since it requires to do for each contamination- an hydraulic simulation over 4 days.

CONCLUSION

The main objective of the project SMaRT-OnlineWDN is the development of an online security management toolkit for water distribution networks (WDN) that is based on sensor measurements of water quality as well as water quantity. In this paper, the concept and first results are presented. The first milestone with proof of concepts was successful. Present work is focused on the implementation of the SMaRT-OnlineWDN modules, the optimal placement of water quality and quantity for the VEDIF and CUS water utilities and the risk analysis and impact assessment.
A TZW pilot scale set that is designed according statistics of T, Cross and N-junctions on real networks.

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REFERENCES

[1] Gleik, P. H. (2006): *Water and terrorism, Water Policy*, 8, 481-503, 2006.
[2] Propato, M. and Piller, O. (2006): *Battle of the Water Sensor Networks*. 8th annual Water Distribution System Analysis Symposium, University of Cincinnati, Cincinnati, Ohio USA, August 27-30 2006, printed by ASCE, 8, 2006.
[3] Deuerlein, J.; Wolters, A; Meyer-Harries, L. and Simpson, A. R. (2010): *Graph Decomposition in Risk Analysis and Sensor Placement for Water Distribution Network Security*. Water Distribution Systems Analysis WDSA 2010, ASCE, Tucson, 394-411, September 2010.
[4] Piller, O. (1995): *Modeling the behavior of a network - Hydraulic analysis and sampling procedures for parameter estimation*. Applied Mathematics thesis from the University of Bordeaux (PRES), 288 pages, Talence, France, defended on the 3rd February 1995.
[5] Fabrie, P.; Gancel, G.; Mortazavi, I. and Piller, O. (2010): *Quality Modeling of Water Distribution Systems using Sensitivity Equations*. Journal of Hydraulic Engineering, 136(1), 34-44, 2010.
[6] Propato, M.; Tryby, M. E. and Piller, O. (2007): *Linear algebra analysis for contaminant source identification in water distribution systems*. World Environmental and Water Resources Congress 2007, Tampa, Florida, USA, 15-19 May 2007, 10, 2007.
[7] Preis A. and A. Ostfeld (2011): *Hydraulic uncertainty inclusion in water distribution systems contamination source identification*. Urban Water Journal, 8(5), 267-277, 2011.
[8] Piller, O., Gilbert, D. and Van Zyl, J. E. (2010): *Dual Calibration for Coupled Flow and Transport Models of Water Distribution Systems*. Water Distribution Systems Analysis WDSA 2010, ASCE, Tucson, 722-731, December 2010.
[9] Deuerlein, J. (2008): *Decomposition model of a general water supply network graph*. ASCE Journal of Hydraulic Engineering, 134, 6, 2008, 822 – 832.
[10] Deuerlein, J.; Simpson, A. R. (2012): A modified global gradient algorithm based on topological decomposition. 14th Annual Symposium on Water Distribution Systems Analysis WDSA 2012, ASCE, Adelaide, Australia, 24-27 September, 2012.