Efficient Online Source Identification Algorithm for Integration within Contamination Event Management System

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Security and reliability of drinking water supply is one of the most important premises of modern societies. Not least recent terrorist attacks have shown that our societies are threatened by malevolent actions. In this context, also the deliberate contamination of drinking water supply systems could be an interesting option for terrorists. For more than one decade a number of researchers have been working on methods for civil protection, real-time detection of contaminations and specific sensor development, management of contamination events and mitigation. Different software tools have been developed tackling problems such as optimal placement of sensors in the system (TEVA-SPOT) and detection algorithms (CANARY).

In the SAFEWATER project, which is funded by the European Union, a comprehensive water supply system security solution is developed. One part of the project is concerned with development of new sensors for detection of chemical, biological and radio-nuclear contaminations. The other part deals with development of a comprehensive Event Management Software (EMS) that collects all the information from the field and from different software components that are connected with the EMS. In addition to a stochastic detection module and hydraulic and water quality simulations that can be run offline (for preparation and training of the Detection Module) and online, also a software component for identification of possible contamination sources is developed.

The Source Identification (SI) module distinguishes from existing solutions by its real-time capabilities, the integration within the EMS and the permanent calculation of the monitoring state of the sensor network even in the case without alarm. In the context of SAFEWATER one basic requirement was that the source identification algorithm must deliver results almost in real-time. For that reason all kind of optimization based approaches were excluded because of the huge number of simulations that are required for stochastic optimization models. Therefore a more direct approach was chosen for the solution of the inverse problem. It has some similarities with the particle backtracking algorithm that was first presented by Shang et.al. (2002). Its core component is an event driven simplified transport algorithm that does not consider

reaction and diffusion mechanisms. For solution a method of characteristics (MOC) is used.

One of the key performance indicators is the usage of memory. In the presented approach a special format was developed that is used for storing the characteristic lines of the transport equation MOC. This information can then be used for particle tracking (forward and backward) as well as reconstruction of time curves (at a certain location) or the concentration along a pipe at a certain time. In combination with the event driven method, which means that instead of time driven simulations only changes in water quality at the boundaries are considered, the memory requirements are minimized. An event is triggered every time a change in the boundary conditions occurs (for example start of intrusion in the forward case or release of sensor alarm in the backward case). The algorithm sends a separator front through the system following the flow velocity of the water in the pipes (forward) or working against it (backtracking case).

For solution of the source identification problem at each external time step the alarm states of the sensors are sent through the system in reverse time (positive, negative, unknown). If at least one of the sensors is positive the nodes and pipes upstream of the sensor are identified, which are possible candidates for the location of the contamination source. If more sensors have positive alarm states that are normally released at different times the results of the backtracking calculations are combined. A match is reached for nodes that are upstream of all positive sensors if the signals that are created by the backtracking procedure are consistent for all sensors. A specific weighting function has been developed that identifies the most probable locations for the contamination source based on the results of the backtracking method. Please note that also negative sensor alarms deliver important information. The backtracking of negative alarm states (under the assumption of perfect sensors) identifies the nodes upstream of these sensors and times when the signal passes the nodes. A contamination starting from such node before the calculated arrival time of the negative separator front is not possible since, in this case, the sensor alarm state must have been positive as well.

Another important application of backtracking of negative sensor alarms consists of the continuously updated monitoring state of the system. The backtracking algorithm calculates a kind of reverse water age for each location under the protection of the sensor network. That means that for any location the time of the last observation is known. In addition, the nodes and pipes that are not covered by the sensor network can be visualized and updated in real-time.

The simplified forward transport calculation is used for estimation of the future spread of contamination and the identification of isolation valves. Here, the assumption is again that more complicated water quality issues such as incomplete mixing, reaction and diffusion are of secondary importance for this particular problem because at the beginning of a real contamination event it is expected that the kind and severity of the substance is unknown. In the project SAFEWATER a second water quality solver is implemented that deals with all of these issues. Once more information about the chemical properties of the agent is available it can be used for more detailed calculation of concentrations.

The presented approach is integrated within the Web-GIS-based Event Management System of SAFEWATER. The communication channels are implemented by use of *ActiveMQ*. In the online application data management is an important issue. Therefore a moving time window approach has been realised that keeps the hydraulic data (flow velocities) calculated by the online simulator (SIR 3S) only as long as required for the backtracking in memory. The user can permanently observe the current monitoring state of the system (also for no alarms). In case of an event the possible contamination sources are signed and based on the utility reaction time the valves that have to be closed for isolation of the contamination are marked. All the calculations run in the same cycle as the online simulation (1 min) in this case. For performance reasons the threads are running in parallel. For guaranteeing the proper order of calculations a Petri-Net has been implemented within the online client *SIR OPC*.

The paper first gives an overview of the theoretical background of the algorithmic development followed by details of the integration within the EMS framework. At the end results of the application cases that were tested in SAFEWATER (mainly in the test lab at Water Supply Zurich) are presented and discussed.

Keywords

Hydraulic online simulation, source identification, contamination event, event management system.

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