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A decision support system for on-line leakage localization

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ABSTRACT

This paper describes a model-driven decision-support system (software tool) implementing a model-based methodology for on-line leakage detection and localization which is useful for a large class of water distribution networks. Since these methods present a certain degree of complexity which limits their use to experts, the proposed software tool focuses on the integration of a method emphasizing its use by water network managers as a decision support system. The proposed software tool integrates a model-based leakage localization methodology based on the use of on-line telemetry information, as well as a water network calibrated hydraulic model. The application of the resulting decision support software tool in a district metered area (DMA) of the Barcelona distribution network is provided and discussed. The obtained results show that the leakage detection and localization may be performed efficiently reducing the required time.

1. Introduction

Water utilities provide clean water service to local communities and charge the service by the metered water consumption. However, not every drop of water produced at a water treatment plant reaches customers and generates revenue for water companies. Instead, a significant proportion of drinking water is lost, due to either water leaking from the distribution pipelines or unauthorized water usage. Water loss represents a major fraction of *non-revenue water (NRW)*[1]: more than *65%* of *NRW* arises from unauthorized water consumption, meter inaccuracies and leaks from the water mains source-to-taps infrastructure (IWA, 2000). On average, more than *15%* of water produced is lost in the United Kingdom (Wu et al., 2010). Regarding the overall water loss of Spain, the estimation of the Spanish Statistics National Institute (INE) was around *791 hm^3/year* in 2009, while the overall water supply was around 4709 hm^3/year. Thus, around *25%* of the supplied water was lost. The *AWWA*[2] *Water Loss Control Committee* (2003) reports that water loss reduction and the associated revenue loss recovery stand among the most promising areas of water resource improvements in North America.

In general, water leakage[3] rate is high which causes financial loss and worsens water utilities' public reputation: it may damage the infrastructure and cause third-party damage, water and financial losses, energy losses and health risks (Wu, 2008). Consequently, a systematic approach is needed to identify likely leakage hotspots so that detection crews can find leaky mains more quickly, leading to quicker repairs. Most of the leakage management related methods developed so far can be broadly classified as follows (Puust et al., 2010): (1) leakage assessment methods which focus on quantifying the amount of lost water; (2) leakage detection methods which are primarily concerned with the detection of leakage hotspots and (3) leakage control models which are focused on the effective control of current and future leakage levels.

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[1] *Non-revenue water (**NRW**)* is water that has been produced and is "lost" before it reaches the customer. Losses can be real losses (through leaks, sometimes also referred to as physical losses) or apparent losses (for example through theft or metering inaccuracies).

[2] *AWWA*: American Water Works Association (http://www.awwa.org/).

[3] Different definitions of leakage in distribution systems exist. The most frequently used one defines the leakage as (amount of) water which escapes from the pipe network by means other than through a controlled action (Ofwat, 2008).

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Continuous improvements on water loss management are being applied, based on the use of new available technologies. Nonetheless, the whole leakage localization process may still require long periods of time (i.e. weeks, months) with an important volume of water wasted before the leak is found (Pérez et al., 2011). To avoid these inconveniences, leakage detection and localization based on mathematical models may be used (Brdys and Ulanicki, 1994) which can "compare" the data gathered by installed sensors in the network with the data obtained by a model of this network.[4] If a meaningful difference is detected between these data sets, a detection of an abnormal event is obtained. This implies that modeling is paramount in order to achieve successful results. It provides the means for detection of possible faults (i.e. leaks) as well as their probable localization in the network. Model-based methodologies are widely used in environmental applications when rational decision-making must be carried out taking into account complex physical processes and existing interlinks among environmental, industrial and social issues (Wierzbicki et al., 2000): i.e. water resource management and operation (Rani and Moreira, 2010; Giupponi, 2007), management of complex networks in the urban water cycle (Ocampo-Martinez et al., 2013), water demand management (Bakker et al., 2013; Makropoulos et al., 2008), climate change effect on water resources and water supply (Pouget et al., 2012; Laucelli et al., 2012).

Regarding the specific problem of water loss reduction tackled in this paper, the use of flow and pressure sensors together with hydraulic models of the water network for leak detection and localization is a suitable approach for the on-line monitoring of water balance. A direct approach based on simulation was proposed in Mandel (1998) and Almandoz et al. (2005). An alternative approach based on an inverse approach that formulates the leak detection and localization problem as a parameter estimation approach was presented by Pudar and Ligget (1992) and further inverse approaches were investigated (Liggett and Chen, 1995; Kapelan et al., 2003; Wu and Sage, 2006). Additionally, other contributions integrating data-driven and model-driven approaches (Farley et al., 2010; Bicik et al., 2013) or based just on a data-driven approach (Romano et al., 2013) were also presented.

Pérez et al. (2011) present a direct modeling methodology developed to help network operators deal with the detection and localization of leaks in district metered areas (DMAs[5]) of water distribution networks. The leakage detection procedure is performed by comparing pressure data of certain DMA inner nodes[6] with their estimation using the simulation of the mathematical network model. Taking into account a fault diagnosis context (*Appendix* 1.2), the leakage localization procedure presented in Pérez et al. (2011) is an application of the binary fault isolation procedure based on the theoretical fault signature matrix (Gertler, 1998), applying a parallel diagnostic inference process between this binary matrix and the binary observed fault signature vector. In Quevedo et al. (2011), this method was updated to work with non-binary observed fault signatures and theoretical fault signature matrices enhancing the overall performance of the method.

Model-based leakage localization methods are an important tool to detect leaks and reduce water losses. They may also be used as support systems in decision-making processes related to the water network maintenance and investments. In general, as stated by Savić et al. (2011), model-based methodologies for environmental applications (i.e. leakage detection and localization) present a certain degree of complexity which limits their use to experts in the modeling field involved in each environmental application. Nonetheless, if computer-based models for environmental applications were integrated into a model-driven *Decision Support Systems* (*DSSs*) (Power, 2004; Power and Sharda, 2007; Savić et al., 2011), this type of models should be useful for managers of environmental systems (i.e. water networks) as support systems in decision-making processes without the need for expertise in the mathematical modeling. The field of leakage localization-based software tools (DSSs) is very active; a number of commercial products are in the market, such as the *TaKaDu*[7] system (Armon et al., 2011) based on a data-driven approach and *WaterGEMS*[8] (Wu and Sage, 2006) based on an inverse modeling approach using Genetic Algorithms.

Focusing on the topic of software tools, the main goal of this paper is to describe a model-driven DSS prototype for leakage detection and localization in water distribution networks. The aim of the presented approach is not to compete with existing commercial tools but to show a straightforward approach which takes benefit from the existing hydraulic models used by the water network operators for operation and planning purposes. A web-based tool has been developed and applied to a DMA in the Barcelona water network in both simulated and real scenarios. Regarding the model-based leakage localization method, this DSS integrates the approach presented by Quevedo et al. (2011). Thereby, this tool has been developed with the main purpose of widening the use of model-based leakage localization techniques by users with low expertise in this modeling field taking benefit from the existent hydraulic models used by the operators. In general, the tool proposed in this paper is based on the integration of the instrumentation data existing in the DMA network and the hydraulic model of the DMA network with advanced model-based leakage localization techniques. As a result of this integration, a set of functionalities efficiently supporting the leakage localization process is available for the intended user.

This paper is organized as follows: *Section 2* presents the case study to which the developed web-based leakage localization DSS prototype has been applied. *Section 3* gives an overview of the requirements and architecture of this software tool and its application to the considered case of study. Then, in *Section 4*, the integration of the considered leakage localization methodology into the proposed DSS is tackled: on the one hand, the foundation of the integrated methodology is recalled and, on the other hand, the integration procedure is given. Next, the main features of the proposed software prototype and the results obtained in leakage scenarios considered in the case of study are reported (*Section 5*). Finally, resulting conclusions are given in *Section 6*. Additionally, and for the paper to be self-contained, a short background in water network mathematical modeling and fault diagnosis is included in the *Appendix* given its importance in the considered model-based leakage localization DSS software prototype.

2. Case study description

2.1. Description of Nova Icaria district metered area (DMA)

The performance of the leakage localization DSS prototype presented in this paper has been tested in one DMA of Barcelona

[4] See *Appendix 1.1* for background information about mathematical modeling applied to water distribution networks.

[5] District metered area (DMA) is a defined area of the distribution system that can be isolated by valves and for which the quantities of water entering and leaving can be metered. The subsequent analysis of flow and pressure, especially at night when a high proportion of users are inactive, enables leakage specialists to calculate the level of leaks in the district.

[6] '*DMA inner nodes*' expression refers to all DMA nodes excluding those ones related to the inlets.

[7] http://www.takadu.com/.

[8] http://www.bentley.com/.