



Methodology for leakage isolation using pressure sensitivity analysis in water distribution networks

Ramon Pérez^{a,*}, Vicenç Puig^{a,b}, Josep Pascual^a, Joseba Quevedo^a, Edson Landeros^c, Antonio Peralta^d

^a Advanced Control Systems Group (SAC), Universitat Politècnica de Catalunya (UPC), Rambla Sant Nebridi, 10, 08222 Terrassa, Spain

^b IRI Institut de Robòtica i Informàtica Industrial (CSIC-UPC), Spain

^c CETAQUA Water Technological Center, Spain

^d AGBAR Barcelona Water Company, Spain

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ABSTRACT

Leaks are present to some extent in all water-distribution systems. This paper proposes a leakage localisation method based on the pressure measurements and pressure sensitivity analysis of nodes in a network. The sensitivity analysis using analytical tools is not a trivial job in a real network because of the huge non-explicit non-linear systems of equations that describe its dynamics. Simulations of the network in the presence and the absence of leakage may provide an approximation of this sensitivity. This matrix is binarised using a threshold independent of the node. The binary matrix is assumed as a signature matrix for leakages. However, there is a trade-off between the resolution of the leakage isolation procedure and the number of available pressure sensors. In order to maximise the isolability with a reasonable number of sensors, an optimal sensor placement methodology, based on genetic algorithms, is also proposed. These methodologies have been applied to the Barcelona Network using PICCOLO simulator. The sensor placement and the leakage detection and localisation methodologies are applied to several district management areas (DMA) in simulation and in reality.

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1. Introduction

Water loss in distribution system networks is an issue of great concern for water utilities, strongly linked with operational costs and water resource savings. Continuous improvements in water loss management are applied and new technologies are developed to achieve higher levels of efficiency. Usually a leakage detection method in a District Metered Area (DMA) starts by analysing input flow data, such as minimum night flows and consumer metering data (Lambert, 1994; MacDonald, 2005). Once the water distribution district is identified to have a leakage, various techniques are used to locate the leakage for pipe replacement or repair. Methods for locating leaks range from ground-penetrating radar to acoustic listening devices or physical inspection (Colombo, Lee, & Karney, 2009; Farley & Trow, 2003). Some of these techniques require isolating and shutting down part of the system. The whole process could take weeks or months with a significant volume of water wasted. Techniques based on locating leaks from pressure monitoring devices allow a more effective and less costly search in situ.

This paper presents a model-based methodology to detect and localise leaks. It has been developed within a project carried out

by Aguas Barcelona, Water Technological Centre CETAqua, and the Technical University of Catalonia (UPC). The objective of this project is to develop and apply an efficient system to detect and locate leaks in a water distribution network. It integrates methods and technologies available and in use by water companies, including DMA and flow/pressure sensor data, in conjunction with mathematical hydraulic models. The method is based on the analysis of pressure variations produced by leakage in the water distribution network (Pudar & Liggett, 1992). This technique differs from others in the literature, such as the reflection method (LRM) or the inverse transient analysis (ITA), since it is not based on the transient analysis of pressure waves (Ferrante & Brunone, 2003a, 2003b; Misiunas, Lambert, Simpson, & Olsson, 2005; Verde, Visairo, & Gentil, 2007). Alternatively, the leakage detection procedure is performed by comparing real pressure and flow data with their estimation using the simulation of the mathematical network model. Simulation of the network in presence and absence of leakage provides an approximation of pressure sensitivity of nodes in a network when a leak is present in a node. The approximation is used to generate a sensitivity matrix that is binarised using a threshold independent of the node. In order to successfully apply this methodology, the characterisation of district metered areas and consumers, considered a critical issue for a correct model calibration, should be also addressed but is not described in this paper (see, e.g. Perez, de las Heras, Aguilar,

* Corresponding author. Tel.: +34937398620; fax: +349373928.
E-mail address: ramon.perez@upc.edu (R. Pérez).

Pascual, & Peralta, 2009a, for further details). Another critical point is the data validation of DMA sensors that can be addressed as it is described for flowmeters in Quevedo et al. (2010). The paper also proposes a methodology for placing pressure sensors within a DMA that optimises leakage detection using a minimum number of sensors based on the approach proposed in Pérez et al. (2009b). Finally, the leakage detection methodology proposed will be tested with sensors installed in a DMA used as case study.

Section 2 reviews water distribution network modelling and presents the case study used to illustrate the proposed methodologies. Model-based fault detection and isolation techniques described in Section 3 are used for the leakage detection and location. Section 4 presents how the leak signature matrix is obtained from the pressure sensitivity matrix. Since the sensor placement is a critical issue for maximising discriminability, an algorithm is presented in Section 5. The signature matrix is generated for the set of sensors selected. This matrix has to be compared with the signature obtained comparing the model and the real measurements. From this comparison, the leakage is located in a set of possible nodes. This methodology is presented in Section 6 and is illustrated by simulation and real results. Finally, Section 7 summarises the conclusions.

2. Water distribution systems: plaça del diamant case study

A water distribution system consists of three major components: pumps, distribution storage, and distribution piping network. Most systems require pumps to supply lift to overcome differences in elevation, and energy losses caused by friction. Pipes may contain flow-control devices, such as regulating or pressure-reducing valves (Brdys & Ulanicki, 1994). The purpose of a distribution system is to supply the system's users with the amount of water demanded, under adequate pressure for various loading conditions. A loading condition is a spatial pattern of demands that defines the users' flow requirements.

2.1. Mathematical modelling

The governing laws for flow in pipe systems under steady conditions are conservation of mass and energy. The law of conservation of mass states that the rate of storage in a system is equal to the difference between the inflow to and outflow from the system. In pressurised water distribution networks, no storage can occur within the pipe network, although tank storage may change over time. Therefore, in a pipe, or a junction node, the inflow and the outflow must balance. For a junction node

$$\sum q_{in} - \sum q_{out} = q_{ext} \quad (1)$$

where q_{in} and q_{out} are the pipe flow rates into and out of the node and q_{ext} is the external demand or supply. Conservation of energy states that the difference in energy between two points is equal to the energy added to the flow in components between these points minus the frictional losses. An energy balance can be written for paths between the two end points of a single pipe, between two fixed graded nodes (a node for which the total energy is known, such as a tank) through a series of pipes, valves, and pumps, or around a loop that begins and ends at the same point. In a general form for any path

$$\sum_{i \in J_p} h_{p,j} - \sum_{i \in I_p} h_{L,i} = \Delta E \quad (2)$$

where $h_{L,i}$ is the headloss across component i along the path, $h_{p,j}$ is the head added by pump j , and ΔE is the difference in energy between the end points of the path. The primary network component is a pipe. The relationship between pipe flow (q)

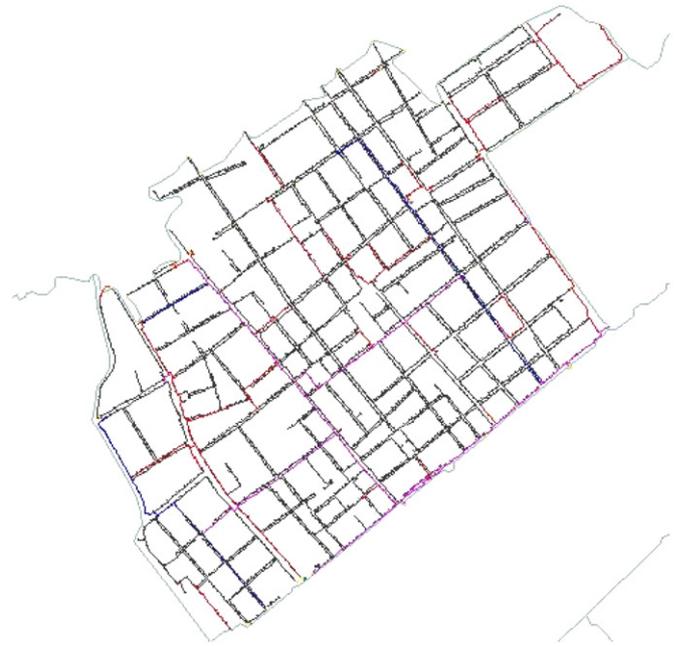


Fig. 1. Case study network: Plaça del Diamant.

and energy loss caused by friction (h_L) in individual pipes can be represented by a number of equations, including the Darcy–Weisbach and Hazen–Williams equations. The general relationship is of the following form:

$$h_L = Kq^r \quad (3)$$

where K is a pipe coefficient that depends on the pipe's diameter, length, and material and r is an exponent in the range of 2.

2.2. Plaça del Diamant DMA case study

The case study used to illustrate the leak localisation methodology presented in this paper is based on Plaça del Diamant DMA at the Barcelona Water Network (see Fig. 1). This DMA is used for illustrating the methodology. Its model contains 1600 nodes and 41.153 m of pipes. This DMA is simulated using PICCOLO software. Demands are assumed to occur in the nodes. In this paper, it will also be assumed that leaks occur at the nodes. Such assumption introduces a minor imprecision compared with those due to the methodology and the uncertainty of the model itself. Distance from the real leakage to the closest junction is much shorter than the diameter of the search zone obtained in the best case. It will be clear with results because the areas obtained include some pipes and nodes. Under such assumption, leaks can be seen as additional demands but with unknown location and quantity.

Simulated leaks introduced in the network are of 1 l/s, more or less 3% of the total demand of the sector (in the nighttime). The demand distribution all over the network is the most variable parameter of the model. Some uncertainty in the demand has also been included in order to test the robustness of the method.

3. Leakage detection and isolation methodology foundations

The methodology of leakage localisation proposed in this paper is mainly based on standard theory of model-based diagnosis described for example in (Gertler, 1998) that has already been applied to water networks to detect faults in flow metres (Ragot & Maquin, 2006) or in open channel with dynamic models (Bedjaoui & Weyer, 2011; Nejari, Pérez, Escobet, & Traves, 2006).

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