International Conference on Hydroinformatics

2014

A Gradient-Type Method For Real-Time State Estimation Of Water Distribution Networks

Olivier A. Piller

Idel Montalvo

Jochen W. Deuerlein

Denis Gilbert

Mathias Braun

See next page for additional authors

Authors
Olivier A. Piller, Idel Montalvo, Jochen W. Deuerlein, Denis Gilbert, Mathias Braun, and Hervé Ung

11th International Conference on Hydroinformatics
HIC 2014, New York City, USA

A GRADIENT-TYPE METHOD FOR REAL-TIME STATE ESTIMATION OF WATER DISTRIBUTION NETWORKS

PILLER OLIVIER (1), MONTALVO IDEL (2), DEUERLEIN JOCHEN (2), GILBERT DENIS (1), BRAUN MATHIAS (3) AND UNG HERVÉ (1)
(1): Irstea, UR ADBX, 50, avenue de Verdun, Cestas, F-33612, France
(2): 3S Consult GmbH, Office Karlsruhe, Albtalstrasse 13, D-76137 Karlsruhe, Germany
(3): Fraunhofer Institute IOSB, Fraunhoferstraße 1, D-76131 Karlsruhe, Germany,

Drinking water distribution networks risk exposure to malicious or accidental contamination. Several levels of responses are conceivable. One of them consists of installing a sensor network to monitor the system in real time. Once a contamination has been detected, it is also important to take appropriate counter-measures. The *SMaRT-Online*^{WDN} project relies on modeling to predict both the hydraulics and water quality. An online model use makes identification of the contaminant source and simulation of the contaminated area possible. The objective of this paper is to present *SMaRT-Online*^{WDN} experience and research results for hydraulic state estimations with sampling frequency of a few minutes. A least squares problem with bound constraints is formulated to adjust the demand class coefficient to best fit the observed values at a given time. The criterion is a Huber function to limit the influence of outliers. A Tikhonov regularization is introduced for consideration of prior information in the parameter vector. Then the Levenberg-Marquardt algorithm is applied that uses derivative information for limiting the number of iterations. Confidence intervals for the state prediction are also given. The results are presented and discussed on real networks in France and Germany.

STATE OF THE ART

Network parameters that are used in the hydraulic and transport models are often rough estimates. This is mainly because the distribution network is buried underground since a long time and the consumption at any time and location is random. The measurement values (pressure, flow, tank levels, concentration, conductivity, etc.) may be used to calibrate the parameters of both the hydraulic and the transport models, and to estimate the unknown state of the network. Given a set of network measurements, is it possible to derive all water quality and quantity unknowns of the network? Carpentier and Cohen [1] defined the observability problem as the one of determining whether the available set of measurements provides sufficient information for the state estimation. They define two levels of observability (topological, which may be assessed with graph theory, and algebraic, by means of analyzing the sensitivity matrix). The quality of the estimation of these parameters, which drives the quality of the predictions, depends on the position, number and nature of the measurements. This choice must ensure the observability of the network but also prevents small errors in measurement resulting in incorrect estimations of the parameters [2].

Several fitness functions may be selected for the parameter calibration. For a review of them, application of hydraulic modeling and suggestion of additional fitness functions and entropy-based criteria one may consult de Schaetzen [3] or still Savic *et al.* [4]. A least-squares formulation that minimizes the deviations between some predicted values and corresponding observations is a standard approach for overdetermined systems. Its weighted form has the advantage of dealing with errors in observations. When the latter ones come from exponential family distribution (e.g., the Gaussian) the weighted least-squares (WLS) minimization problem corresponds to a maximization of a likelihood function. The WLS problem reads:

$$\min_{\underline{\mathbf{x}} \le \mathbf{x} \le \overline{\mathbf{x}}} \quad \tfrac{1}{2}\int_{t_0}^{t_f} \left(\mathbf{S}\mathbf{y}(\mathbf{x},t) - \mathbf{y}^{mes}(t)\right)^T \mathbf{W}\left(\mathbf{S}\mathbf{y}(\mathbf{x},t) - \mathbf{y}^{mes}(t)\right) dt \qquad (1)$$

where **x** is the vector of parameters to determine; **y**(**x**,t) is the hydraulic and transport state that is implicitly defined by the hydraulic and transport equations; **S** is the selection matrix to select the state vector components that corresponds to the measurements; $\mathbf{y}^{\mathrm{mes}}$ is the vector of measurements; and **W** is a diagonal weight matrix. Most authors have considered a simpler form of (WLS) without the time dependency, for example Kapelan *et al.* [5] or, with a quadrature formula for the integral, Piller [6].

Preis *et al.* [7] use the Huber function to modify the least-squares criterion Eq. (1) for large residuals to be least absolute deviations (L^1 norm). This way the parameter estimation is more robust against outliers. More efficient solving methods are gradient type methods that use derivatives of the criterion; for example, [6] applies the Levenberg-Marquardt (LM) method for solving WLS calibration problems for water distribution networks. However, as the criterion may exhibit several local minima (and maxima) a genetic algorithm (GA) was preferred for the first iteration steps in a hybrid GA/LM approach, see Kapelan [5]. In that situation, Piller *et al.* [8] propose to convexify the LS criterion with addition of a Tikhonov regularization term that penalizes departure from a prior solution.

CONCLUSION

In the *SMaRT-Online^{WDN}* project we applied calibration state-of-the-art for real-time demand calibration of large-size networks in France and in Germany with hydraulic and water quality models from Porteau software [9] and Sir 3S software [10]. A constrained Least-squares problem is solved with a projected Levenberg-Marquardt method. The criterion consists of two terms, a Hubert function of the residuals and a Tikhonov regularization term, for convexification of the problem. The main novelty here is that we got online “reliable” models with time step sizes inferior to 20 min.

ACKNOWLEDGEMENTS

The project is supported by the German Federal Ministry of Education and Research (BMBF; project: 13N12180) and by the French Agence Nationale de la Recherche (ANR; project: ANR-11-SECU-006).

REFERENCES

[1] Carpentier P. and Cohen G., "State Estimation and Leak Detection in Water Distribution Networks ", *Civil Engineering Systems*, Vol. 8, (1991), pp. 247-257.

[2] Piller O., Bremond B., and Morel P, "A Spatial Sampling Procedure for Physical Diagnosis in a Drinking Water Supply Network*", International Conference on Computing and Control for the Water Industry CCWI '99*, Exeter, UK, Vol. 1/2, (1999), pp. 309-316.

[3] de Schaetzen W.B.F., "Optimal Calibration and Sampling Design for Hydraulic Network Models*", Engineering thesis from the University of Exeter*, Exeter, UK, (1000), 277 pages.

[4] Savic D. A., Kapelan Z. S., and Jonkergouw P. M. R., "Quo vadis water distribution model calibration? ", *Urban Water Journal*, Vol. 6, No. 1, (2009), pp. 3 - 22.

[5] Kapelan Z., "Calibration of water distribution system hydraulic models", *Engineering thesis from the Univ. of Exeter*, Exeter, UK, (2002), 335 pages.

[6] Piller O., "Modeling the behavior of a network - Hydraulic analysis and sampling procedures for parameter estimation", *Applied Mathematics thesis from the University of Bordeaux (PRES)*, Talence, France, (1995), 288 pages (in French).

[7] Preis A., Whittle A. J., Ostfeld A., and Perelman L., "Efficient Hydraulic State Estimation Technique Using Reduced Models of Urban Water Networks", *Journal of Water Resources Planning and Management*, Vol. 137, No. 4, (2011), pp. 343-351.

[8] Piller O., Gilbert D., and Van Zyl J., "Dual Calibration for Coupled Flow and Transport Models of Water Distribution Systems", Water Distribution Systems Analysis 2010, Tucson, AZ, (2011), pp. 722-731.

[9] Porteau, Irstea (2014). http://porteau.irstea.fr/, last access on the 30th March 2014.

[10] SIR 3S, 3S Consult, (2014). http://www.3sconsult.de/sir3s.html, last access on the 30th March 2014.