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ScienceDirect

Procedia Engineering 119 (2015) 13 – 18

Procedia Engineering

www.elsevier.com/locate/procedia

13th Computer Control for Water Industry Conference, CCWI 2015

Real-time burst detection in water distribution systems using a Bayesian demand forecasting methodology

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Abstract

The negative consequences of non-revenue water losses from Water Distribution Systems (WDS) can be reduced through the successful and prompt identification of bursts and abnormal conditions. Here we present a preliminary investigation into the application of a probabilistic demand forecasting approach to identify pipe bursts. The method produces a probabilistic forecast of future demand under normal conditions. This, in turn, quantifies the probability that a future observation is abnormal. The method, when tested using synthetic bursts applied to a demand time-series for a UK WDS, performed well in detecting bursts, particularly those >5% of mean daily flow at night time.

Peer-review under responsibility of the Scientific Committee of CCWI 2015

Keywords: Pipe Burst, Detection, Demand Forecast, Bayesian Statistics, Anomaly Detection, Probability

1. Introduction

Non-revenue water losses in Water Distribution Systems (WDS) resulting from background leakages and pipe burst events come at significant financial cost to water companies because of the loss of treated water, and repair costs. Furthermore, substantial leakages can result in customer service interruptions, resulting in further costs to the water company. As a result of these issues, coupled with additional pressures on water supply resulting from population growth and climatic changes, there is a need to detect pipe bursts as soon as is possible, thereby reducing water loss, associated costs, and service disruption to consumers.

Developments in hydraulic sensor technology and on-line data acquisition systems has enabled water companies to collect larger, and more accurate datasets to understand the state of their distribution networks. In turn, a number of methods and algorithms have been developed that attempt to utilize these data to detect bursts [1, 2, 3, 4, 5]. The variability in pressure and flow signals returned from online sensors will reflect changes in both consumer demand

Peer-review under responsibility of the Scientific Committee of CCWI 2015
doi:10.1016/j.proeng.2015.08.847

and abnormal demand (e.g. bursts and leaks). Thus, methods for burst detection are often based on analysis of the difference between measured demand and a forecasted water demand, derived under (assumed) normal, non-burst conditions [1]. Such detection methods need to make an appropriate trade-off; they need to differentiate between normal and abnormal demand successfully in order identify real bursts, whilst also avoiding false alarms. The quality of this tradeoff, and therefore the accuracy of burst detection, ultimately depends on the accuracy of the demand forecast. Demand forecasting is, however, highly uncertain, due to a range of socio-economic factors that affect demand, and limited meter penetration in many countries, which limits the accuracy of any forecast. To make appropriate use of demand forecasts to identify bursts, and achieve an appropriate trade-off in burst detection, an understanding of forecast accuracy is beneficial.

This paper presents the first stage in the development of a methodology for burst detection based on a probabilistic demand forecasting approach [6]. The approach utilizes the probabilistic forecast of future normal demand to quantify the likelihood of abnormal conditions. We compare the performance of two probabilistic approaches for quantifying demand uncertainty when applied to detect bursts: the first, based on a Gaussian assumption of residual errors in the demand forecast; the second, based on a heavy tailed, heteroscedastic quantification of future demand uncertainty. Section 2 describes the methodology, which in this paper is initially applied to a synthetic case study, based on a District Meter Area (DMA) in the UK (Section 3).

2. Methodology

The methodology here is developed for the detection of abnormal conditions (e.g. pipe bursts) from sensor measurements in a DMA, which for narrative purposes are here assumed to be pipe flows. In order to identify abnormal conditions the methodology calibrates a model to forecast future pipe flows from a given sensor, based on past recorded values, which are assumed to have been recorded under normal conditions (e.g. no burst). Once applied online, the residual difference (ε) between the forecasted pipe flow and the actual observed pipe flow can be used to infer whether a burst has occurred. A deterministic forecast of future flow, however, provides no information on predictive uncertainty, which might compromise the accuracy of burst detection if, at a particular forecast time, the model forecast error is large, and therefore dominates ε. Hutton and Kapelan (2015) [6] developed a probabilistic approach for the development of demand forecasting models, to derive a statistically robust description of model forecast errors. Here, instead of using a deterministic forecast error, the probabilistic description of prediction uncertainty is used as the base metric upon which to detect burst conditions.

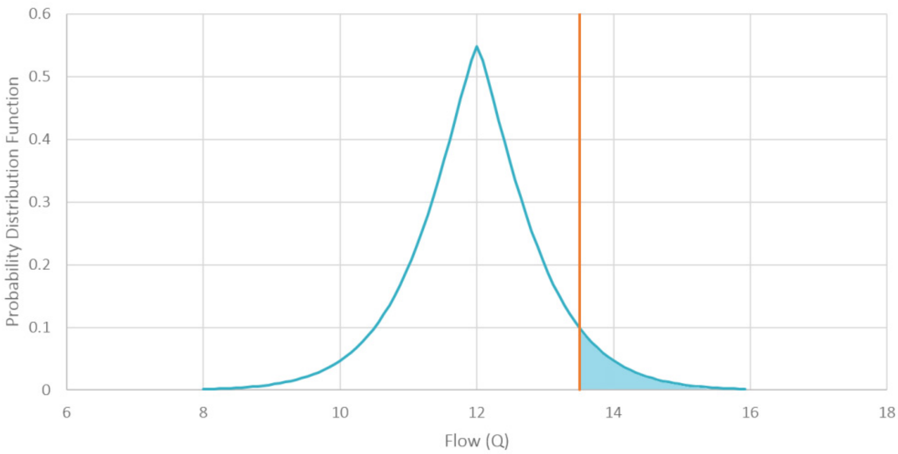

Fig. 1. Probabilistic forecast of future flow under normal conditions (green distribution) at time *t*; Observed flow at time *t* (vertical orange line); probability of observing larger flow than observed, under normal conditions (blue shaded area).