Detecting and Localizing Leakage Hotspots in Water Distribution Networks via the Regularization of an Inverse Problem: An Application to the Battle of Leakage Detection and Isolation Methods 2020 Competition

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ABSTRACT

Introduction

Near real time leak (burst) detection and localization in water distribution networks is a critical activity for water companies in order to manage their serviceability commitments and reduce water losses. In this study, we investigate the application of a hydraulic model-based leak detection and localization method, which uses an inverse problem formulation, on the data set provided for the Battle of Leakage Detection and Isolation Methods 2020 [1].

A major challenge in detecting and localizing leaks using a hydraulic model are the uncertainties associated with customer demand, frictional head loss coefficients and additional factors such as unknown status of control components. In addition, the number of measurement locations in operational networks is significantly smaller than the number of possible leak locations which results in an ill-posed inverse problem.

The proposed analysis includes the application of a tailored k-means algorithm to partition the daily water demand into a set of clusters to identify changes in water demand. The identified changes in the water demand profile are then investigated within a two-stage leak detection and localization process. In the leak detection stage, flow residuals between measured and predicted water demand are analyzed. The leak localization stage is based on solving a regularized inverse problem [2]. The problem formulation, which is described in detail in [2], is extended to account for multiple time steps simultaneously and it includes the modelling of pressure reducing valves (PRVs).

Method

The analysis to detect and locate leaks in the data set, which is provided for the Battle of Leakage Detection and Isolation Methods, is described in Figure 1.

Firstly, the daily demand profiles for the whole network over a period of one year (e.g. 2019) are partitioned into clusters using the k-means algorithm with a correlation-based distance function. The clusters correspond to days with similar flow patterns so that variations in the derived clusters can be used to identify changes in demand that may be attributed to leaks. In this way, weekly and seasonal water demand variations are also identified.

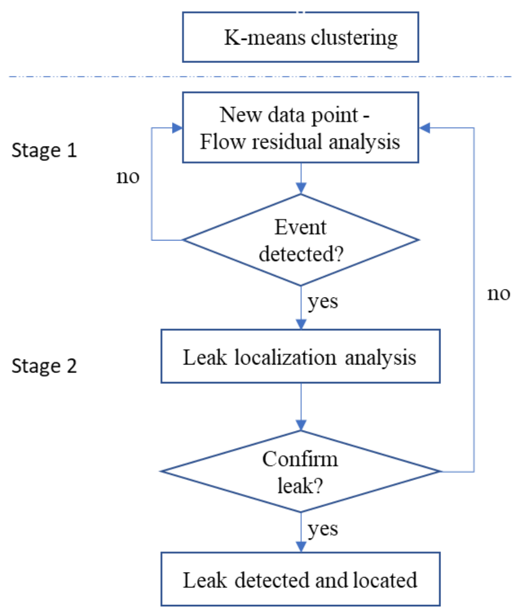

Figure 1 Leak detection and localization process

To investigate the presence of leak events (Stage 1 in Figure 1), flow residuals, which are the difference between the expected demand and the measured flow, are calculated. The expected water demand is derived from the flow profiles of five preceding days based on their cluster membership. If the residuals show an abrupt or gradual increase in flow, a possible leak event is detected, and the leak localization analysis is applied to confirm or reject the leak event hypothesis (Stage 2 in Figure 1). If the residuals do not indicate a leak event, the residual obtained with the next data point (measurement) is evaluated.

For the leak localization analysis, the inverse problem formulation described in [2] is extended to include the modelling of PRVs. The inverse problem is solved every 30 minutes, using 13 data readings over a 1-hour moving window. Each solution of the regularized inverse problem results in a set of candidate nodes (leakage hotspot area). If the same set of candidate nodes is identified using data from several 1-hour time windows, the occurrence of a leak is confirmed. If the presence of a leak cannot be confirmed, the event detected by the flow residual analysis is rejected.

Results

The leak detection and localization process is illustrated using a burst event in January 2019.

Table 1 shows days in January 2019, which have been partitioned into different clusters based on the k-means clustering for the entire 2019 data set. The k-means algorithm also distinguishes between weekends and weekdays, and it identifies a change in the daily flow profile on 16th of January, 2019.

Tue	Wed	Thu	Fri	Sat	Sun	Mon
01. Jan	02. Jan	03. Jan	04. Jan	05. Jan	06. Jan	07. Jan
08. Jan	09. Jan	10. Jan	11. Jan	12. Jan	13. Jan	14. Jan
15. Jan	16. Jan	17. Jan	18. Jan	19. Jan	20. Jan	21. Jan

Table 1 Flow profile clusters in January 2019

The predicted water demand for the 15th and 16th of January, 2019, is estimated from the daily flow profiles of the preceding five days, which belong to the same cluster (e.g. demand of weekdays between 8th and 14th January). Figure 2 shows the residuals calculated using the difference of predicted demand and measured demand for a time period between 14th and 18th January. A step change (increase) in flow is detected at 23:00 hrs on the 15th January 2019. The water flow increase is approximately 7 l/s.

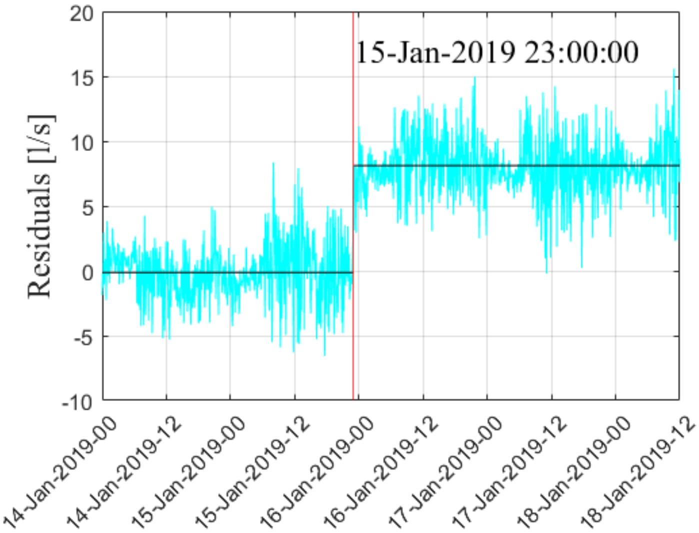

Figure 2 Flow residual analysis 14th to 18th January 2019

To confirm or reject this leak event hypothesis, the leak localization problem is then solved using data collected over 1h time windows. Figures 3 and 4 show the leak localization results before, during and after the leak event is detected.

The results using data up to 23:00 hrs on 15th January 2019 indicate either no leaks or varying attributed leak coefficients. As soon as the time window includes data collected after 23:00 hrs, the localization results produce a consistent set of leak candidates. This confirms the detection of a leak event occurring at 23:00 hrs. As stated in the method section, the solution to the inverse problem formulation results in a set of nodes that are possible leak candidates. In order to satisfy the requirements of the Battle, where only one pipe has to be listed as the identified leak location, we select the pipe adjacent to the center of the detected leak hotspot area.

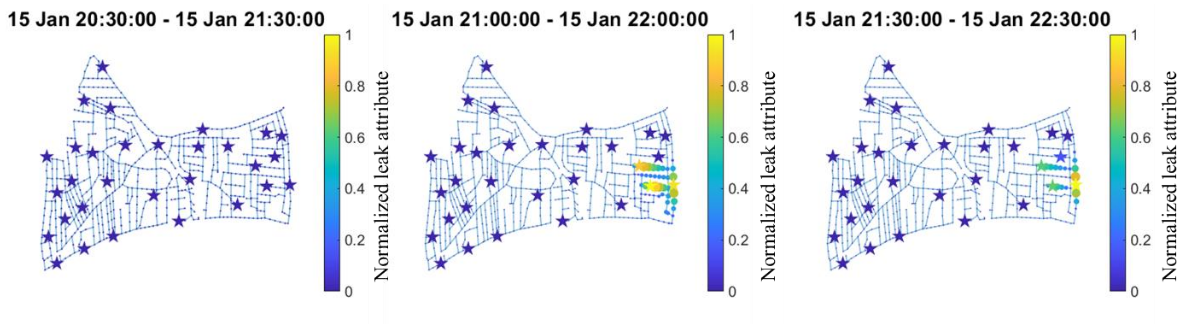

Figure 3 Leak localization results up to 23:00 hrs on 15th of January, 2019

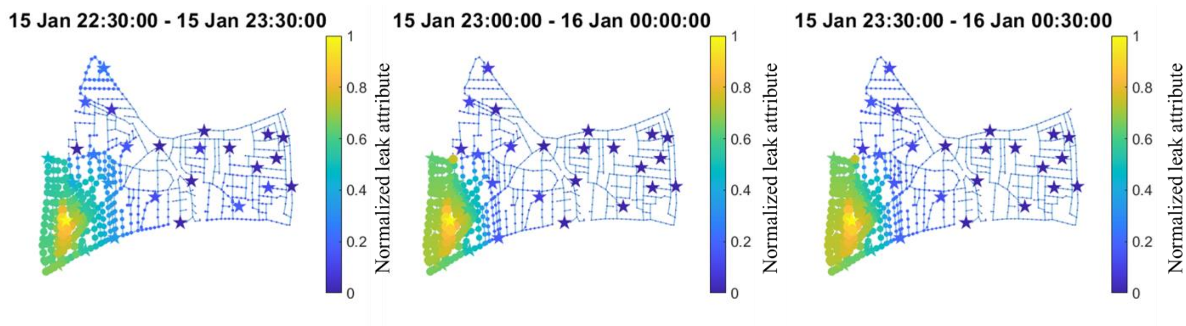

Figure 4 Leak localization results before, during and after 23:00 hrs on 15th of January, 2019

Discussion and conclusion

For the 2019 data set, we detected and located nine leak events ranging from small leaks to bursts in the areas A and B, and one leak event in area C.

The method identifies a leak hotspot area to allow operators to target a specific sub-area for a further investigation of the exact leak location. A key advantage of the proposed method is that it can identify multiple hotspot areas when multiple leaks are present simultaneously. However, in the context of the Battle of Leak Detection and Isolation Methods 2020, a single candidate was derived from an identified hotspot area. This will inevitably introduce uncertainties in the estimate of the exact leak location.

The localization method relies on the application of a calibrated hydraulic model. Consequently, the minimum size of detected and localized leak events depends on the uncertainties associated with the hydraulic model.

Keywords: Battle of leak detection and isolation 2020, Water distribution networks

SUMMARY

The application of a model-based leak localization method on the data set provided for the Battle of Leakage Detection and Isolation Methods 2020 is investigated. First, an analysis of flow residuals is used to detect a possible leak event which is then confirmed or rejected by the model-based leak localization. A prior clustering of daily flow profiles results in the identification of possible leak days, and leak-free days, in the entire data set.

REFERENCES

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