Demo Abstract: Real-time Burst Event Detection in Water Distribution Systems

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ABSTRACT
In this paper, we present an overview of a system that we are developing for the continuous monitoring of water distribution systems in Singapore. We discuss the design and implementation of the system that enables real-time detection of pipe burst events.

Categories and Subject Descriptors
C.2.4 [**Distributed Systems**]: Distributed applications

General Terms
Design, Experimentation, Measurement.

Keywords
Sensor networks, water distribution system, burst event detection.

1. INTRODUCTION
In recent years, there has been tremendous progress in deploying wireless sensor network technology in the real-world for practical applications. Sensor networks are now designed for long-term monitoring of physical environments, and they have enabled us to monitor environments and detect events in real time with high precision.

Large-scale urban utility infrastructures are critical systems that affect a large number of people and thus require proper monitoring and maintenance. A city-wide water distribution system (WDS) is a good example of such infrastructures. Sudden pipe bursts may occur in high-pressure water transmission and distribution pipelines in a WDS. These events can be very expensive and disruptive due to the outage time while the pipe is repaired, the cost of repair, and the damage to surrounding property and infrastructure. Thus, it is necessary to minimize the detection and location time after the burst event occurs. Currently, the high cost of continuous monitoring of a WDS limits the data collection to a small number of locations. There were some previous proof-of-concept efforts to develop a WDS monitoring system [1,2]. They report leak detection results for laboratory tests done on single pipe section.

We are currently developing a large-scale sensing infrastructure for continuous monitoring of WDS in Singapore as part of the WaterWise@SG project. This is a real-life system implementation with the system design being driven by application requirements. The goals of this monitoring system are: (i) continuous pressure measurements at critical points in the WDS for integration with hydraulic models to improve operational efficiency through demand prediction, (ii) monitor water quality parameters and detect presence of contaminants, and (iii) develop techniques to detect and localize pipe bursts using pressure and acoustic signatures, and state parameter approaches for slow leaks.

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2. SYSTEM DESIGN AND DEPLOYMENT
The design of the current prototype WaterWise@SG WDS monitoring system is illustrated in Figure 1. The sensors are inserted into the water distribution pipelines via tapping points, and measure parameters such as pressure, audio and water quality. The sensor nodes also log and transmit diagnostic data such as battery level, data transmission statistics and memory usage. The sensor nodes perform some local processing of the recorded data before transmitting it to the backend data archive. The data is windowed into 30 second files and compressed before transmission. All the nodes are time-synchronized within 1 msec using GPS, which is used to globally time-stamp the data.

On the server side, the data is parsed, pre-processed and archived into the database as well as file system. We have implemented a suite of data processing and analytical tools on the server including algorithms to detect leak and pipe burst events, and hydraulic models to predict demand patterns. The analysis results of these models and algorithms are made available via a web portal. In addition, we have various services running on the web server, such as a station map depicting the current status of the network deployment, interactive plotting of real-time and archived data, and data download facility to client machines.

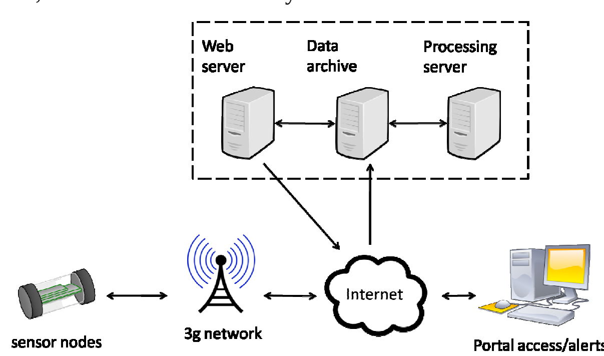

Figure 1. WaterWise@SG system design.

The WaterWise@SG WDS monitoring system will be deployed in three phases. The first phase has been successfully completed. We have installed 8 sensor nodes at locations in downtown Singapore, sampling pressure and audio data at 2 kHz. The following key objectives have been achieved during the first phase: (i) capturing high data rate sensor data for integration with the hydraulic models and developing data analysis algorithms, (ii) gaining experience with a long running test bed, and (iii) developing middleware and algorithms for real-time event detections.

3. BURST EVENT DETECTION

We have carried out controlled leak-off experiments to gather data for developing and analyzing burst detection algorithms. During these experiments a solenoid-controlled valve is connected to the pipeline via an air-valve or fire hydrant. Pipe burst events are artificially created by opening the valve within 0.1 sec. The fast opening of the solenoid-activated valve creates a sudden pressure drop which can travel a long distance along the pipe before being fully damped. This pressure front and the associated transients were recorded by the sensor nodes.

We have developed a light-weight, statistics-based feature identification algorithm which uses three simple statistics computed from the time-domain data to identify features in the pressure signal. The running variance allows us to identify signals which are noisy and not well-suited for automated detection. The max-min difference helps to identify signals with abnormal pressure variations, and the windowed gradient helps to identify sharp transients in the pressure signal. As an example shown in Figure 2, the sharp pressure drop associated with an emulated pipe burst event is clearly registered by the variance (by setting an appropriate threshold). The statistics-based algorithm can be used to identify interesting features in the pressure data. As the pressure data is recorded by the sensor nodes, the middleware modules compute the above mentioned statistics and these are input to a burst detection algorithm running on the sensor nodes.

Based on the preliminary detection by the sensor nodes, the identified signal features are further analyzed by a wavelet-based detection/classification algorithm. The wavelet-based algorithm allows us to classify various types of events and identify pipe burst events. These algorithms are currently implemented on the server. However, the eventual goal is to move all the event detection processing to the nodes. In future phases of the network deployment, this will enable us to eliminate the need for transmitting all the high-rate pressure and acoustic data to the backend data archive. Instead, the sensor nodes will exchange data between themselves for cross-correlation and transmit the high-rate data to the server only when they detect an event.

The wavelet-based detection algorithm enables us to determine the approximate time of the pressure front arrival (due to the down-sampling operation during the wavelet decomposition) at various sensor node locations. These time estimates are further refined by a local search algorithm. Finally, to determine the location of the pipe burst [3], the arrival time estimates of the pressure front are input to a burst/leak localization algorithm. Our localization algorithm uses a graph-based search procedure to determine the physical location which best matches the observed pressure front arrival time differences across the various sensor node location pairs. This is identified as the most probable burst location.

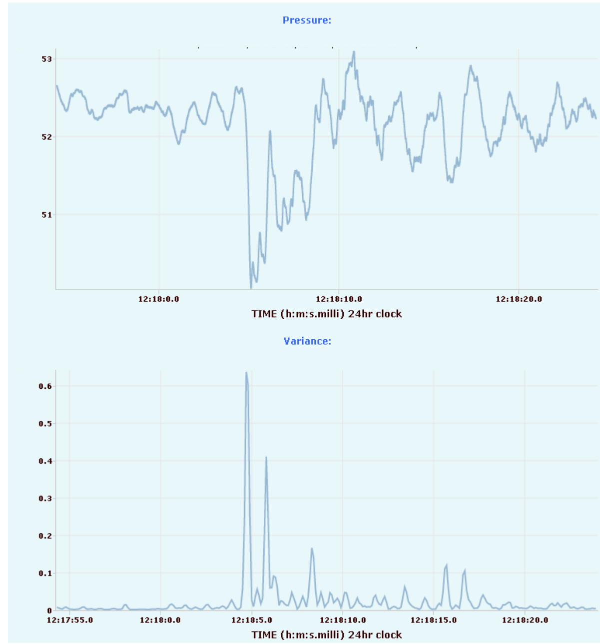

Figure 2. Statistical analysis of pressure data from an emulated pipe burst event.

4. DEMONSTRATION HIGHLIGHTS

During the demonstration, we will playback real data from some of the leak-off experiments and show how burst event detection can be achieved. Results of the statistics-based feature identification trigger the wavelet-based detection/classification algorithm running on the server. We will display the raw pressure data (as it streams in), the results of the wavelet-based algorithm and the time instants when the burst event was detected at various sensor node locations on the web portal. These time estimates will be input to the localization algorithm to determine the location of the burst event which will be displayed on a map.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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