A Real Time Method to Detect the Burst Location of Urban Water Supply Network

Weiping Zhang[b], Jingqing Liu,[a,]* Li Feihan[b] , Yalin Li[b] Xiujuan Li [b], Zhiman Shi [b], Junfeng Yu[b], Jiangxia Wang[b] ,

[a]*Zhejiang University College of Civil Engineering and Architecture, 310027, Hangzhou, Bld. AnZhong, Zijingang Campus*

[b]*Binhai Industrial Technology Research Institute of Zhejiang University, 300301, Tianjin, Binhai High Tech Zone Gaoxin 6Road China;*

**corresponding.Liu Jingqing, Email: zhangweiping@zjubh.com.*

ABSTRACT

This paper proposes a practical method for rapid and accurate detection of pipe burst segment. By using the water pressure of the measuring points that are optimally arranged in the water supply network through the SCADA system and utilization status assessment, calculates the water pressure of all nodes of the network under the normal state and the pipe burst state and characteristic value of pipe burst based on the limited information collected through the measuring points and finally determine the pipe burst location by fuzzy similarity priority ratio. This method is combined with SCADA system to effectively utilize the pressure measuring points in the pipe network and make the whole pipe network under real-time control by combining with the state estimation. Our burst identification and location model has been applied to pipes burst events in 2018, which verifies the validity of the model. We applied the model to 2019 data, identified 8 pipe burst events, and predicted the time and location of pipe burst.

Extended Abstract

In the water supply network, the detection and location process of pipe burst can be divided into detection and location where the detection process determines the start and end time of pipe burst, and the location process is used to confirm which pipe is burst. In pipe burst detection, we use WNTR tool[1] to calculate the difference between simulated value and actual monitoring value to extract pipe burst signal. In fact, under the working condition of DWDN without burst pipe, the monitored value will still fluctuate up and down under the influence of water demand, which is called noise. This noise will interfere with the identification of burst pipe to some extent. In order to reduce the interference and enhance the burst signal, we corrected the water demand by DFM algorithm[2], and then calculated the difference between the simulated value and the actual monitoring value after demand calibration. The detection and location process mainly includes: 1) definition and calculation of characteristic values of pipe burst, and 2) determination of fuzzy similarity priority ratio and pipe burst location.

We have verified the burst location model with burst events in 2018, as shown in Figure 2, where the red line is the real burst pipe, and the green line is the model positioned pipe, from which we can see that our model can accurately locate the burst pipe. Based on the analysis of the data in 2019, through the above analysis method, it is identified that there are 8 pipe explosion events in 2019, including 6 in Zone A, 1 in zone B and 1 in zone C.

To localization pipe burst, it is realized by comparing the similarity ranking between the real pipe burst characteristic value and the simulated pipe burst characteristic value of different pipe sections, which mainly includes six steps: generating the pipe burst node, water demand distribution, generating the pipe burst pattern, pipe burst simulation, calculating the similarity, and pipe burst location.

1. Generate Pipe burst node. Firstly, the leakage node is generated at the middle point of each pipe section, and the process of simulating the leakage of pipe section can be equivalent to the process of adding leakage amount to the leakage node for hydraulic simulation.

2. Water demand distribution. Before the hydraulic calculation, the water demand distribution is required first. According to the monitored data of reservoir flow, pump flow and level change in Zone C, the total water supply can be calculated. Then, after deducting the leakage, combined with the water consumption

mode of each node and the data of remote transmission meter in zone C, the water demand of each node under normal working conditions can be obtained. The water demand of each node can be obtained by distributing the deducted leakage to the specified node.

3. Generate burst pattern. In order to optimize the time of the whole simulation calculation, it is necessary to simulate the change of the pressure detection point after each pipe burst. We define a burst pattern matrix M × n, as shown in Fig. *, M is equal to the number of burst nodes, n is equal to m + 1, each of which represents the burst pattern of a burst node. Among them, the number of the first row is all zero, which is used to simulate the pressure monitoring point value under normal working conditions. Columns 2 to N form a diagonal matrix, with the letter N of the diagonal representing the amount of leakage.

$$\begin{bmatrix} 0 & n & 0 & 0 & 0 & 0 \\ 0 & 0 & n & 0 & 0 & 0 \\ 0 & 0 & 0 & n & 0 & 0 \\ 0 & 0 & 0 & 0 & n & 0 \\ 0 & 0 & 0 & 0 & 0 & n \end{bmatrix}$$

4. Pipe burst simulation. Each row of the burst pattern matrix is allocated to each corresponding burst node, and then the burst simulation of each burst segment is carried out by using the delay simulation function of EPANET. The pressure value of the monitoring point under normal working condition and the pressure value of the monitoring point under different pipe burst conditions can be obtained, and the difference between the pressure change of the monitoring point under normal working condition and simulated pipe burst condition can be calculated as the characteristic value of pipe burst. The difference between the normal working condition and the real monitoring point pressure change is calculated as the real burst characteristic value.

5. Calculate the similarity. The similarity between the characteristic value of Pipe burst and the real characteristic value of Pipe burst is calculated. The reference indexes of similarity calculation include Pearson correlation coefficient, Jaccard similarity coefficient and Euclidean distance.

6. Location of explosion Pipe. Through the comparison of three indexes, the similarity degree between the characteristic value of each pipe section and the real characteristic value of each pipe section is ranked. Finally, the pipe section with the largest similarity degree is taken as the pipe section of the pipe section to complete the location of the pipe section.

1 Characteristic Values of Pipe Burst

1.1 Definition of Characteristic Values of Pipe Burst

From the perspective of hydraulics, the pipe burst of the pipe network can be regarded as a sudden increase in flow, which will inevitably cause the change of the operating state of the pipe network, resulting in a series of changes in the pipe network state, such as the water pressure at the nodes, flow rate of the pipe segment and head loss of pipe segment etc. When a new flow suddenly appears in the pipe network, studying the water pressure change of the pipe network before and after the new flow, we can found that the water pressure change value forms a certain fluctuation characteristic on the whole. The value of the water pressure change of each node used to represent the characteristic is called the burst flow characteristic value. Since the same new flow causes different maximum node pressure change values at different pipe segments, we standardized the characteristic values of burst flow. The standardized characteristic value of the burst flow is called the characteristic value of pipe burst, which will only change very slightly with the change of the burst flow in the same pipe segment, thus it can be used as the basis to distinguish the size and location of the new flow.

1.2 Calculation of Characteristic Value of Pipe Burst

When the water supply pipe network is abnormal, the information of the reference state of the pipe network can be obtained by conducting calculation and analysis of the reference state of the pipe network. The characteristic values of the burst pipe can be obtained by comparing the reference state of the pipe network with the actual operating state of the pipe network [3]. It is the difference between the water pressure under reference state $(H_{k,1}, H_{k,2}, \ldots, H_{k,JD})_{basis}$ and the water pressure under the state of pipe burst $(H_{k,1}, H_{k,2}, \ldots, H_{k,JD})_{break}$. Obviously, the maximum change in nodal water pressure value ΔH_{max} should be at a certain node in the segment where the outlet flow occurs.

When calculating the characteristic value, the reference state and the burst state are known, In this case, the characteristic value of pipe burst can be obtained by Calculating hydraulic adjustment of pipe network, and then minus the node pressure under the burst state by the water pressure of the corresponding nodes under reference state.

$$\Delta H_{k,1} = (H_{k,1})_{break} - (H_{k,1})_{basis}, \quad \Delta H_{k,2} = (H_{k,2})_{break} - (H_{k,2})_{basis}, \dots \quad (1)$$

The ΔH_{max} caused by the same outlet flow on different pipe segments is not the same. In order to facilitate analysis and comparison, all elements in each column are standardized, that is, $\Delta H_{k,i}$is treated as follow:

$$X_{k,i} = \frac{\Delta H_{k,i}}{\Delta H_{max}} \quad (i = 1,2, \dots, JD) \qquad (2)$$

$\Delta H_{k,i}$ stands for water pressure change at node i when there is intermediate leakage ΔQ_k in pipe segment k.

ΔH_{max} sands for maximum water pressure change at node i when there is intermediate leakage Q_k in pipe segment k (theoretically it should be one of the two ends of pipe segment k) .

X_k is used to represent characteristic value of pipe bust, The characteristic value of all pipe segments $X_k = (X_{k,1}, X_{k,2}, \dots, X_{k,JD})$ is represented by the following matrix:

$$X_{k,i} = \begin{bmatrix} X_{1,1} & X_{1,2} & \cdots & X_{1,JD} \\ X_{2,1} & X_{2,2} & \cdots & X_{2,JD} \\ \cdots & \cdots & \cdots & \cdots \\ X_{p,1} & X_{p,2} & \cdots & X_{p,JD} \end{bmatrix}_{p\times JD} \qquad (3)$$

The matrix above is the characteristic value of all pipe burst under the ideal state. When the outlet flow ΔQ_k changes, the characteristic value of pipe burst will also change, but when the outlet flow of the burst pipe exceeds 4% of the total water supply, this change is not obvious. Therefore, when calculating the actual characteristic value of pipe burst of the pipe network, the average daily water leakage can be calculated according to the size of the local water leakage rate. The average daily water leakage is taken as the outlet flow of the pipe burst in one pipe segment, and this group of characteristic values is taken as the characteristic values of all the burst pipes of the pipe network under the ideal state.

2 Determination of Fuzzy Similarity Priority Ratio and Pipe Burst Location

2.1 Introduction of Fuzzy Similarity Priority Ratio

Similarity priority ratio is a form of fuzziness measurement, which is to compare a pair of samples with a fixed sample to determine which one is more similar to the fixed sample, so as to choose the one with a greater degree of similarity to the fixed sample. In this paper, the paired samples are the characteristic values of pipe burst in P pipe segments of a fixed pipe network, and the fixed samples are the calculated characteristic values of pipe burst in a certain pipe segment when pipe burst occurs.

Assuming that samples x_i and x_j are compared with fixed samples x_e, their similarity priority ratioR_{ij} must meet the requirements:In fuzzy priority ratio analysis, Hamming distance is generally adopted as a measurement of R_{ij} in similarity priority ratio. According to calculate the similarity priority ratio between the two samples we obtain the fuzzy similarity matrix. After the fuzzy similarity matrix is established, the similarity sample is selected from the λ level set. In general, if there are m factors in each sample, there will be a fuzzy similarity matrix for each factor. Therefore, each factor in each sample will generate an ordinal value reflecting the degree of similarity. Finally, the ordinal values of each factor in each sample will be added and the result is a comprehensive reflection of the similarity degree between the sample and the fixed sample.

2.2 Positioning of Pipe Burst

2.2.1 Similarity Analysis

The similar system refers to the existence of several similar elements between systems. The more similar elements there are between two systems, the greater the value of similar elements, and this will lead to a higher degree of similarity between two systems.

The location of pipe burst can be seen as the similarity comparison between the corresponding characteristic values of pipe burst in pipe segment A of the pipe network and the characteristic values of pipe burst in each pipe segment (including pipe segment A) under the ideal state. It can be seen from figure 1 that when a pipe burst occurs in the same pipe network and in the same pipe, the amount of water leakage can change the variation value of water pressure, but the overall change trend of water pressure at each node does not change. If the pressure changes at each node caused by each change in water leakage are considered as a system, it shows that the systems are similar to each other.

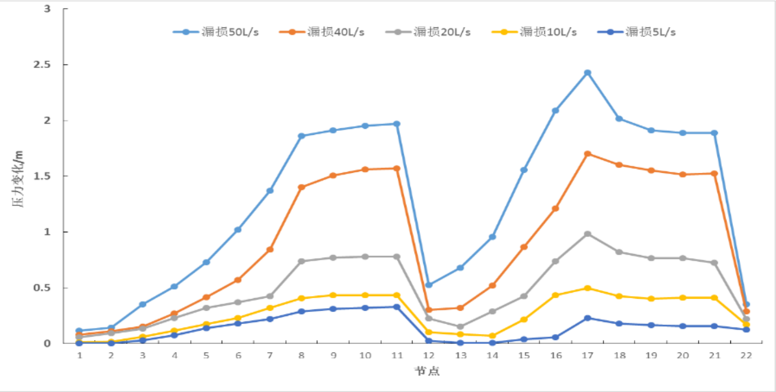

Figure 1. Node Pressure Changes in one pipe under Different Outlet Flow of Pipe Bursts

2.2.2 Positioning

For a fixed pipe network, the daily average leakage quantity is taken as outlet flow of pipe burst of each pipe segment to calculate the characteristic value matrix $[x_{ki}]$ of the burst pipe in the ideal state. The matrix is used as the sample to be identified. When the pressure at the pressure measuring point drops suddenly and exceeds the pressure warning line of the SCADA system, the SCADA system will send out an alarm message to estimate the status of the burst pipe and obtain the water pressure at each node. The characteristic value of pipe burst is calculated according to equation (1). The characteristic value of the pipe burst is $X_k^{'} = (X_{k,1}, X_{k,2}, \ldots, X_{k,JD})$and it is taken as a fixed sample. By comparing all the characteristic values of pipe burst in the ideal state with the characteristic values of pipe burst under the pipe burst state, that which characteristic values of pipe burst under the ideal state is more similar to the characteristic values of pipe burst under the pipe burst state can be determined, consequently, those with higher degree of similarity with the characteristic values of pipe burst in the state of pipe burst are selected.

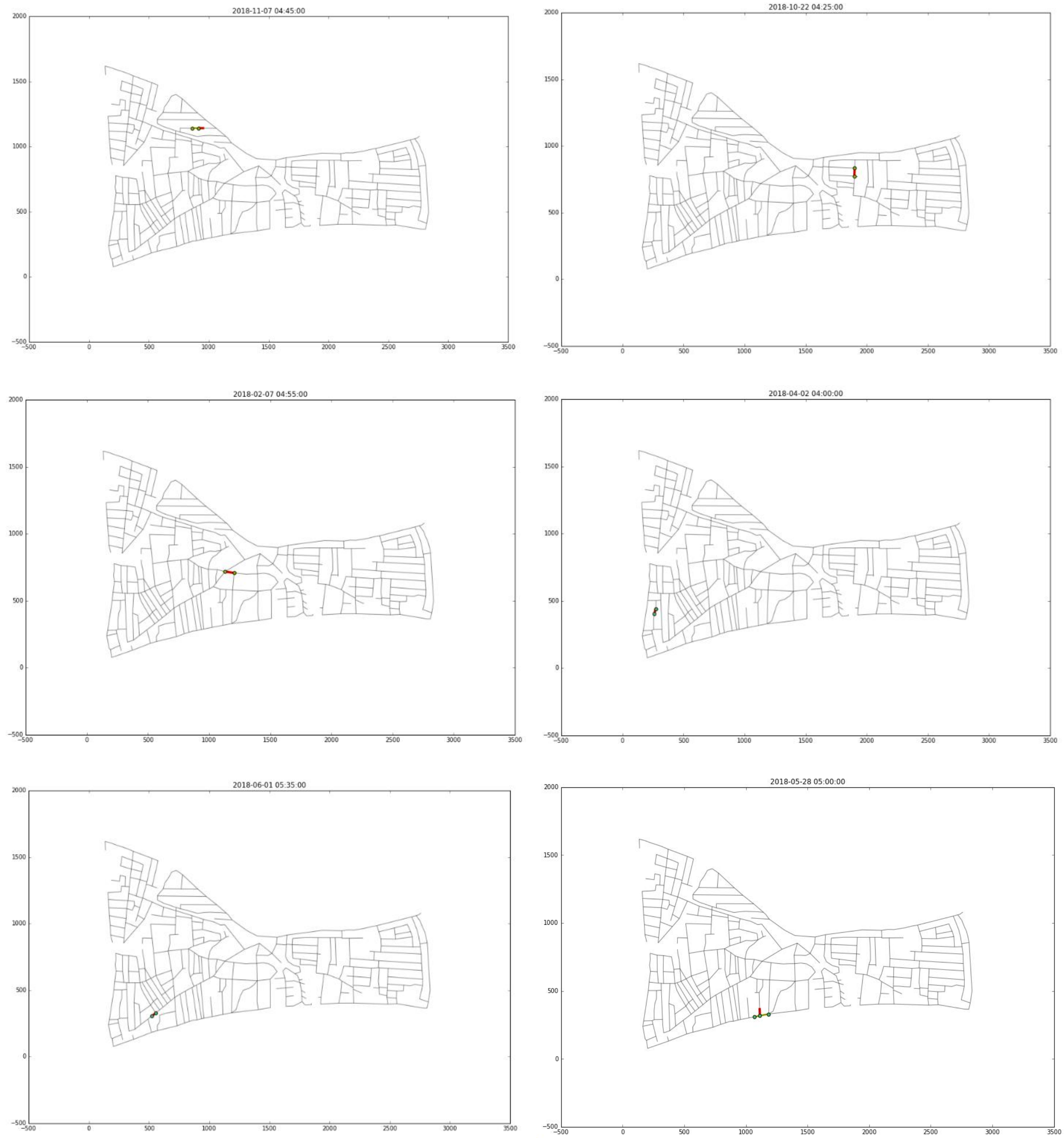

Figure 2. Examples of the results of our location model for the 2018 pipe burst events

Keywords: *Water Distribution Network; Pipe Burst Identification; Location; Characteristic Values; Similarity Analysis*

SUMMARY

Drinking Water Distribution Networks (DWDN) are susceptible to infrastructure failures, which may lead to water losses. The early detection and localization of some leakage event is extremely important, as this would reduce the time required for accommodating the event and therefore reducing the risk of further infrastructure degradation, contamination events and consumer complaints. In recent years, large and medium-sized cities in China has successively set out the Supervisory Control and Data Acquisition(SCADA) system for water supply pipe network, but most of the cities still cannot make full use of the SCADA system to detect

the pipe burst location. The system is only used to detect the pipe burst segment is near the pressure measuring point according to dramatic change of water pressure at the pressure measuring point, and no effective method is set up to conduct real time leakage and burst location detecting of the network. In the event of a large burst, it is still difficult to find the exact location in time. Aiming at these problems, we propose a practical method based on SCADA system combining state estimation. This method uses fuzzy similarity priority ratio to detect the burst location of urban water supply network in real time.

Reference

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