Development of real-time freezing burst diagnosis service using smart water meter reading data

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Abstract **— It is more efficient to anticipate the possibility of occurrence in advance and deal with it through preventive measures rather than responding to the occurrence of freezing in winter. Therefore, in this study, freeze prediction based on water consumption was performed using real-time meter readers installed in 1600 households. To this end, the patterns of water use by household for 2 weeks were clustered and classified into 5 types, and reconstructed into 3 types based on the amount of usage at night time, which is vulnerable to freezing. Based on this, the freezing and breakage diagnosis results were finally defined as 5 alarm stages by considering the usage pattern of each household, the minimum temperature, and the pipe diameter of each household. Through this study, it is expected that by providing user-customized freezing burst diagnosis results, it will be possible to reduce various damages caused by freeze occurrence by promoting active freeze prevention measures for users.**

Keywords—smart water, time-series data, freeze and burst prediction

I. INTRODUCTION

As climate change accelerates around the world, abnormal temperature occurrences are becoming more frequent. In particular, even in the case of a cold wave that occurs in winter, it is stronger than before and occurs for a longer period of time, which acts as a direct factor in increasing the occurrence of freezing burst in water meters.

Existing freeze prevention measures have used a direct method of taking measures to keep warm, such as installing a heating wire in a water supply pipe, or running water at a time when a freeze or burst is expected to occur. Therefore, existing studies on freeze generation also optimize the internal structural design of water meters [1], use water meters using bellows tubes [2], etc. to minimize the effect on freeze generation, and use hot air systems. Researches have been conducted to directly prevent freezing by controlling the temperature inside the meter box [3] or by installing a heating wire in the water supply pipe and establishing a control system [4].

However, existing studies have not solved the problem that it is difficult to introduce on a large scale because the burden of equipment replacement or continuous maintenance is required, and that users still have to recognize and take action against the risk of freezing. Therefore, in this paper, we propose a real-time freeze diagnosis service using smart water meter reading data that collects meter reading data based on IoT water meters and provides freeze prediction services according to usage patterns of each household based on this.

To perform freeze prediction, water supply usage patterns by household were converted into 2-day units to extract water supply usage patterns, and then water supply usage patterns were divided into freeze prediction groups based on late-night usage from 0:00 to 06:00, which is most likely to cause freezes. If there is a risk of freezing or bursting at 21:00 every day, the risk of freezing burst is calculated using the amount of water used and the piping characteristics of the water meter, and a notification is sent to the user.

Through this, waterworks usage is clustered to predict freezing burst based on usage patterns, enabling more efficient prediction than directly predicting usage during late-night hours. It is hoped that a diagnosis of the possibility of occurrence will be possible.

II. SMART WATER SERVICE ARCHITECTURE

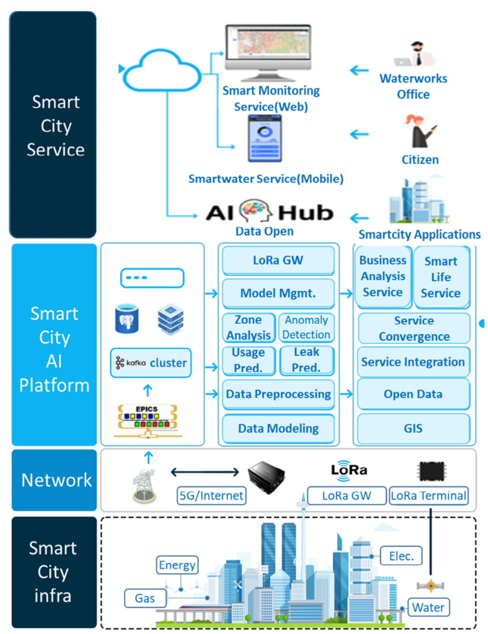

Fig. 1. Smartwater service architecture

This study was conducted as part of the smart water service. The smart water service collects water consumption data related to people's lives in real time and uses it to provide convenience to people's lives by predicting usage / progress, diagnosing commercial districts, diagnosing abnormalities of people living alone, and diagnosing water leaks. As a platform that provides , it is shown in Fig. 1. Among them, this study aims to reliably provide prediction results of usage and progressive stages to consumers who have installed remote meter readers.

III. REAL-TIME FREEZING DIAGNOSIS MODEL

The real-time freezing diagnosis model is a model that diagnoses the possibility of freezing and breaking by utilizing the user's usage pattern, water supply pipe characteristics, and weather forecast at 21:00 every day, and sends a notification to the user. To this end, it collects real-time usage by user, analyzes usage patterns, and finally operates on the smart water service that provides intelligent life convenience services based on large-scale meter reading data to transmit freezing diagnosis results to users.

The most important factor used in the real-time freeze diagnosis model is the usage pattern of each user, and the usage pattern is analyzed based on the usage of the preceding two weeks every Sunday. Usage pattern analysis creates one usage pattern from 06:00 to 06:00 the next day in order to predict the usage pattern from 0:00 to 6:00, which corresponds to the late-night time that is vulnerable to freezing and bursting, based on the weekly usage pattern. It is divided into 5 clusters through means clustering technique. The cluster is re-clustered into three groups based on late-night usage: high usage, general usage, and low usage.

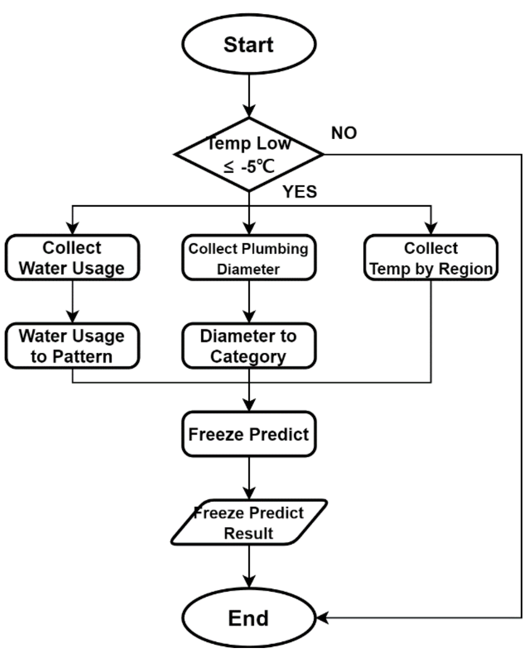

Fig. 1. Freeze diagnosis model structure

Real-time freeze diagnosis is performed at 21:00, but data may be received only until at least 15:00 because data is received once every 6 hours due to the characteristics of low-power IoT communication. Therefore, in order to improve the accuracy of usage pattern analysis, the average of the usage of 24 hours ago for each cluster is used together to analyze the usage pattern additionally.

Fig. 1 shows the overall structure of the freeze diagnosis model. Since the freezing diagnosis model operates only when there is a possibility of freezing, it is checked whether the lowest temperature is below -5 degrees from 0:00 to 6:00 the next day based on the weather forecast announced at 20:00. If the freeze criterion is not met, the freeze diagnosis model is terminated. If the minimum temperature is -5 degrees or less, the minimum temperature by region is collected, the customer's pipe diameter is collected, and the customer's water consumption is collected in order to perform a freeze diagnosis.

In the case of the minimum temperature by region, there are cases where there is a difference of more than 4 degrees even within the same city, and this can indicate different temperature characteristics for each region. In the case of the customer's pipe diameter, three types are used depending on the diameter as shown in Table 1. The smaller the pipe diameter, the higher the risk of freezing and bursting [5]. sort by type.

TABLE I. CHARACTERISTICS OF FREEZING DIAGNOSIS MODEL

Category	Detailed characteristics
Usage Pattern	39H usage is classified into 5 clusters and used as 3+1 (high/medium/low/none) characteristics
Pipe	The customer's pipe diameter is used as three (15mm/20mm/other) characteristics
Temperature	Used in three types (below -5 degrees / -10 degrees / -15 degrees) according to the minimum temperature

When performing freeze diagnosis, whether or not freeze diagnosis is necessary is checked every day at 21:00, and if diagnosis is required, cluster-based classification is performed based on real-time usage received from 06:00 the previous day to 21:00 the same day. Then, the user's usage pattern is analyzed based on the group to which the cluster belongs. Finally, 27 types are calculated by utilizing 3 types of usage patterns, 3 types of piping characteristics, and 3 types of temperature characteristics. In addition, real-time freezing diagnosis results are returned by dividing the system into 5 alarm types according to the ratio of whether the usage amount enough to prevent freezing in the middle of the night has occurred.

IV. PERFORMANCE EVALUATION AND DEMONSTRATION

A. Verification Environment

In relation to this study, in 2022, in Dong-gu, Daejeon Metropolitan City, 1616 remote meter reading data collection infrastructures were established through LoRa private networks.

Each customer collects meter reading data every hour by grouping them into 6-hour units, and meter reading data is stored in the data collection platform and provided for learning and service. Among them, a total of 1015 households were able to learn and predict through preprocessing, and 1007 households for home and general use, excluding special industries, were used for learning and verification.

Fig. 2. Digital meter(left) and meter reading terminal(right)

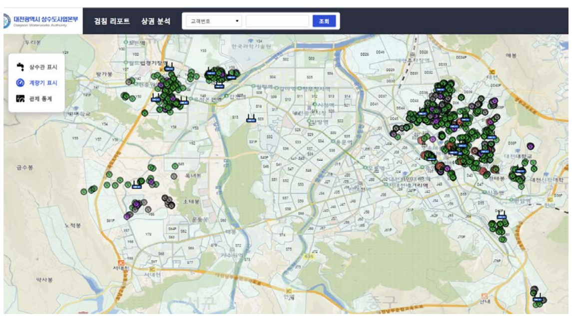

Fig. 3. Meter reading network monitoring

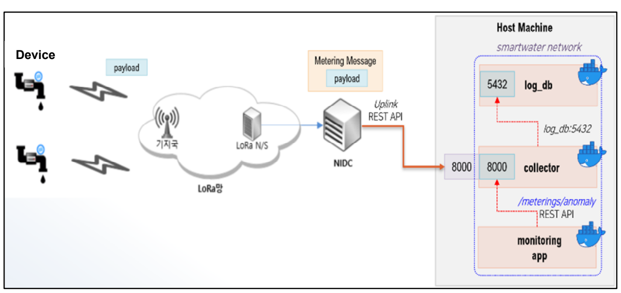

Fig. 4. Meter reading data logging

B. *Performance Evaluation*

To evaluate the performance of the real-time freeze diagnosis model, data collected from real-time meter readers installed in 1,600 households in Daejeon were used. Freezing diagnosis was conducted based on data for 7 weeks (2022/12/11 - 2023/01/28). In the case of analysis of usage patterns for freezing and burst diagnosis, it was conducted based on data for about 8 weeks (2022/11/26 - 2023/01/22). In the case of freeze diagnosis, since it was conducted for customers who can analyze usage patterns, the number of customers subject to freeze diagnosis per week will vary, but data of at least 1440 consumers was used.

The purpose of the real-time freeze diagnosis service is to provide customized freeze and break diagnosis results according to the customer's characteristics (usage pattern and pipe characteristics, temperature difference by region), rather than the existing batch freeze warning. Therefore, performance evaluation was performed from two perspectives: suitability for subdivision of type stage and warning stage according to the characteristics of consumers, and whether the freezing and bursting diagnosis results were appropriate according to temperature changes.

The subdivision of warning levels according to the characteristics of customers is aimed at reducing unnecessary information by notifying customers with a relatively high probability of freezing and bursting, thereby improving the reliability of customers for the results of freezing and bursting diagnosis. The following Fig.2 is a table showing the ratio of actual freezing prevention measures and classification according to usage patterns (clusters) and pipe diameters according to temperature.

Yellow	Cluster			
Diameter	C1	C2	C3	Not use
M1	3.54%	13.46%	13.63%	0%
M2	10.67%	26.98%	26.3%	
M3	21.72%	50%	57.3%	

Orange	Cluster			
Diameter	C1	C2	C3	Not use
M1	2.92%	11.98%	13.66%	0% (1/632)
M2	13.82%	21.1%	28.05%	
M3	21.42%	49.57%	53.20%	

Red	Cluster			
Diameter	C1	C2	C3	Not use
M1	5.7%	15.76%	11.43%	0%
M2	7.14%	32%	25.92%	
M3	32.6%	65.95%	50%	

Level 1 Level 2 Level 3

Level 4 Level 5

Fig. 5. Real-time freeze diagnosis performance evaluation result

To prevent freezing burs, it is necessary to use more than 15L per hour at the caution level and 20L per hour at the warning level or higher. Consumers with relatively high nighttime usage and large pipelines can maintain a low warning level because they use a lot at night. In addition, when there is no usage during the daytime and there are many cases where there is no usage even at night, there is a high possibility of freezing and bursting, so it is necessary to transmit the highest level warning.

Even in the case of freeze diagnosis according to regional temperature differences, it is used to send more accurate guidance, similar to the subdivision of warning levels. The following figure shows the result of frozen wave diagnosis based on data from 2023/01/22 to 2023/01/28.

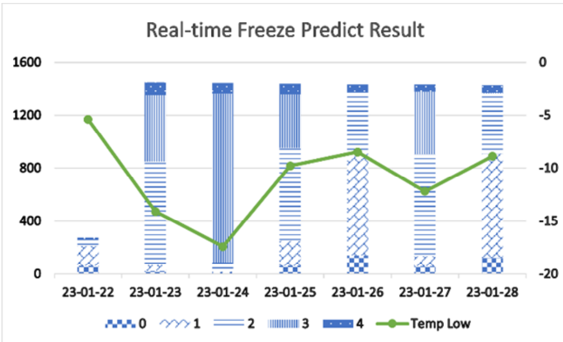

Fig. 6. Real-time Freeze Prediction Result

Even when the service was conducted for the same Daejeon area, a temperature difference of up to 3 degrees occurred on the same date, which is more when the temperature is lower (2023/01/23) even though the average temperature is in the same freeze forecast range. A high warning level has occurred, and when the temperature is high (2023/01/25), it can be seen that a more effective freeze diagnosis is possible, considering that a low level alarm has occurred.

V. CONCLUSION

The possibility of freezing can be recognized in advance through weather forecasts, etc., and it is important to take preventive measures in advance because inconvenience and high costs due to unavailability of waterworks occur after freezing occurs. Therefore, in this paper, a user-customized real-time freeze diagnosis service was proposed considering the user's usage pattern, piping characteristics, and regional temperature characteristics. In order to diagnose freezing and breaking in consideration of the user's late-night usage pattern, a standard water supply usage pattern was calculated based on the real-time water usage data of the last two weeks. A warning level was calculated.

However, in this study, there is a limitation that only statistical analysis-based efficiency verification was performed for the real-time freeze diagnosis model. Therefore, in future research, real-time freeze diagnosis service will be added to smart water service to provide freeze diagnosis results to users based on actual usage, and it will be confirmed whether users have taken freeze prevention measures based on customized freeze diagnosis guidance. Through this, the effectiveness of the real-time freeze diagnosis service will be demonstrated.

ACKNOWLEDGMENT

This work is supported by the Korea Agency for Infrastructure Technology Advancement(KAIA) grant funded by the Ministry of Land, Infrastructure and Transport(Grant: RS-2022-00155803).

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