Design of an Urban Waterlogging Monitoring System Based on Internet of Things

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Abstract. The Internet of things (IoT) is the network that composed of different devices (e.g. computers, vehicles, RFID and sensors etc.) and allows these things to connect, interact, generate data and exchange data. The IoT technology plays a role in people and has become a research hotspot. Due to the expansion of urban area, the construction of underground pipelines lags behind, the increase of rainfall makes it impossible to drain rainwater from the city interior, which endangers the safety of life and property. On the one hand, the planning of urban drainage system is unreasonable, on the other hand, the water monitoring system of city road is not formed, the data monitoring and data processing is not timely enough, so that it is failure to achieve effective early warning. In view of the above problems, this paper proposes an urban waterlogging monitoring and warning system. In view of the above problems, this paper proposes a urban waterlogging monitoring and warning system. The system combines Vehicle Network, Sensor Technology and Cellular Network technology to realize an IoT application of rain water monitoring, data transmission, processing and warning system of urban waterlogging situation, which makes the traffic environment in the city more networked and intelligent, and reduces the occurrence of property and personal safety incidents.

Keywords: IoT · Vehicle Network · Sensor Technology · Cellular network · Urban waterlogging

1 Introduction

With the continuous prosperity of social economy and the rapid development of cities, the city circle is also growing [1, 2]. However the planning of underground drainage pipelines of some roads is not reasonable enough, it is difficult to transform, so there are some potential drainage hazards. Urban waterlogging is a phenomenon of urban flooding caused by heavy or continuous precipitation exceeding urban drainage capacity. The objective reasons are the concentration of rainfall area and rainfall intensity. Water is formed into areas where rainfall is particularly heavy and concentrated [3–4]. Once the city suffers heavy rainfall, in key areas prone to water accumulation, such as tunnels, low-lying areas, rainwater can not be discharged in time, will form a "river", light traffic jam, heavy casualties and property losses. Therefore researchers and industries aim to realize urban waterlogging warning system. Sun [3] networked the water level sensors and uploaded information to the server. The water level information monitored in real time

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was calculated and judged by threshold to get the corresponding warning level and sent to the relevant departments. Dong [9] combined the early warning system with GIS and establishes the urban rainstorm waterlogging model. The model involves knowledge of meteorology, hydrology, hydrodynamics, river dynamics and drainage engineering. Finally, the early warning and forecasting information is sent to the relevant departments. Naranmandra team [10] networked rainfall stations, water level detectors and other sensors, cameras and other equipment, uploaded relevant information to the server, finally, issued decision-making and warning information on the server side.

In this paper, the Urban Waterlogging Warning System monitors the water level in real time via set up sensors on cars and roadsides. The sensors monitor water level and generate data, then send the data to the server. The server processes the data, and uses the time series exponential smoothing prediction method to predict the water level of the road, and integrates the prediction results and collected information, then send the corresponding warning information to the user's mobile phone in the way of mobile application software push, reminding people of the water situation ahead.

In Sect. 2, the authors present the design method of system. In Sect. 3, the authors implement the design and give the results. Finally, the conclusion is made in Sect. 4.

2 System Design

The Traditional Urban Waterlogging Monitoring and Warning System is that sensors are placed in low-lying areas and under overpasses. The sensors sense water level data and send to a control center but not to the people around the area. Hence it cannot provide timely warning to people and vehicles around. In addition, for a long time used road, the ground is always uneven. Hence, sensors deployed on the two sides of road always cannot accurately reflect the water level of the road center area.

In view of the above situation, this paper has made improvements as follows:

(1) The innovative use of hydraulic sensors on cars can measure the real-time water depth of cars passing through the road section and send early warning information to the cars and people around them in time.
(2) The time series exponential smoothing prediction method is used in the road water accumulation prediction algorithm. This method is very effective for the irregular change of rainfall results. It can predict the road water depth at the next moment and improve the prediction accuracy.

2.1 Overview of System Design

The system is composed of two parts. One part we call Accurate Monitoring Center (AMC) and another is Instant Warning Center (IWC). In AMC, it provides the functions of rainfall monitoring, water depth monitoring and the prediction of water accumulation in the section. In IWC, the hydraulic sensors are installed on the cars. The pressure value that measured by the contact of the hydraulic sensor to the liquid during the driving process of the car is converted to the water depth of the passage section, and the real-time water level data of the road surface is sending to the cars nearby.

As shown in Fig. 1, proposed Urban Waterlogging Warning System is formed by water level sensor node, data processing center, wireless terminals, cars, hydraulic sensors and road. The AMC uses Cellular network to send data to the server at a predetermined time interval. The server gathers road water accumulation data from the roadside sensor and the sensors set up the cars to calculate road water accumulation forecast data, then sends the data to the mobile client. In IWC, the hydraulic sensor installed on the body of the car measures the dynamic parameters of real-time water accumulation on the road surface when driving through, and gets the dynamic water depth of data conversion. The water depth value getting from the car passing through the road section is sent to the cars nearby, reminding users that there is water accumulation in the front of the road section, thus realizing the purpose of real-time early warning.

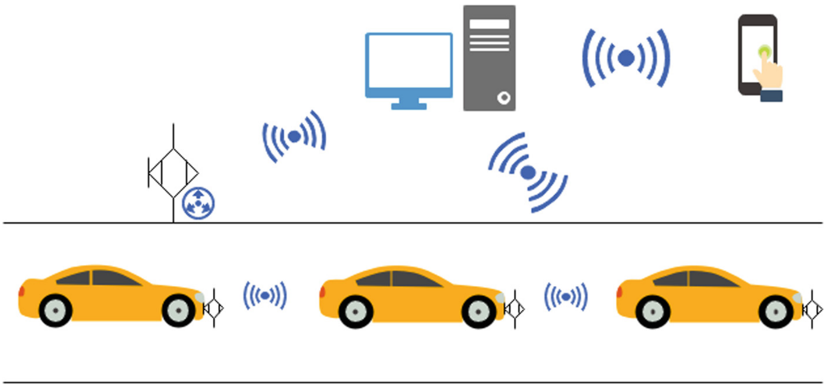

Fig. 1. Actual scene diagram

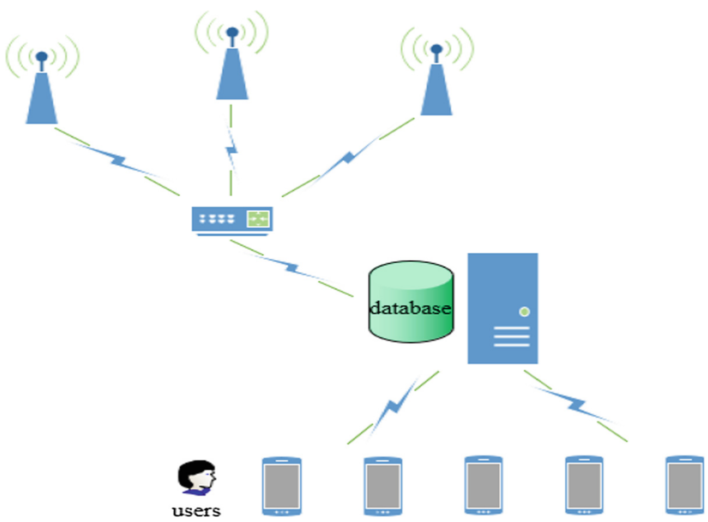

Fig. 2. Network topology diagram

Figure 2 is the network topology of the AMC. Sensors include rain gauges, electronic water gauges and hydraulic sensors. The data they collected included rainfall, road depth of water and liquid pressure. Wireless transmission terminals support operator network, multiple network protocols and data transmission is efficient. The server receives the data transmitted by wireless transmission terminals for storage, processing, and then sends the data to the client.

2.2 System Structure Design

AMC Structure

The AMC includes three parts: Road water logging monitoring, out-of-car hydraulic monitoring and processing center.

(1) Road water monitoring stations are responsible for data acquisition and data transmission. It consists of electronic water gauge, rain gauge, wireless terminal, storage battery and solar panel.
(2) External hydraulic monitoring is responsible for monitoring the real-time water accumulation of cars passing through the road, which is composed of hydraulic sensors setting outside of a car.
(3) The processing center is responsible for data reception, data processing and data transmission. The hardware equipment is database server and web server, and the installation software is application software.

Working flow of AMC

After collecting rainfall data and road water depth value, the sensors transmit their data to the server through wireless transmission. The server obtains the data and calculates whether it exceeds the water level threshold. If it exceeds the threshold, it sends early warning information to the user through cellular network. If it does not exceed the threshold, the server stores the data and continues to calculate the next value. At this end, users can log in and query sensor data, real-time information and predictive information freely (Fig. 3).

IWC Structure

IWC includes hydraulic sensors, cars and car alarm.

Working flow of IWC

The pressure data collected by the hydraulic sensor are converted into water level data, and determine whether it exceeds the warning threshold. If so, do real-time alerts and also send information to the surrounding cars and roadside servers. If the threshold value is not reached, the water level data are sent to the server through wireless transmission for further accurate prediction.

2.3 Prediction Algorithm of Water Accumulation

In order to achieve more accurate warning data, this system applies Exponential Smoothing Prediction of Time Series to get predicted data of waterlogging warning system.

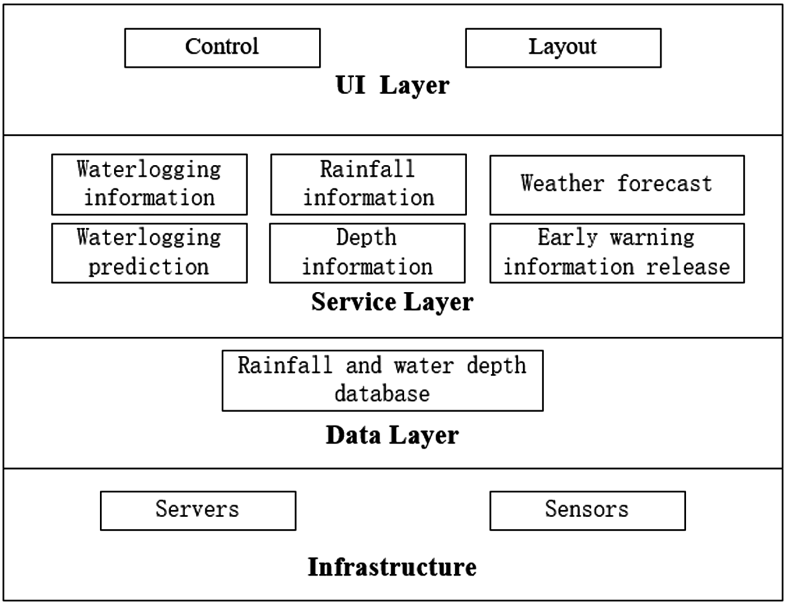

Fig. 3. Structural design of AMC

Exponential Smoothing Prediction of Time Series

The principle of this method is weighted average. It uses the growth trend of water level data to calculate the short-term prediction technology of water level data at a certain time in the future. In the past period of time, the continuous time points constitute a series of water level data arrays $H_{(t)}, H_{(t-1)}, H_{(t-2)} \cdots$, which are continuous in time. Then the weighted average of the array is obtained. Finally, the data of the predicted time points is obtained. The iterative formulas are as follows:

$$H_{(t+1)} = \alpha H_{(t)} + \alpha(1-\alpha)H_{(t-1)} + \alpha\left(1-\alpha^2\right)H_{(t-2)} + \cdots \quad (1)$$

Parameter description: $H_{(t+1)}$ is the predicted value of water level data at t + 1 time, and $\alpha = 1/n$, n is the number of accumulated arrays.

In practical application, the distribution of weighting coefficients should increase the weighting coefficients of the latest time points and reduce the weighting coefficients of the past time points. The whole calculation process should show a gradual change in time. Different weighting coefficients can reflect the influence degree of the time points closer to the predicted time points. This short-term prediction method has the advantages of simple operation and easy realization.

3 Simulation

3.1 Simulation Setting

In this section we give a simple test to examine the efficiency of our prediction algorithm. Because the current weather can not collect the seeper data, we use Excel to generate random data, ranging from 20 cm to 30 cm and test for different coefficient values of Exponential Smoothing Prediction method.

3.2 Simulation Result

We generated half an hour's data in the period of concentrated rainfall. The data interval is every minute. In Fig. 4 We take the damped coefficient of the time series exponential smoothing prediction method as 0.1, 0.5 and 0.9, respectively, and get the following results:

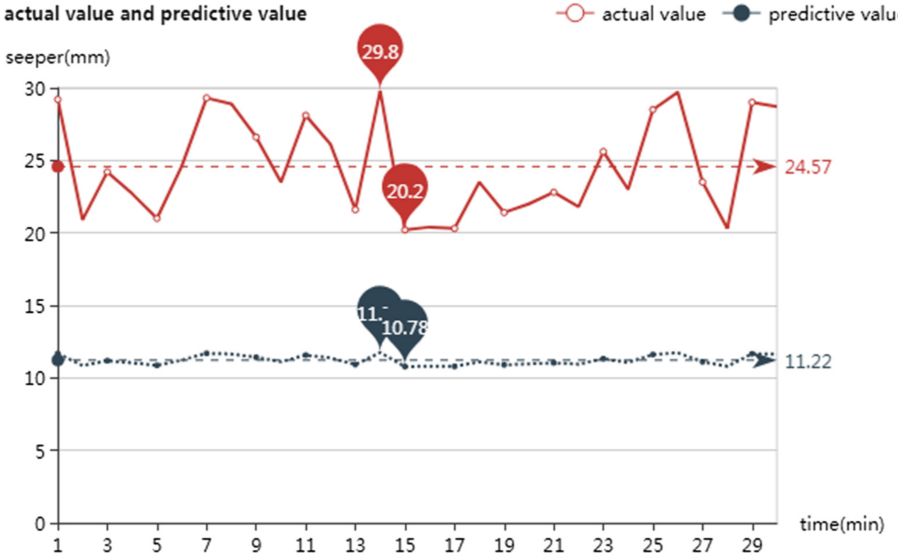

Fig. 4. Damped coefficient $\alpha = 0.1$, actual value and predictive value

For the data collected by sensors, the time series exponential smoothing prediction method is used to predict the depth of road water accumulation. When the damped coefficient is different, the prediction results are slightly different. In view of the prediction error, we calculate the relative error to evaluate the prediction results. The specific formula is as follows:

$$\text{Error}(\%) = |\text{Actual Value} - \text{Predictive Value}| / \text{ Actual Value} \quad (2)$$

When damped coefficient $\alpha = 0.1$, the predicted value is too gentle to reflect the results well. Then we calculate the relative error is 0.54. The predicted results are far from the actual results.

When damped coefficient $\alpha = 0.5$, The forecast is better than before. Then we calculate the relative error is 0.3. But it still can not reflect real situation (Fig. 5).

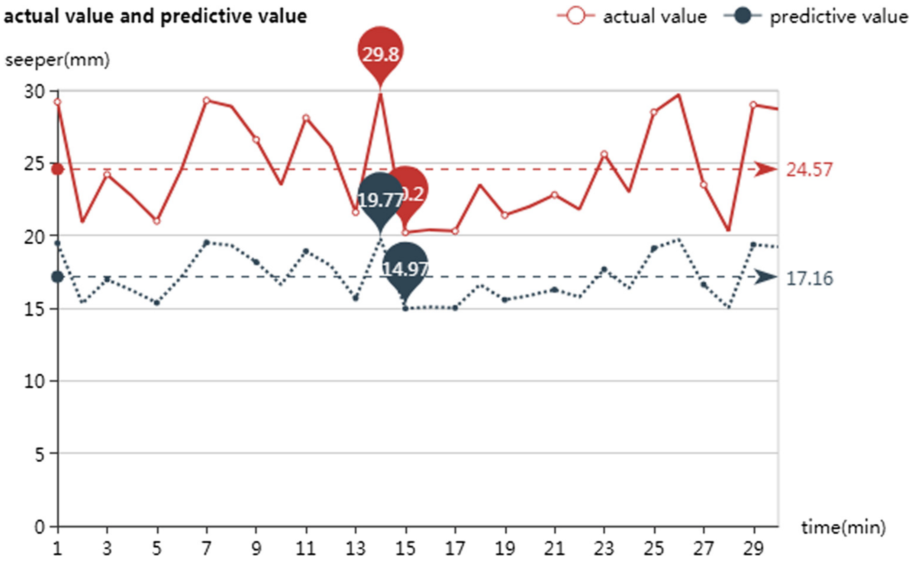

Fig. 5. Damped coefficient $\alpha = 0.5$, actual value and predictive value

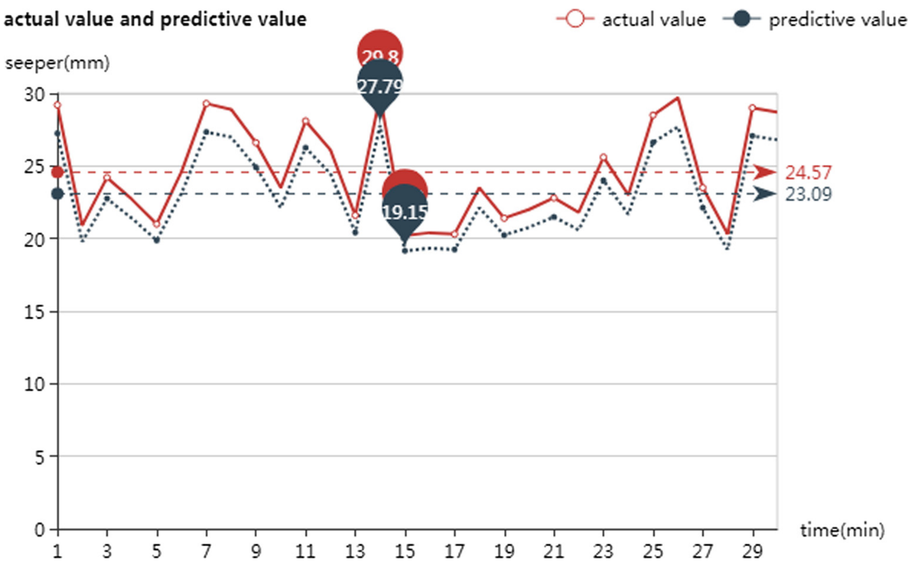

Fig. 6. Damped coefficient $\alpha = 0.9$, actual value and predictive value

When damped coefficient $\alpha = 0.9$, from the results reflected in Fig. 6, we can see that they are very close to the real results. Then we calculate the relative error is 0.06. So the algorithm we use is calculated with the current damped coefficient.

By using time series exponential smoothing method to predict the data collected from the experiment, we know that the larger the damping coefficient is, the stronger the random fluctuation of the data is, and the prediction results are closer to the actual results.

4 Conclusion

This paper designed an urban waterlogging monitoring and warning system which composed of Accurate Monitoring Center (AMC) and another is Instant Warning Center (IWC). For achieving accurate prediction in AMC, the time series exponential smoothing prediction method is used. The result shows that the larger the damping coefficient is, the stronger the random fluctuation of the data is, and the prediction results are closer to the actual results.

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