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Leak Detection in Smart Water Distribution Network

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Abstract: This paper presents an experimental smart water distribution network that addresses the hydraulic parameters of water i.e. flow rate and pressure for leak detection. An experimental test rig was developed in CSIR-CEERI lab and data collected from all the sensors is sent to the SCADA software using PLC. Data of infield sensors (i.e. pressure, flow, temperature and pump frequency) is collected. Detection of leakage is performed by two techniques (i) by monitoring change in pressure, flow rate, temperature trends using SCADA (ii) by using machine learning techniques - Logistic Regression and Support Vector Machine (SVM).

Keywords: Leak Detection, pressure sensors, flow sensors, PLC, SCADA, Water pipeline, Machine Learning Techniques

1. INTRODUCTION

The National Institution for Transforming India (NITI Aayog), Government of India has released the report "Composite Water Management Index" in June 2018 and listed Delhi and other 21 cities in India which would run out of groundwater by 2020[1].Leakage in water distribution networks is a significant economic and environmental problem worldwide, which results in loss of billions of litres of water per year. It is estimated that around one third of water utilities report a loss up to 40% due to leakage. Most significant leakages are caused by damage from nearby excavation. Aging water distribution infrastructure have contributed the most to these losses. Causes of leakage includes corrosion, material defects, faulty installation, excessive water pressure, water hammer, ground movement due to drought or freezing and excessive loads and vibration from road traffic. Leakage occurs in different components of the distribution system: transmission pipes, distribution pipes, service connection pipes, joints, valves, and fire hydrants. Leakage waste both money and precious natural resource along with it creates public health risk. The primary economic loss is the cost of raw water, its treatment and its transportation. In addition to this, leakages are costly in terms of energy consumption[2].

The paper is organized as follows: Section 1 gives basic introduction and existing pipeline leakage detection approaches and Section 2 describes the water test bed that was developed in CSIR CEERI lab and gives insights of water flow path and data flow architecture from sensors to SCADA. In Section 3 results are analysed .Finally the work is concluded in Section 4.

Different water leakage detection techniques have been discussed in literature. Early acoustic techniques incorporated many variations, such as the use of metal rods equipped with earphones that are sunk to pipe level and transmit vibration to the listener used in conjunction with leak position interpolation devices[3].
Aya Ayadi from CES research lab presented leak detection in water pipeline by means of pressure measurements for WSN and presented the behaviour of pressure sensors in the presence of leakage[4].Experimental validation of leak and water ingression detection in low pressure gas pipeline using pressure and flow measurement and explain variation of flow and pressure before and after the leakage point[5].The work presented an approach for detecting ,locating and estimating the size of leakage in a pipeline using pressure sensors and flow rate sensors. The pipeline system is modelled and simulated in EPANET software and the input output data acquired from it are used in MATLAB[6].
Literature shows the use of various machine learning algorithms which are applied on pressure and flow dataset for the detection of leakage in water distribution network. Some of the ML techniques commonly used are SVM(Support

Vector Machine), ANN(Artificial Neural Network), Decision Tree, KNN and Naive Bayesian Network etc as per the type of dataset [7].

The need of the hour is to develop smart water networks, which are dynamic to demands, monitor vital parameters such as flow rate, pressure, altitude, measures water quality and detects leakages in line. Smart water distribution can detect leak with high accuracy and can direct alerts to concerned authorities for immediate action. Smart water distribution network was proposed for Indian scenario which can supply consumers with adequate amount of water as per demand along with it can detect any abnormal conditions in the water network such as leakage breaks in pipes, failures of valves meters etc and address them on a priority scheduling basis[8].

There is direct correlation between pressure -flow trends and leakage. For better accuracy and sensitivity sensors should be placed near to leakage. But number of sensors are directly related to the cost of the water distribution network. So Optimum number of sensors are used to detect leakage by monitoring trends through SCADA and Machine learning techniques are applied to detect leakage, if go unnoticed by SCADA system.

2. EXPERIMENTAL TEST SETUP

IOT based Smart Water Grid System is developed in CSIR–CEERI, Pilani. Experimental setup consists of two layers. Layer 1 has three pressure transmitters (PT1, PT6, PT7), three flow meters (FM1, FM14, FM15), one temperature transmitter (TT1), one post indicator valve (PIV1), one solenoid valve (SV3), and two leaks are created in pipeline (LK1, LK2). Layer 2 has four pressure transmitter (PT2, PT3, PT4, PT5), twelve flow meters (FM2, FM3 to FM13), two solenoid valves (SV1, SV2), one temperature transmitter (TT2), one post indicator valve (PIV2). Pump with operating frequency range of 30-50Hz is used to flush water from tank of capacity 10,000 litre into the layers using motorised control valve. Water from both the layers is fed back to the tank using SV4 and SV5. SV6 is used for drainage purpose.

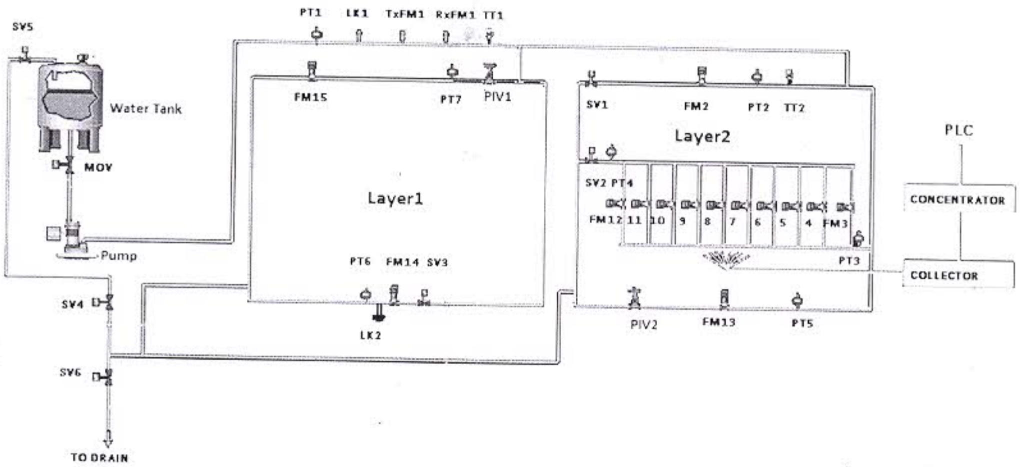

FIGURE 1. Experimental Setup

Pressure sensors are interfaced using 4-20mA line while flow sensors and vibration sensors are interfaced by RS 485 with PLC. Frequency of pump is varied from 30-50Hz. Different leak sizes are taken into account such as 25%, 50%, 75% and 100% for each frequency of pump. Data from all these sensors are collected on SCADA software with a sampling rate of 10 seconds. In this way we can have 360 (6*60) points in an hour.

2.1. PLC and SCADA

SCADA stands for Supervisory Control and Data Acquisition, a computer system for gathering and analysing real time data. The water test bed at CEERI deploys SCADA system to monitor and control water distribution network. PLC signifies Programmable Logic Controller, a PLC is a special form of microprocessor-based controller that uses a programmable memory to store instructions and to implement functions in order to control machines and processes[9]. In water network pressure sensors are interfaced using 4-20mA line while flow sensors and vibration sensors are interfaced by RS 485 with PLC. Data from all these sensors are gathered on SCADA software with a sampling rate of 10 second.

2.2. SVM and Logistic Regression

Support Vector Machine (SVM) and Logistic Regression (LR) techniques are both supervised classification algorithms which uses the training dataset to train the model and further predict results on test dataset using the trained model. A Support Vector Machine (SVM) is a discriminative classifier formally defined by a separating hyperplane. In other words, given labelled training data (supervised learning), the algorithm outputs an optimal hyperplane which categorizes new examples. Hyperplane classifies leakage and no leakage data in water grid[10].
Logistic regression model predicts a dependent data variable by analysing the relationship between one or more existing independent variables. Our Logistic model has a dependent variable with two possible values, 1 for leakage and 0 for no leakage.

3. RESULTS

3.1. Leak detection using flow, pressure and temperature trends in SCADA software

FM05, PT-1, PT-4 are positioned downstream to water flow and TT-1 is installed upstream. Pressure, temperature, and flow values are plotted during leakage (figure 2). These graphs are obtained from SCADA which shows that detection of leakage can be done directly on the basis of temperature, pressure and flow signature. Number of sensors and location of sensors in water distribution system plays a paramount role in leakage detection. Leakage could be effortlessly detected if sensors are placed near to leakage as this gives higher sensitivity in the pressure, temperature and flow rate signature. Graphs clearly shows that we can distinguish the trend of leakage or no leakage.

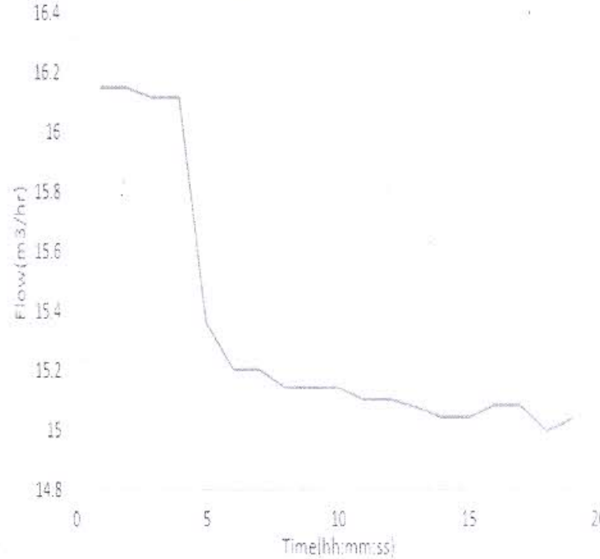

FIGURE 2.1. Profile of flow meter(FM-05) due to leakage

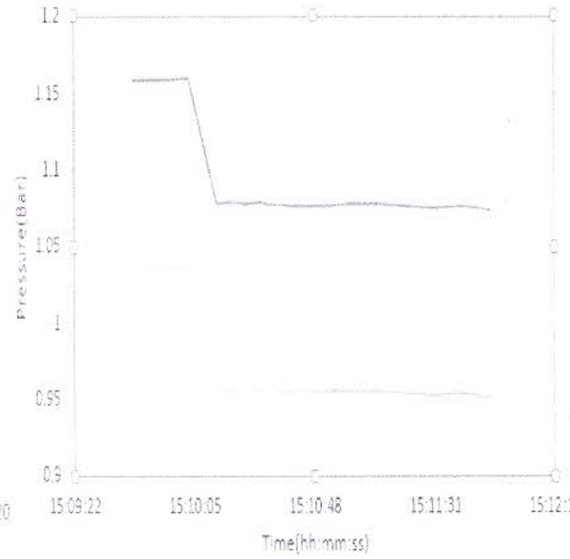

FIGURE 2.2. Profile of pressure transmitter (PT-01, PT04)

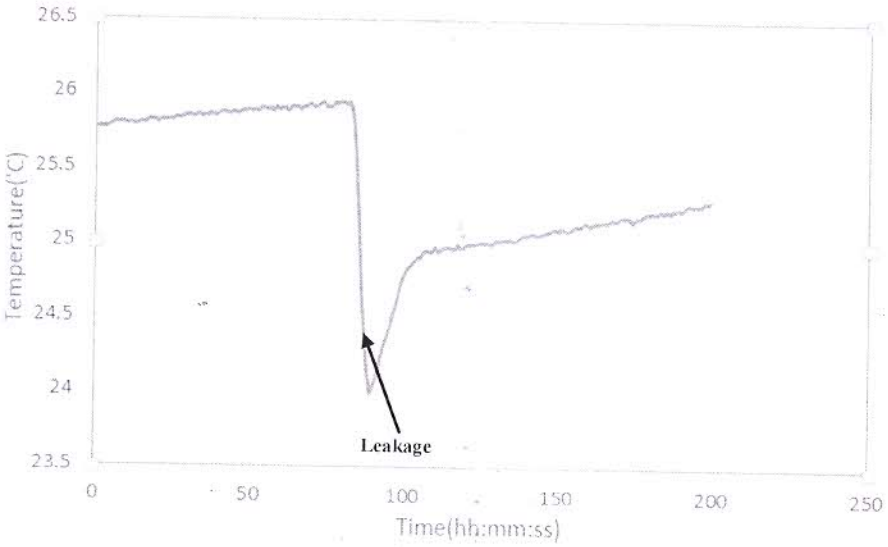

FIGURE 2.3. Profile of temperature transmitter (TT-1) due to leakage

The above flow trend of FM05 which is situated after the leakage point shows there would be a decrease in flow rate due to leakage. The pressure sensor PT-1 and PT-4 that are positioned before the leakage point displays the decline in pressure in the pipeline. Abnormality in the trend of temperature is observed due to leakage.

3.2. Leak detection using SVM and Logistic Regression

The collected input data from 15 flow meter,1 level transmitter,7 pressure transmitter,2 temperature transmitter and pump frequency and output data of possibility of leakage in the pipeline are used to develop SVM and logistic Regression model using Python software and by utilizing the training data(6000 entries).Based on training data the model select 10 important features from 26 input parameter. Feature importance gives list of features which contribute most to our prediction of our model. Figure shown below gives feature importance for SVM and Logistic Regression. Accuracy, Precision, Recall and F-1 score for SVM and Logistic Regression algorithms is tabulated. Results are reported with and without Normalization. The goal of normalization is to change the values of numeric. columns in the dataset to a common scale, without distorting differences in the ranges of values. SVM is found to be more accurate than Logistic Regression.

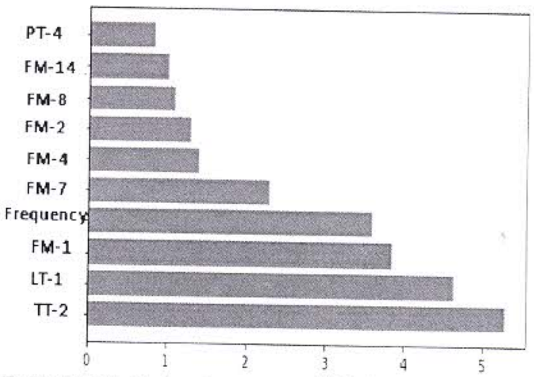

FIGURE 3.1. Feature importance (SVM)

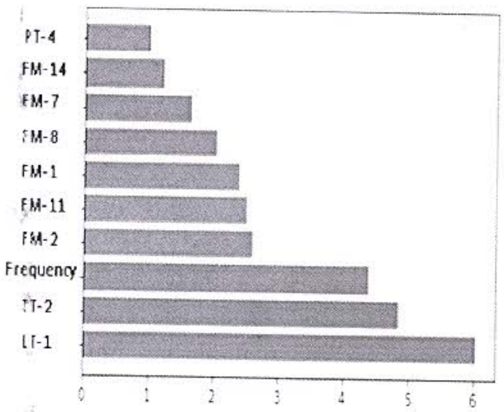

FIGURE 3.2. Feature importance (LR)

However, if there are fewer number of sensors in the network then it is complicated to detect leak directly from hydraulic trends. In such a scenario, machine learning techniques are applied. Real time data collected from our experimental setup in CSIR-CEERI and two machine learning techniques logistic regression and support vector machine are applied. F1 score obtained in Logistic Regression is 79.84% while it is 81.22% in SVM. The performance of SVM is better . So, the cost of sensors could be reduced in water distribution network without compromising with loss of water.

TABLE 1. (With Normalization)

	Logistic Regression	SVM
Accuracy	87.25%	88.62%
Precision	87.27%	86.11%
Recall	76.59%	82.44%
F1 score	79.84%	81.22%

TABLE 2. (Without Normalization)

	Logistic Regression	SVM
Accuracy	78.59%	84.09%
Precision	71.60%	76.51%
Recall	70.49%	82.70%
F1 score	72.09%	82.05%

4. CONCLUSION

In this work we focused on flow, pressure and temperature trends as well as machine learning techniques for detecting the leak. The proposed leak test bench is developed at CEERI, where the data for sensor measurements with different leak size and different pump frequency are used for training Logistic Regression and SVM models. Accuracy of SVM and Logistic Regression are 88.62% and 87.25% respectively. Further work will include determining the size and location of leakage in water distribution system.

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