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Comparative Study of Model Based Leakage Detection Techniques for Water Pipeline Structure

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Abstract: The ambitious target of doubling farm income by 2022 is projected to be achieved by India. Due to increased investment in agricultural infrastructure such as irrigation facilities, warehousing and cold storage, the agriculture sector in India is expected to generate better momentum in the next few years. For about 58 percent of the population of India, agriculture is the primary source of livelihood. Agriculture, forestry and fishing gross value added (GVA) was calculated at Rs. 19.48 lakh crore (US$ 276.37 billion) in FY20. India has 18% of the world's population, and 4% of the world's fresh water, of which 80% is used for agriculture. Water is important for seed germination, plant root development, and for the nutrition and multiplication of soil species. In the plant's hydraulic phase, water is important. This water crisis poses a serious challenge to agriculture, with unmonitored waste of water resulting in tremendous losses for farmers in drought-prone areas facing increased production costs and poverty. In farm production, India ranks second in the world, and agriculture contributes 17 percent of the GDP of the country. By following effective water management procedures, including minimizing water shortages, avoiding water waste, etc., the efficiency of water usage can be improved. Use of modern technology like sensors and IoT based methods are being used as a replacement of traditional farming and a boom to smart farming. Water distribution pipes face this leakage problem due to numerous factors like corrosion, loosening of joints, and cracks, material type, external factors, etc. real time monitoring and detection of leak can solve this problem to a certain extent. There are varieties of technology ranging from signal based to model based for detection, monitoring, and localization of leak in the water pipelines. All methods have some merits and demerits but none of the methods can be implemented in the fields in a comprehensive ways. Our papers try to focus on some of the model-based leak detection techniques along with their applicability and limitation in the field of smart agriculture for leakage detection in water pipeline structure. It is concluded that cellular automata has immense scope in addressing some burning issues of agricultural problems faced by the farmers.

Keywords: Internet of Things (IoT), Model Based Leakage Detection Techniques, Smart Agriculture, Sensors, Cellular Automata.

I. INTRODUCTION

India's economy is an agro-based economy. Around 70% of rural population of India depends on agriculture for their livelihood [1]. Income from agriculture contributes to around 17% in GDP [2]. According to researchers around 70% of the available fresh water, mainly is being consumed in agricultural activities [3].The matter of concern is that all 70 % is not fully being utilized for agriculture. Major portion of water gets wasted while irrigating the fields in traditional way of farming.

The farmers lack the knowledge of moisture level of soil and hence a lot of extra water gets supplied through the fields. Not only this geographical boundary limits the farmers to exchange and update their knowledge. Traditional means of field irrigation restricts the timely detection and localization of leak in water pipeline. The leak gets identified when the moisture level of the soil becomes more or some vegetation is grown on that area due to excess water [4].

In the recent years, a lot of technological development took place in the field of wireless based sensor network, smart agricultural machinery, IoT device, solar based irrigation equipment etc, which motivated the farmers to adopt smart farming. With the help of automated gadgets and sensors, the monitoring of field, crop, temperature, etc and other essential parameters and factors having a role in the monitoring and management of agricultural fields can be done accurately and that too in real time [5]. With the involvement of intelligent techniques and use of IoT sensors, the physical presence of farmers in the fields may be reduced or minimized, long working hours got compact, varieties of crops can be grown on same piece of land, and water wastage can be detected and corrected on time [6].

Though immense development took place in agricultural sector, water pipeline leakage is still a matter of concern as there is no single comprehensive technique available, so far, to detect the leakage in water pipeline structure. It not only causes heavy financial losses, but also affects the health and the county's development inversely [7]. Therefore, to minimize damage, first the detection with less false positive cases, then the position and magnitude of leakage must be detected efficiently and precisely.

Another reason for leak minimization is due to the damage caused in the crop due to over flooding of water. Excess water can damage crop thereby reducing its yield and can increase ground water contamination resulting in various types of diseases in crops. Similarly, soil type also plays an important role in holding the water level [8]. In sandy soil where excess water percolates downwards and it does not harm to the crop, in fine texture soil water remains on top causing diseases due to flooding of water.

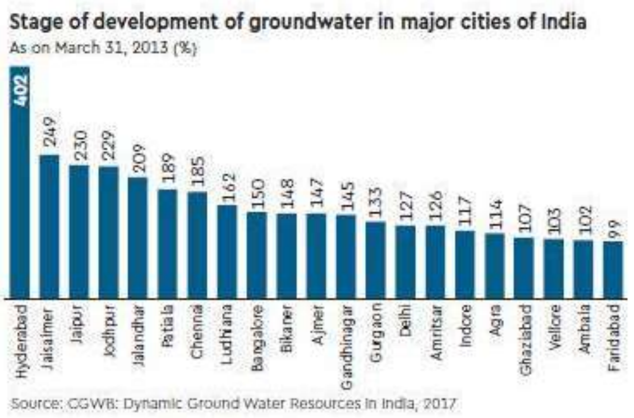

Figure1. Water Crisis Statistics

Excess water presence at any point of crop growth could slow down the crop growth, and in several situations, it could leads to dangerous results leading to economic losses. Therefore, there is a necessity for easy and precise leak detection techniques. With the advent of sensors based smart farming various approaches are present for leak detection and localization. These techniques can be classified into signal based and model based techniques for leakage detection in water pipeline structure. However, signal based leakage detection techniques are more suitable for underground and buried pipelines and since the water pipelines in the irrigation setup is mostly on or above ground hence model based techniques are most apt for the detection of leakage.

In this paper, we discuss the various model based leakage detection techniques suitable of irrigation setup and water pipeline structure and a comparison is drawn taking into consideration the various contributing parameters. Some future research directions are also provided. The rest of the paper is organized as follows: section II focuses on the model based techniques of leakage detection, section III provides a tabular comparative study of the contributing parameters, section IV deals with the importance of cellular automata in water pipeline leakage detection, section V highlights the future research directions, and conclusion is provided in section VI.

II. Model Based Leakage Detection Techniques for Leakage Detection in Water Pipeline Structure

This section highlights the top six model based leakage detection techniques for leakage detection in water pipeline structure.

A. *Regression Analysis (RA)*

The analysis of regression is focused on providing a broad number of data points that reflect different aspects of a selected sample. In the case of leak detection using noise loggers, for example, the considerations which include the highest and lowest signal intensity, the incremental distance between the two sensors and the frequency of the signals received. The model is tested for statistical soundness using a series of statistical tests after model creation. As an emerging method in leak detection with pinpointing accuracies exceeding 93 percent, regression analysis is having a lot of success.

Drawback: A regression analysis model built is situational, i.e. it cannot be used for various pipelines or networks as they may have different operating conditions than the conditions under which the model was produced.

Plausible Solution: By combining them with artificial intelligence, regression models can be enhanced, so that the model can be continuously improved with new data. In addition, by considering new characteristics of water networks such as pipeline content, soil type, pipeline age, and water pressure, current regression models can gain more precision.

B. *Neural Network (NN)*

The Neural Network operates in the same way as the human nervous system, using neurons in a biosystem-like manner in different layers. And of the neurons analyzes parts of the input and continually transfers the information to the next layer and neurons until a valid output can be achieved. It is ideally used for nonlinear and complicated issues requiring high computational power.

Drawback: While working with IoT systems it has some issues due to low complexity and low power devices. Also a good and balanced dataset is mandatory for accurate results.

C. *Decision Tree (DT)*

A certain function is used to separate the data in the decision tree into a hierarchical partition of training data, with this division being performed iteratively until the leaf node contains a number of records that can be used to classify the data.

Drawback: A slight change in the training dataset will lead to a significant change in the tree, making it more difficult to reliably predict the next values. Due to over fitting, overly complex trees may be grown.

D. *Random Forest (RF)*

For classification concerns, Random Forest is best applied. It incorporates the aggregation bagging method and Decision Tree by choosing a subset of features from the tree's individual nodes, by avoiding correlation with the bootstrapped collection, and by working with a variety of trees in which a classification is given by each tree.

Drawback: For real-time predictions, a large number of trees will make the algorithm too slow and ineffective.

E. *Support Vector Machine (SVM)*

For classification, Support Vector Machine (SVM) is used often. It classifies the data by constructing 'n' dimensions between two classes and finding an ideal hyperplane to categorize the data, using the distance between the neighboring points and distinguishing the minimum error margin between classes.

Drawback: It is not suitable for large datasets. They does not applies well if the there is too noise in the data. The SVM will underperform in situations where the number of features for each data point exceeds the number of training data samples.

F. *Cellular Automata (CA)*

Using cellular automata, the system can express space structures and patterns of complex nature, which are difficult to perform only with mathematical equations. It has increased the scope of GIS application in Multi Criteria Evaluation (MCE) and makes the application practical for decision-making.

Drawback: Difficult to prove the behavior exhibit by cellular automata model.

III. Comparison of Model Based Detection Technqiues for Leakage Detection in Water Pipeline Structure

Following section shows a tabular comparison of model based detection techniques for leakage detection in water pipeline structure.

Table1. Parameterised Comparison of Model Based Leakage Detection

Parameters	RA	NN	DT	RF	SVM	CA
Mathematical Model	Y	Y	Y	Y	Y	Y
Black Box Approach	N	Y	N	Y	Y	N
White Box Approach	Y	N	Y	N	N	Y
Leakage Accuracy	M	M	M	H	H	H
Handle Multiple Leak	Y	Y	Y	Y	Y	Y
Handle Complexity	M	H	M	M	H	H
Handle Large DataSet	Y	Y	N	N	N	Y
Decision Making	Y	Y	Y	Y	Y	Y
IoT Sensor Integration	C	M	M	M	M	E
Consider Water Network Characteristics	L	M	M	M	M	H

Y – Yes, N – No, L – Low, M – Medium / Moderate, H – High, C – Complex, E – Ease

IV. Future Research Directions

- By combining regression analysis with artificial intelligence, regression models can be enhanced, so that the model can be continuously improved with new data. In addition, by considering new characteristics of water networks such as pipeline content, soil type, pipeline age, and water pressure, current regression models can gain more precision.
- As a result of using the Artificial Neural Network to detect leakage, if there are more segments in the pipeline structure, more data and operating states will be generated and the accuracy of the leak position will be improved.
- To avoid the problem of over fitting in decision tree, pruning, setting the minimum number of samples needed at a leaf node or setting the maximum tree depth are necessary steps. Moreover, balancing the dataset before the induction of the decision tree is a good practice to provide fair and equal opportunities for every class.
- Along with random forest, dynamic integration techniques can be employed to resolve class imbalance and increase robustness and versatility of classification.
- In addition to Support Vector Machine, cloud computing technique can be integrated so that some hybrid model may be developed to address the issue of large datasets.
- Cellular automata model may be implemented in drip irrigation system to model the irrigation setup and design and develop a water pipeline leakage detection and localization technique.

V. Cellular Automata and Water Pipeline Leakage Detection

Cellular automata may be considered as a collection of cells on a grid of a given form that evolves over time in accordance with a set of rules governed by the state of the neighboring cells [9]. Cellular automata may be used for a variety of purpose in agricultural areas like modeling and predicting cropping patterns [10], simulation of future agricultural land use and cover changes [11], etc.

A single-dimensional cellular automaton (CA) consists of a "cells," row in which each cell can be in one of several "states," and a set of "rules" to alter those states. The cells can be visualized as squares, where the cell's state corresponds to the square's color [12]. The one dimensional cellular automata concept can be implemented on the smart irrigation setup [13] to detect plausible leakage [14] and also to localize the leakage location [15].

Although lot of work has been carried out in the detection and localization of leakage in water pipeline structure [16] but most of them are centered around the acoustic based models [17][18] and detecting small leakage in the pipeline [19][20] is still a challenge and further localizing it accurately is another challenge which may be addressed by a hybrid model of cellular automata and IoT [21] [22]. For our research work we choose smart drip irrigation which has small diameter pipeline structure and in this research paper we define one dimensional cellular space & neighborhood, states, properties, and transition rules for the main pipeline, drip pipeline structure, and field and we have used IoT sensors like water flow sensors, soil moisture sensors, and rain sensors to record real time data coming from the synchronized work of these sensors in a drip irrigation setup to detect leakage and to minimize false positive cases.

In this section, first discuss about the generalized concept of cellular automata which includes the cellular space and neighborhood, states, properties, and transition rules.

A. *Generalized Cellular Automata*

The sub section provided the generalized view of cellular automata as follows:

1) Cellular Space and Neighborhood

Drip Irrigation Model based on cellular automata model is a model of a system of "water pipeline" and "field" with the following characteristics: (i) Cell in a grid, (ii) each cell has an adjacent area (neighborhood), (iii) each cell has a state. Usually, the number of possible states of cells is finite. The simplest instance is that there are two possibilities which may exist with respect to the state of the cell and i.e., either '0' and '1' state or 'on' and 'off' state or 'open' and 'close' state), and (iv) The transition rules determine the change in the state of each cell.

C1	C2	C3
C8	Cx	C4
C7	C6	C5

a. Moore Adjacent Area

	C1	
C4	Cx	C2
	C3	

b. von Neumann Adjacent Area

Figure 2. (a) shows that Cx has an adjacent area of with 8 cells and (b) shows that Cx has an adjacent area with 4 cells.

A community of cells surrounding an existing cell is the adjacent area of the cell, identifying an affected area, the cell state, and its adjacent area at the time affects the cell state at the time t +1. Suppose that i_{xy} is the cell at position (x, y), then $S_{i_{xy}}$ is the state of the cell i_{xy} at time 't', $S^{t+1}_{i_{xy}}$ is the state of cell at time 't' and can be defined as

$$S^{t+1}_{i_{xy}} = f\left(S^{t}_{i_{xy}}, S^{t}_{\omega_{i_{xy}}}\right) \quad \text{.........................} \text{ eq 1}$$

The set of the cells in the neighborhood of the adjacent area of the cell i_{xy} is given by $\omega_{i_{xy}}$. $S^{t}_{\omega_{i_{xy}}}$ represents the set of states of the cells $\omega_{i_{xy}}$ at time 't' and 'f' is a function which is represented by a set of transition rules. To evaluate the state of the cell under consideration at time 't+1' the function 'f' representing the set of transition rules will assume the value of the cell state at time 't' and the states of the neighboring states at time 't'.

2) State

The transition rule of a cellular automata with state set 'S' and size 'm' neighborhood is a function f : $S^m \rightarrow S$ that specifies the new state of each cell based on the old states of its neighbors. So, if the neighbors of a cell have state S1, S2, S3, ….., Sm then the new state of the cell is f(S1, S2, S3, ….., Sm).

3) Properties

CAs can exhibit emergent behavior of varying types, including universal computation. So, properties can be employed to predicting the behavior from the specification of the system which is a signification task. Cellular properties are the characteristics of the cell in a grid. Properties can be static and dynamic in nature.

4) Transition Rules

In cellular automata all the cells in a grid follow the same transition rule and also the transition rules are applied in a concurrent manner. The result is a global change in the whole configuration. For example, configuration 'C' is changed into configuration "C′" where for all $\vec{n} \in Z^d$.

$$C'(\vec{n}) = f[C(\vec{n} + \vec{n}_1), C(\vec{n} + \vec{n}_2), C(\vec{n} + \vec{n}_3), \dots, C(\vec{n} + \vec{n}_m)]$$

… eq (2)

The transformation C → C' is referred to as a global transition function of the cellular automata and is a function $G : S^{Z^d} \rightarrow S^{Z^d}$. The function 'G' is iterated which produces a time evolution

$$C \rightarrow G(C) \rightarrow G^2(C) \rightarrow G^3(C) \rightarrow \cdots \quad \text{… eq (3)}$$

Here time 't' refers to the number of applications of 'G' performed and takes one time step i.e., $G^t(C)$ which is considered as the configuration at time 't' for all t = 1, 2, 3, ….

VI. CONCLUSION

The paper presents the study of various model based leakage detection techniques for on and above ground water pipeline structure with the parametrised comparison to select the best plausible solution for implementation in the smart drip irrigation system to detect and locate leakage to conserve water. A generalized depiction of cellular automata with its space and neighborhood, states, properties, and transition rule is also provided. The conclusion drawn from the study advocates for implementation of cellular automata based leakage detection and localization model for detecting and localization of leakage in the smart drip irrigation setup due to its simple implementation yet complex behavior modeling.

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