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Research Paper

Cellular Automata Based Leakage Detection in Smart Agriculture for Crop Disease Prevention

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ABSTRACT

The issue of leakage in the irrigation pipeline of an agricultural setup not only contributes to the wastage of water but if the water becomes contaminated then its spread due to leakage may harm the crop and also add to the spread of the disease, if any, in the crop. There are many signal based as well as model based techniques for detection of leakage in the water pipeline. From the study carried out, it is evident that model-based techniques are more suitable for agriculture's irrigation setup. This research paper presents cellular automata-based leakage detection techniques in smart drip irrigation setup for preventing disease to spread in the crop by detecting the leakage, cutting the water supply to that drip pipe and sending SMS to the farmer so that timely action could be taken to treat the leakage area thereby preventing contamination and spread of water to the field preventing the spread of disease to the crop and aiding in water conservation. Moreover, the paper also demonstrates experimental results and discussion of the real time data collected from the soil moisture sensors, flow sensors, rain sensors for three different dates and different time validates the proposed work.

***Key words*:** Crop disease, Prevention, Smart agriculture, Cellular automata-based leakage detection

Water is a necessary resource for life, health, economic growth and the environment globally. Since water is important to all, it is necessary to ensure its availability and quality [1]. Some of the global factors like climate change [2], population overgrowth and imbalance [3], drought [4] are playing a major role in reducing the existing fresh water resources. India's economy is an agro-based economy [5]. Around 70% of rural population of India depends on agriculture for their livelihood [6]. Income from agriculture contributes to around 17% in GDP [7]. According to researchers around 70% of the available fresh water, mainly is being consumed in agricultural activities [8].

Leaky pipes can cause flooding and water infiltration, which can lead to cause more severe problems in an agricultural setup. Most commonly, water leaks are from cracked or broken water pipes. A number of factors, including erosion and the shifting of the landscape or soil, can result in cracked pipes. Other factors which can contribute to the leakage in pipe can be due to the result of weather exposure, aging of pipelines, physical damage to the pipeline, tree roots, or other sharp instruments. Leaks can be big or small and require some techniques to detect it. The leakage problems should be immediately addressed by the replacement or repair of damaged valves and pipes so that the after effects which may occur due to water pipeline leakage can be reduced to a greater extent [9].

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Some of the issues erupting as a result of contamination of water in agriculture due to leaky pipes are water stress on crop [10], pesticide runoff [11], increased erosion [12], increased nutrient levels and eutrophication resulting in algal blooms [13], waterlogging and salinization of soils [14]. The damage to the pipe has a major effect on the water quality and hydraulics of the water delivery system [15]. Broadly, two classifications exist for leakage detection and localization of water pipeline structure in irrigation setup i.e., signal based techniques and model-based techniques.

In signal based techniques, observation is used as a manual process which is a time consuming process and required manual intervention and inspection by a person, which is not ideal for a large field [16], acoustic which is a traditional way of identifying leakage and its accuracy is dependent only on the placement of sensor and it is not ideal from smaller leakage [17], infrared which can be used for shorter distance with continuous monitoring [18], fibre optics which gives precise leak detection but it is suitable for shorter distance [19], tracer gas which uses combination of insoluble gases to detect the leakage but they are not suitable for old pipelines as the gas may evade through the gaps of the joints [20], and ground penetrating radar which employs electromagnetic waves to detect and locate leak in the pipeline but they are more suitable for underground pipelines and also the disturbance if any may make this technique inefficient to detect and locate leakage [21].

In model based techniques, deep learning model is employed which uses logic based learning models like CNN and ANN with limitation that higher number of hidden layers are needed for more accurate detection [22], negative pressure wave model with limitation of more false alarm [23], mass balance with low detection rate and suitable only for small leak [24], real time transient model which is based on mathematical model, with fast leakage detection rate but expensive [25], statistical data analysis which is costlier due to inclusion of lot of data variation [26], and cellular automata which have shown promising results in the leakage detection and localization of oil and gas pipelines which are non-linear in nature and can also be used for predictions [27].

Table 1 Rating of signal based and Model Based Leakage Detection and localization techniques (less scoring for models means they are more appropriate)

Techniques		Parameters						Total
		A	B	C	D	E	F	
Signal based	Observation	1	3	3	1	1	1	10
	Acoustic	1	1	3	1	1	1	8
	Fibre Optic	3	2	2	1	1	1	10
	Tracer Gas	1	3	3	1	1	1	10
	GPR	2	4	3	1	1	1	12
Model based	Cellular Automata	1	1	1	1	1	1	6
	Deep Learning	3	1	1	1	1	1	8
	NPV	2	2	3	1	1	1	10
	Mass Balance Method	1	3	3	1	1	2	11
	RTTM	3	1	1	2	1	1	9
	Statistical Data Analysis	3	1	1	2	1	1	9

Table 2 Rating for initial setup cost – A, false alarm - D

Value	Numerical Value
High	3
Medium	2
Low	1

Table 3 Rating for accuracy – B, feasibility – C

Value	Numerical Value
High	1
Medium	2
Low	3

Table 4 Rating for detection – E and localization - F

Value	Numerical Value
No	2
Yes	1

The evidence shown in (Table 1) proves that model-based leakage detection method is better than signal based leakage detection method and among the model-based leakage detection method, the cellular automata model proves to be more promising with a scoring of '6'.

This research paper presents leakage detection techniques based on cellular automata in smart drip irrigation setup to prevent disease spreading in the crop by detecting leakage, cutting the water supply to that drip pipe, and sending SMS to the farmer so that the leakage area could be treated in a timely manner.

MATERIALS AND METHODS

Hardware, software, and data used

In the experimental setup i.e., the smart drip irrigation setup, for hardware, we used one arduino 2650 microcontroller, 9 soil moisture sensors, 8 water flow sensors, 1 rain sensor, 1 GSM/GPRS Sim900A interface module, and drip irrigation hardware as shown in (Fig 1 – 6).

The software used is linux operating system, Arduino IDE 1.8.13 for linux for microcontroller coding and interfacing with various sensors, fourmilab for simulation. The data of 2 water flow sensors installed on the either ends of main pipeline and 3 pairs of water flow sensors installed on either side of drip pipeline of drip irrigation setup, 9 soil moisture sensors, rain sensors were collected in real time and stored on the local machine for further calculation and analysis. The actual pressure of main pipeline and drip pipeline were calculated according to Hazen Williams Equation (for main pipeline) and darcy weisbach equation (for water pipeline) and stored in a repository.

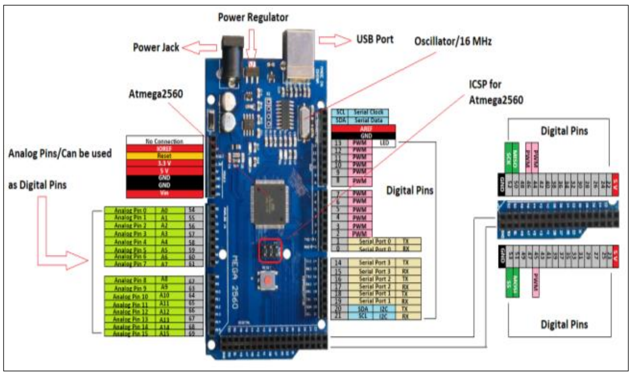

Fig 1 Arduino 2650 Microcontroller

Source: https://www.theengineeringprojects.com/2018/06/introduction-to-arduino-mega-2560.html

Methodology

Composition of cellular automata

In a discrete complex system of time and space, cellular automata run. Each cell takes a finite discrete state, follows the same rules and updates simultaneously, spreading in a grid. In general, a CA contains four tuples called A = (L, S, N, F), including L for the cell space, S for the finite discrete state of the CA, N for a set of neighboring cells (including the central cell, as per Moore Neighborhood, can be diagonal and straight), and F for CA regulations.

The irrigation main pipeline of length TL_{mp} is divided into a one-dimensional cellular space as shown in (Fig 7). Then a one-dimensional CA model is set up so that the water flow of the main pipeline can be simulated. Each cell is a grid and the CA model of drip pipeline contains $CS_{mp\ n} = DPCP_n$ where $CS_{mp\ n}$ is the number of cells in the main pipeline's cellular space, and $DPCP_n$ is the number of drip pipeline connection point on the main pipeline. The cells are numbered from 1 to n, with the main solenoid valve connected to cell 1 and flow sensor connected to cell 1 and cell 'n'. The water flows from cell 1 to cell n. The irrigation drip pipeline of length $TL_{dp\ i}^{1-n}$ is divided into a one-dimensional cellular space as shown in (Fig 7). Then a one-dimensional CA model is set up so that the water flow of the drip pipeline can be simulated. Each cell is a grid and the CA model of main pipeline contains $CS_{dp\ n} = EPV_n$ where $CS_{dp\ n}$ is the number of cells in the drip pipeline's cellular space, and EPV_n is the number of drip emitter connection point on the drip pipeline vertically. The cells are numbered from 1 to n, with the drip solenoid valve connected to cell 1and flow sensor connected to cell 1 and cell 'n'. The water flows from cell 1 to cell n.

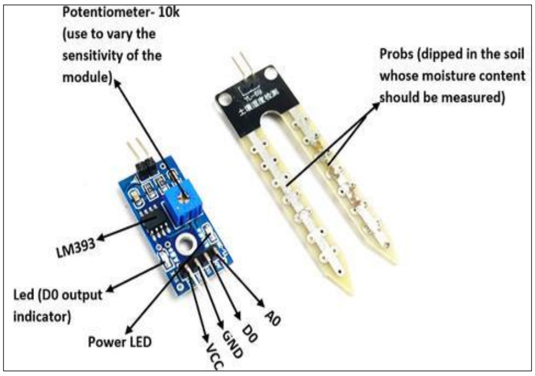

Fig 2 Soil Moisture Sensor
Source: https://quartzcomponents.com/products/soil-moisture-sensor-module

Fig 3 Water Flow Sensor
Source: https://www.instructables.com/How-to-Use-Water-Flow-Sensor-Arduino-Tutorial/

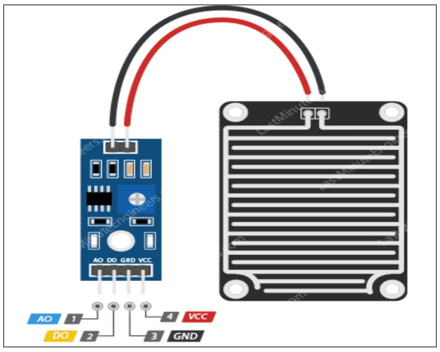

Fig 4 Rain Sensor
Source: https://lastminuteengineers.com/rain-sensor-arduino-tutorial/

Fig 5 GPRS/GSM SIM A900 Module
Source:https://www.circuitstoday.com/interfacing-gsm-module-to-8051

Fig 6 Drip Irrigation Hardware

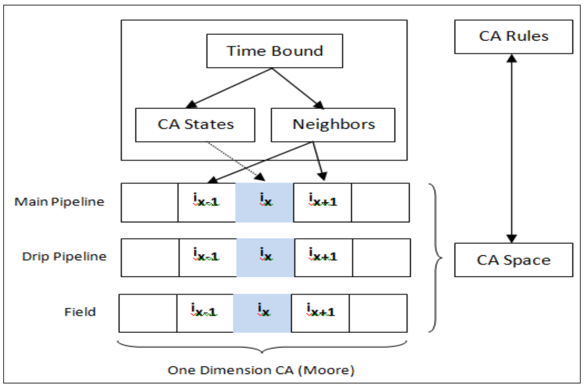

Fig 7 Composition of Cellular Automata Space, Neighbors, States, and Transition Rules

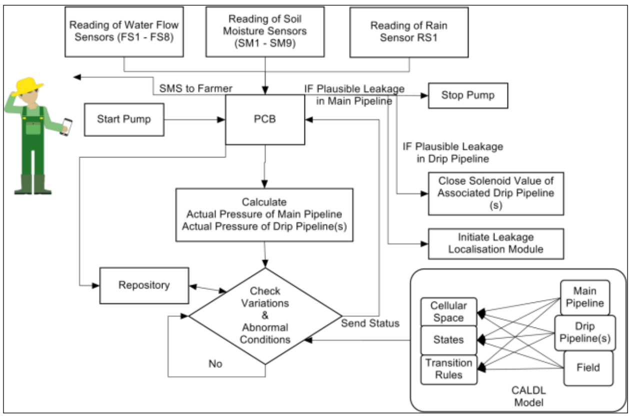

Fig 8 Flow chart of the proposed Cellular Automata Based Leakage Detection and Localization (CALDL) Model Based Technique

The entire field is divided on the basis of the number of drip emitter connection point on the drip pipeline horizontally across the field i.e., EPH_n and the number of soil moisture installed around the drip emitter connection points i.e., SM_n horizontally as shown in (Fig 7). Then a one-dimensional CA model is set up so that the soil moisture readings across the field can be simulated. Each cell is a grid and the CA model of field contains $CS_{f\ n} = EPH_n$ where $CS_{dp\ n}$ is the number of cells in the field's cellular space, and EPH_n is the number of drip emitter connection point on the drip pipeline horizontally across the field. The cells are numbered from 1 to n, with each cell containing the drip emitter and soil moisture sensor.

The broader methodology, will involve the following process

The farmer will initiate the setup, where first it will check that whether the required water quantity is present in the water tank, if the required quantity is present, then the reading of rain sensor will be taken to see whether there is rain or not, if there is no rain then the pump will start the flow of water through the main pipeline to the drip pipeline(s). The real time reading of the water flow sensors, soil moisture sensors will be taken by the print circuit board (PCB) and the actual pressure of main pipeline as well as the drip pipeline will be calculated.

If there is high variation in the pressure of main pipeline or any drip pipeline(s) and the status of the cellular space of either main pipeline, drip pipeline(s), and field gives abnormal conditions according to the transition rule then it will be concluded that there is a plausible leak in either the main pipeline or drip pipeline(s) and the status will be send to the PCB for further action. The PCB will stop the pump if there is leakage detected around the start of the main pipeline or else the associated drip pipeline's solenoid valve will be closed to prevent water to flow through that leaked pipeline. The leakage localization module will be called to pinpoint the exact location of the leakage and a SMS will be sent to the farmer suing GSM/GPRS SIm900 interface module in real time.

RESULTS AND DISCUSSION

Since the dataset is very voluminous and is stored per milliseconds so it is not possible to show the entire dataset due to page limitation, however, snapshot of the soil moisture sensors, water flow sensors, and rain sensor are shown in the below (Table 5).

Table 5 Soil moisture sensor, flow sensor, and rain sensor readings for 3 dates (Range)

Time	Soil Moisture Sensor Reading (Range)									Flow Sensor Reading (Range)						Rain Sensor Reading (Range)
	SM1	SM2	SM3	SM4	SM5	SM6	SM7	SM8	SM9	FS1	FS2	FS3	FS4	FS5	FS6	RS1
Day 1																
T1 - Tn	0-60	0-60	0-59	0-57	0-56	0-59	0-59	0-57	0-60	0-6	0-6	0-6	0-6	0-6	0-6	1
Day 2																
T1-Tn	0-59	0-59	0-57	0-57	0-54	0-54	0-56	0-54	0-59	0-6	0-6	0-6	0-6	0-6	0-6	1
Day 3																
T1-Tn	0-72	0-70	0-59	0-57	0-56	0-59	0-59	0-57	0-60	0-7 (7-4)	0-5	0-6	0-6	0-6	0-6	1

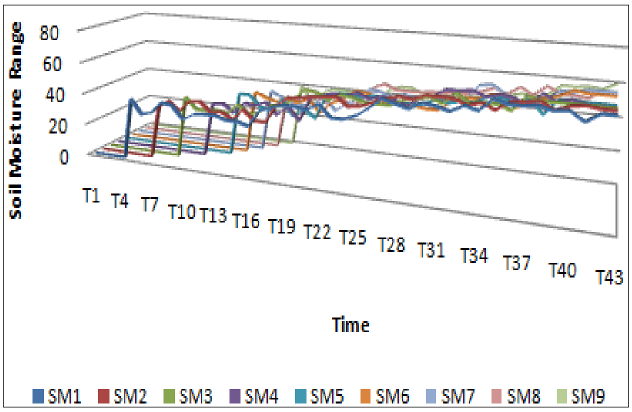

Fig 9 (a) Soil Moisture Reading – Day 1

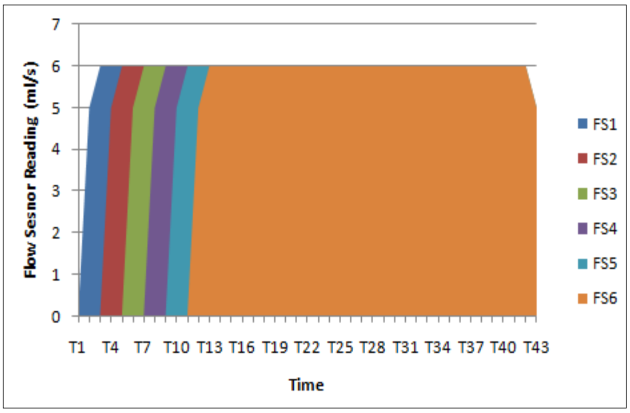

Fig 9 (b) Flow Sensor Reading – Day 1

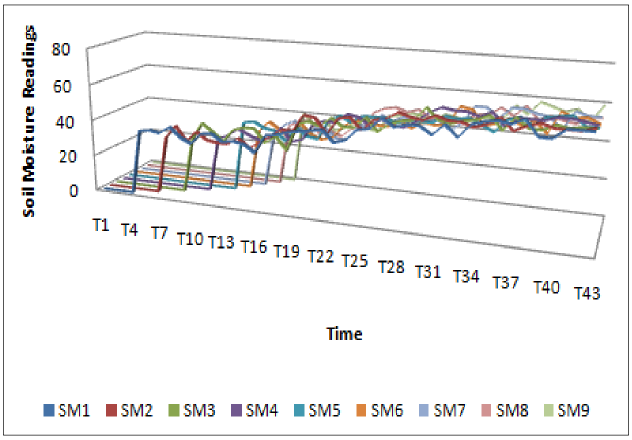

Fig 10 (a) Soil Moisture Reading – Day 2

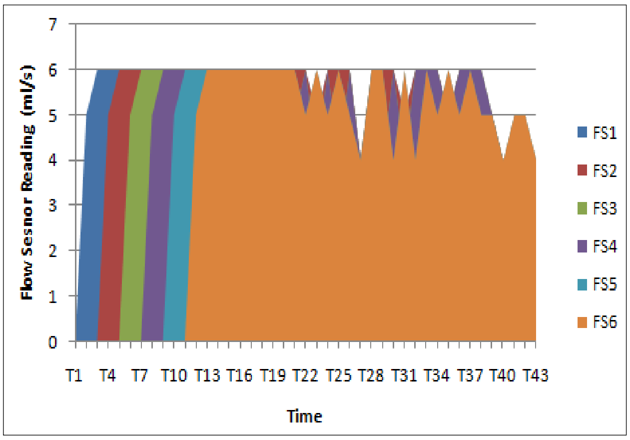

Fig 10 (b) Flow Sensor Reading – Day 2

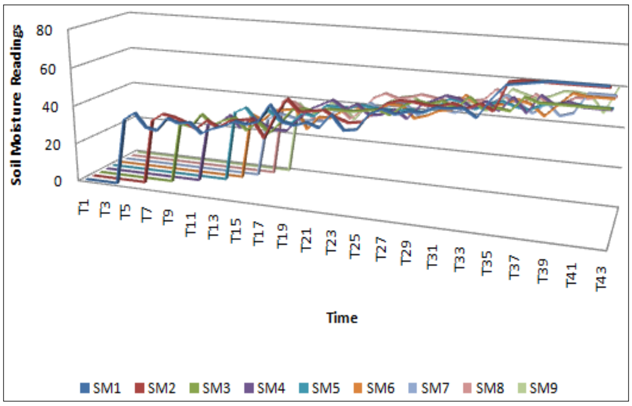

Fig 11 (a) Soil Moisture Reading – Day 3

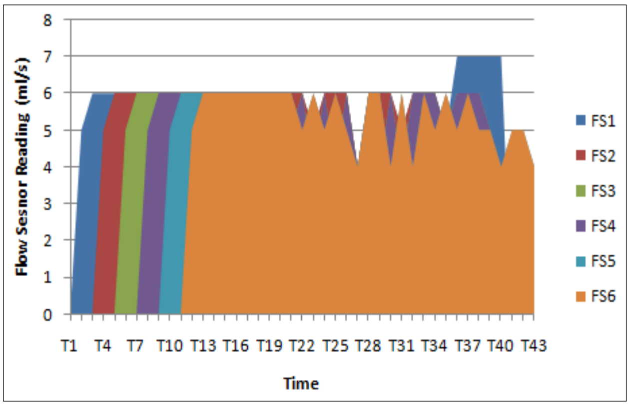

Fig 11 (b) Flow Sensor Reading – Day 3

Fig (9a – b), (10a – b), and (11a – b) depicts the graphical readings recorded in a file in real time from the various soil moisture sensors and flow sensors installed on the testbed setup. The readings will form the basis for the construction and transformation of the field cellular state and can help in the detection of any abnormality through the shift in cell states.

All soil moisture ranges from 0 to 61 in day 1 readings, as per (Fig 9a), reflecting that no excess water is present in any of the field cells and thus suggesting that no plausible leakage is present. The graphical readings of water flow sensors mounted on the drip pipes with usual readings ranging from 0 to 6 ml/s flow are shown in (Fig 9b) and the corresponding pair of flow sensors installed on both ends of each drip pipe do not report high variance during the flow of water, indicating that no irregular readings appear to occur and thus no leakage.

In day 2 readings, as depicted in (Fig 10a), the measurements of all soil moisture range from 0 to 61, suggesting that there is no excess water in any of the field cells, and therefore indicating that there is no plausible leakage. (Fig 10b) shows the readings of water flow sensors installed on drip pipes with normal readings ranging from 0 to 6 ml/s and the associated pair of flow sensors installed on both ends of each drip pipe, although some minor variation during water flow was reported, but the difference between the FS1 and FS2 pairs was equivalent to time indicates that no abnormal readings seem to occur, hence no leakage. While there was a small variance in the reading of the FS1 and FS2 flow sensors, it was regarded as a FALSE POSITIVE leakage case due to no difference.

In day 3 reading, (Fig 11a) shows the measurements of all soil moisture levels from 0 to 72 that reflect the presence of excess water in any of the field cells and therefore suggests that there could be plausible leakage. (Fig 11b) shows the graphical readings of water flow sensors installed on the drip pipes with usual readings of 0 to 6 ml/s and the associated pair of flow sensors installed on both ends of each drip pipe, although some substantial variance between the pairs FS1 and FS2 was not equal to time, suggesting that irregular readings appear to occur and hence may be a case of plausible leakage. Because there was a substantial variance in the reading of the FS1 and FS2 flow sensor with discrepancy in the FS1 and FS2 pair readings and also the SM1 and SM2 soil moisture readings that were mounted on the field near the drip pipeline where the FS1 and FS2 flow sensor pairs were installed and therefore a case of plausible leakage.

CONCLUSIONS

This research paper presents leakage detection techniques based on cellular automata in smart drip irrigation setup to prevent disease spreading in the crop by detecting leakage, cutting the water supply to that drip pipe, and sending SMS to the farmer so that the leakage area could be handled in a timely manner. In addition, the paper also shows the experimental results and addresses the real time data obtained for three different dates and different times from soil moisture sensors, flow sensors, and rain sensors. It concludes that if the proposed technique is implemented, then every possibility of accurate leakage detection is available and timely detection will be communicated to the farmer via the GPS/GPRS SMS 900A interface module via SMS, and the water flow to the associated water pipeline will also be disconnected. The various issues of water contamination may not happen thereby preventing the spread of disease to the crop and aiding in water conservation. Future work may involve the study with more data and large field with practical implementation.

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