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Intelligent Lab view based Fuzzy Logic Controlled Irrigation System using IoT and LoRa Technology

Abhisekh Behera[1] and Roop Pahuja[2]
[1-2]Dr. B. R. Ambedkar National Institute of Technology/Instrumentation and Control Department, Jalandhar, India
Email: abhisekh30@gmail.com, pahujar@nitj.ac.in

***Abstract*— This paper investigates and compares experimental techniques in irrigation systems, focusing on crucial factors such as soil fertility, moisture level, pH level, water availability, and temperature for efficient agriculture and increased food productivity. The proposed method involves transmitting data from sensors (e.g., soil-moisture, pH, temperature, and air moisture) to an IoT platform utilizing LoRa communication protocol, processing it, and utilizing it for developing a fuzzy-control action to determine the optimal irrigation valve opening while also notifying the irrigation water pH. LoRa is a low-power wide area network solution enabling long-range communication with minimal energy consumption. The objective is to create a smart irrigation system for efficient water management in agriculture. The system monitors parameters like soil moisture, ambient temperature, and water pH, utilizing a fuzzy logic controller to regulate irrigation and minimize water wastage. LabVIEW facilitates data processing, valve control, and sensor data acquisition. LoRa is used for data transmission to a data concentrator and then broadcasted to the TTN platform for visualization and analysis. This setup demonstrates the effectiveness of LoRa and the fuzzy logic controller in achieving resource-efficient irrigation practices for sustainable agriculture.**

***Index Terms*— WSN, IoT, Sensors, LoRa, GUI, TTN, UDP, LPWAN,**

I. INTRODUCTION

India, with a population of 1.42 billion [1], heavily relies on agriculture, which supports 55% of its people [2]. However, traditional irrigation methods and dependence on monsoons limit productivity. Crop failures, particularly in drought-prone regions, are worsened by water mismanagement and climate change. Due to limited awareness, technological advancements, and inadequate efficient agricultural practices, crop yields in India often fall short of their potential.

The quality of irrigation water, which is not adequately evaluated prior to use, is one contributing factor. While the impact may not be catastrophic, it significantly affects crop nourishment. Water pH has a profound influence on nutrient absorption and soil health. Emphasis should be given towards the regulation of water pH according to soil type and crop needs that involves neutralizing acidic or alkaline water before supplying it to farmland. Some simulation-based models have been employed previously for pH control of irrigation water that have yielded satisfactory results. The pH measurement of irrigation water is crucial in precision agriculture, aiming to optimize resources and enhance crop productivity [3]. Understanding water pH is vital as it directly affects nutrient availability, soil health, and plant growth. Accurate pH measurements provide insights into water acidity or

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alkalinity, guiding decisions on water treatment, fertilizer use, and crop selection. Maintaining the optimal pH range ensures nutrient accessibility to plants, impacting solubility and uptake. Moreover, pH measurement identifies potential issues like high alkalinity, preventing nutrient lockout and harmful ion accumulation. Two methods, namely liming action and acidification, can be employed to manipulate the pH level of a solution or mixture [4].

In order to tackle these issues, it is crucial to modernize agricultural practices and utilize water efficiently, while also maintaining the suitable irrigation water pH levels. Smart irrigation presents a promising solution by enhancing agricultural practices, boosting productivity, and minimizing water wastage.

The technologies used here for achieving smart irrigation are LoRa technology for data transmission, fuzzy logic control designing on LabVIEW for irrigation valve control mechanism, TTN website as IoT cloud platform for real-time LoRa gateway status and sensor node data and curve-fitting for obtaining relationship between sensor output data (volts) and measurement value of actual parameter under consideration for smart system. Simulation tests for the developed FLC have been discussed in results section.

II. Related Work

A. Prevailing Smart Irrigational models

A group of authors suggests a solar-powered irrigation system with a pump to extract water, a tank with an automatic valve regulated by a controller [5] and a moisture sensor, utilizing solar energy, and a stepper motor for valve control, requiring low maintenance and ideal for sprinkler irrigation whereas another author discusses the placement of humidity and soil moisture sensors in the plant's root zone to monitor environmental conditions. A microcontroller regulates water supply based on the sensed values, but this system lacks real-time notifications or updates to keep the farmer informed about the field's status [6].

The authors [7] introduce a smart irrigation system that adjusts watering based on predefined ranges for soil moisture and temperature. By connecting the water pump and servo motor to the output pins, the system efficiently manages irrigation operations. The Arduino code sets moisture range and temperature range using digital resistance values. This cost-effective system effectively conserves water and minimizes wastage.

The authors [8] have carried out a comparative study between Fuzzy logic and ANN control action by considering several parameters in play depending on the type of plantation and has provided evidence of ANN being better choice and showcasing better efficiency. Parameters considered here are soil humidity level, ambient temperature, wind speed and light intensity.

A proposed system by some authors [9] combines Arduino Uno and LabView software to measure and monitor moisture levels in the tank and soil, calculates relative humidity, controls the water pump motor, and enables plant irrigation based on sensor outputs. Bluetooth ensures a continuous data connection, facilitated by the Arduino compatible LabView toolkit. The system easily differentiates between dry and wet soil conditions using soil conductivity, resulting in three scenarios: the pump remains off for insufficient water level, turns on for sufficient water level in dry soil, and remains off for sufficient water level in wet soil.

The author [10] develops an IoT-based system utilizes an Arduino Uno platform, YL-69 moisture sensor, and LM393 comparator modules to monitor and regulate soil moisture levels. When necessary, the system automatically initiates watering. A dedicated webpage is created to display the status of the water sprinkler, providing information on the moisture content of two soil samples (one using sensor A and the other using sensor B) and the corresponding pump on/off status.

Another group of authors [11] present a LabView-based irrigation system designed for drought-prone regions. It integrates the NImyDAQ system, wireless sensors for remote soil moisture and temperature monitoring, and a Wi-Fi network with a web-publishing tool for wireless connectivity. Using the LabView platform, users can set desired soil moisture and temperature values to regulate the pump motor's operation as it provides an intuitive, spreadsheet-based data visualization, enabling easy observation of parameter trends. Temperature sensor nodes are strategically placed to monitor soil temperature near the plant roots, mitigating the risk of heat shocks.

The authors propose a [12] LabView-based monitoring system using a DAQ card developed to monitor temperature, humidity, soil moisture, and sunlight intensity. This data is used to optimize the timing of watering and pesticide spraying on plants. By controlling the water and pesticide pumps, the system ensures efficient irrigation and pest control. Real-time data from the four sensors (humidity, light, temperature, soil moisture) is displayed on an LCD screen using an ATmega 89C52 microcontroller. Additionally, the data is logged and accessible on a PC, allowing for remote monitoring and control of the pumps.

The authors [13] introduce an IoT-based automated irrigation system that optimizes water delivery to plants by utilizing moisture, light, and temperature data from sensors. The system includes a smartphone application integrated with cloud storage, allowing farmers to monitor these parameters. By analysing and comparing data from previous years with the current data, the system effectively conserves water.

Another proposed system by the authors [14] utilizes Arduino UNO as the sensor node and base-station, incorporating components like LDR, mini water pump, NRF24L01, and Wi-Fi module (Node MCU-ESP8266). A moisture sensor collects soil humidity data, which is transmitted to the base-station. The data is recorded in a Thingspeak cloud server database, accessible via an android application.

The proposed concept by author [15] combines human interaction and automation in a smart sprinkler system. It utilizes a capacitive active soil moisture sensor integrated with real-time weather data from the Indian Meteorological Department. By integrating sensor data on soil moisture and weather reports obtained through GPRS, using an ARM microcontroller and UART, the system enables efficient water management. The weather website provides 24-hour data and six-day forecasts, including temperature details, allowing for the adjustment of plant watering schedules based on rain forecasts.

The author [16] highlights the potential of cloud-based IoT in enhancing connectivity and data accessibility in precision agriculture, real-time monitoring and control thereby improving resource management.. It emphasizes the use of IoT in efficiently allocating resources in farming. Sensor nodes collect vital parameters like soil moisture, temperature, humidity, and light levels, enabling informed decision-making for actuator control. Transmitting data to the cloud through an IoT platform allows remote access and monitoring. An Android app provides convenient access to agricultural data.

The authors [17] present a novel development of a fuzzy control system for Variable Rate Irrigation (VRI) using remote sensing data from the i-ekbase web tool using satellite imagery from Landsat and Sentinel (Satellites). The study introduces a decision support system based on fuzzy logic that creates prescription mappings for VRI with central pivots. By analysing remote sensing information like canopy temperature and upper layer soil moisture, the fuzzy control system adjusts irrigation rates according to the specific needs of different field areas.

B. Prevailing Fertigation models

The irrigation system by author [18] utilizes fuzzy logic to control three input parameters: soil moisture, soil temperature, and water level. The system is enhanced by the Rain Detection Model (RDM) and Fertilizer Control Model (FCM), ensuring effectiveness and innovation. With the sprinkler system dispensing fertilizer fluids, farmers achieve optimal results with minimal water and fertilizer usage, promoting increased crop productivity. When activated, the irrigation system's FCM automatically initiates the opening process.

C. Significance of Irrigation Water pH monitoring

A group of authors [19] concluded from their experiment that the pH level of irrigation water significantly affects crop growth (here hop plant) . Maintaining a pH range of 6.5 to 7 enhances potassium absorption, accumulation, and availability in hop leaf tissue. This range also boosts photosynthetic capacity and leads to higher yields compared to other treatments. These findings emphasize the importance of optimizing pH levels in irrigation water to promote the growth and productivity of hops.

D. Prevailing Irrigational water pH control models

The author accomplished the design and implementation of a PID-based simulation model for achieving pH neutralization of irrigation water. The results demonstrated excellent accuracy and precision, allowing for the irrigation of optimum quality water tailored to the specific soil types, pH values, and crop characteristics. This implementation proved to be a remarkable success in the realm of agricultural automation, effectively enhancing crop yields [3].

III. MOTIVATION

The effectiveness of agricultural methods and the improvement of food production depend on various key elements within irrigation systems, such as soil fertility, moisture levels, pH levels, water availability, and optimal temperature conditions. However, farmers have encountered significant obstacles in gathering, integrating, comprehending, and implementing data-driven control for their irrigation systems.

IV. PROBLEM DOMAIN

The problem domain of this research constitutes of data communications utilizing LoRa technology and data transmission through UDP protocol, graphical user interface (GUI) LabVIEW, theory and application of fuzzy control, intelligent automated systems and internet of things cloud platforms such as The Things Network.

V. PROBLEM DEFINITION

Collecting soil and environment data, integrating, understanding and applying the acquired data-based control in irrigation system is a real challenge for researchers even after so much research. The quality of irrigation water is not rendered important but is one crucial factor for achieving precision agriculture via smart irrigation. On/off controls is not good enough mechanism for better tracking of actual input variable and applying required control action anymore, hence fuzzy logic control is needed to replace the existing ones. Besides these, solar power source would be a good alternative for powering the system and integrating LoRa technology to this would just add in more advantage of long range, low power, bi-directional data transmission.

VI. STATEMENT

Long range data transmission without any delay, use of renewable energy resource for power and better control action than on/off mechanism and real-time check on the status of irrigation is some of the few problems towards which attempts have been taken to find a solution better than the existing ones.

VII. INNOVATIVE CONTENT

The development, simulation and testing of a system consisting of the solutions for the above mentioned problems speaks of its novelty that takes a further step towards a more efficient system towards some improvement in the field.

VIII. PROBLEM REPRESENTATION

It has been evidently proven that fuzzy logic control action is much better than its on/off counterpart. Some authors developed an on/off and a fuzzy logic controller (FLC) model for automating greenhouse irrigation systems [20]. The FLC determines the optimal irrigation actions by analysing sensor data like soil moisture level and environmental conditions. Its simulation results reveal that the FLC outperforms a simple on/off controller as the FLC effectively tracks the desired soil moisture without oscillations, exhibiting an error range of only 2.8-4.6% which is much better than the on/off control. FLC has found application across numerous engineering domains and industrial sectors, such as bioprocess, greenhouse climate control, and automatic feeders for aquaculture [21].

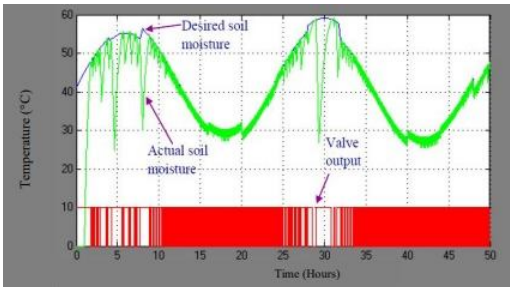
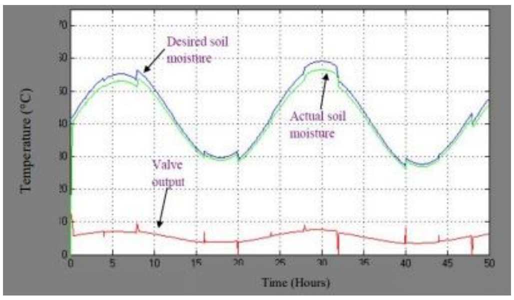


Fig. 1 (a)Simulation results of on/off control



(b) simulation results of fuzzy control [20]

IX. SOLUTION METHODOLOGIES

A. Monitored parameters

The parameters that have been monitored are

a) *Soil Matric Potential*- SMP assesses the energy status of water in the soil matrix, influencing its retention and the force required for plants to extract water and measured in units of pressure as kilopascals (kPa) or bars. A negative value indicates water tightly held in the soil, impeding plant access, while a positive value indicates available water for plant uptake. The 200SS Watermark sensor is a robust and reliable solid-state device. It detects changes in tension as soil moisture levels fluctuate, leading to corresponding variations in its resistance.

b) *Ambient temperature*- It represents the temperature of the air volume near the measurement sensor and represented by degree Celsius (C^o) or Kelvin (K). LM35DZ Temperature sensor is a popular analog sensor known for its precise temperature measurement capabilities. It functions by translating the ambient temperature into an equivalent voltage output. With a linear output directly proportional to the temperature in Celsius

c) *Water pH*- The pH of a liquid solution, a fundamental concept in chemistry, is determined by the concentration of hydrogen ions (H+) present within the solution. It serves as a measure of the solution's acidity or alkalinity and is represented on a logarithmic scale ranging from 0 to 14. A pH value of 7 is considered neutral, while solutions with a pH below 7 are categorized as acidic, and those above 7 are regarded as alkaline or basic. The pH sensor detects the concentration of hydrogen ions in the liquid using a glass electrode and a reference electrode. When the glass electrode touches the liquid, it generates a voltage that corresponds to the pH level.

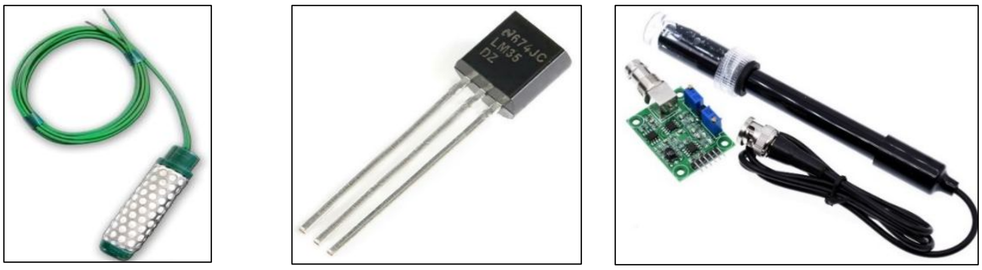


Fig. 2 (a) Watermark 200SS soil moisture sensor (b) LM35DZ Temperature sensor (c) pH liquid sensor [22]

B. The proposed model

It comprises of two block diagrams, Fig. 3 (a) and Fig. 2 (b), illustrating the setup of a LoRa sensor node for optimizing soil moisture monitoring near the crop root. Accurate pH measurements of the irrigational water are obtained by placing the pH sensor electrode at an appropriate distance from the inputs. The analog sensors are connected to the Raspberry Pi's analog channels via a 12-bit ADC. To ensure real-time data transmission, the system utilizes LoRa technology. Data is sent to the WisLink-LoRa RAK2243 module, a high-performance LoRaWAN gateway with exceptional connectivity options. This gateway broadcasts data through a 4G GSM module network, enabling seamless transmission to the TTN IoT platform using UDP. Node-RED software processes and manipulates the sensory data, allowing access on the LabVIEW GUI for further analysis. A Fuzzy Logic Controller (FLC) is designed using the SMP and AT variables, derived from the parsed voltage data obtained in comma-separated string format. The FLC automates the valve opening duration, optimizing irrigation and minimizing water wastage. The LabVIEW Graphical Interface, communicating via UDP, facilitates user access to the data. The pH value of the irrigation water is used for notification purposes, while the user must ensure the addition of sufficient liquid fertilizer to the irrigation water for the field.

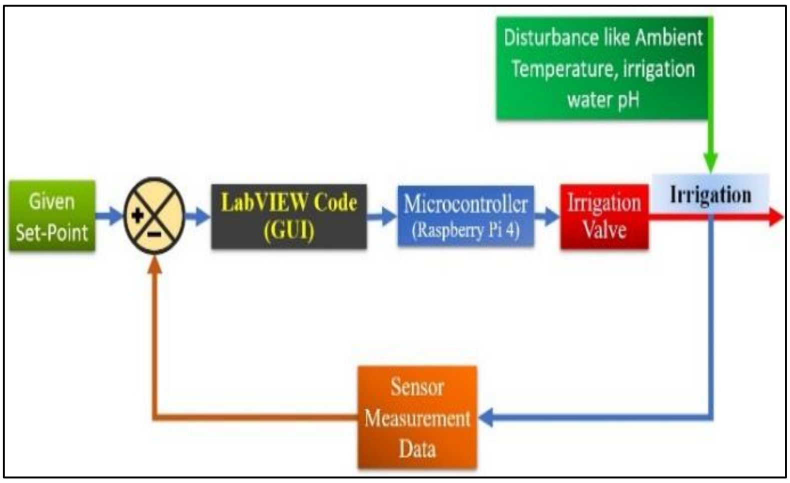
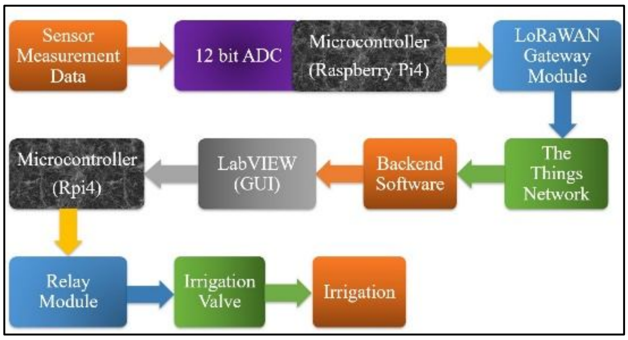


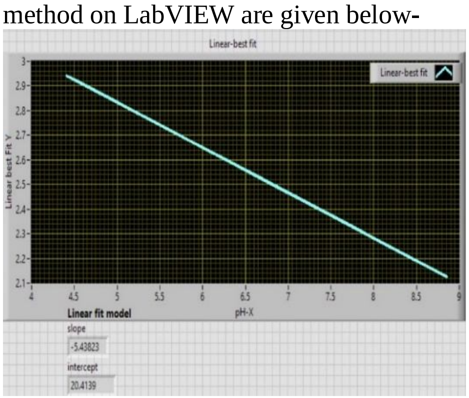
Figure 3. (a) Proposed Control Block Diagram



(b) Data-flow Diagram

X. RESULTS

The parameters were continuously monitored as graphs and numerical values after going through mathematical operations based on the curve-fit models employed using the datasheet (voltage vs equivalent parameter value) of the sensors deployed in this set-up. The Graphical User Interface of LabVIEW software enables the graphical display of the parameters in real-time until the monitoring process is stopped. This data is then utilized further in the development of the FLC for the control of the irrigation valve opening according to the fuzzy inference system and user-defined fuzzy rules using the input variables and output variable. The raw data from the sensor nodes can be seen in the TTN (The Things Network) website in real-time. The Things Network (TTN) is an IoT cloud platform specifically designed for LoRaWAN-based devices. The output response of the Fuzzy Inference system tracks the change in the input variables time-to-time within the fuzzy defined limit and controls the watering accordingly. The equations obtained for conversion of analog voltage to real parameter value using curve-fit method on LabVIEW are given below-



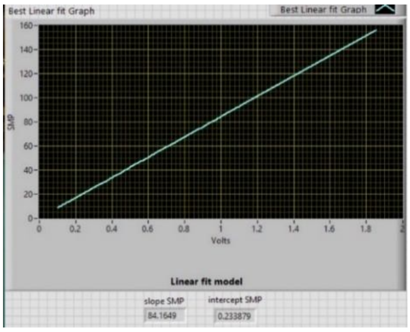


Figure 4. (a) Curve-fit of pH dataset on LabVIEW (b) Curve-fit of SMP dataset on LabVIEW

a) from voltage to SMP $y = 84.16488x + 0.233879$ (1)

b) from voltage to Temperature $y = 100x$ (2)

c) from voltage to pH $y = -5.43823x + 20.4139$ (3)

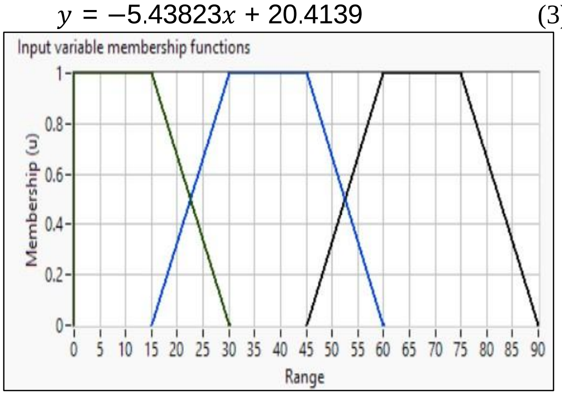
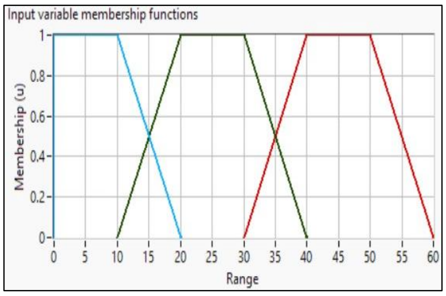
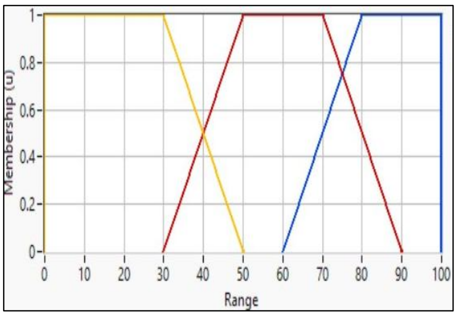


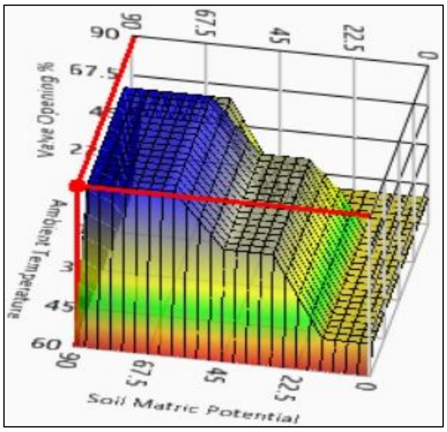
Figure 5. (a) Soil Matric Potential – 1st i/p Membership Function



(b) Ambient Temperature – 2nd i/p Membership Function



(c) Opening percentage – o/p Membership Function



(d) Input-Output Relationship 3D plot with SMP in X- axis, Temperature in Y-axis and Valve Open % in Z axis

XI. Data Model

A Fuzzy Logic Controller is designed on the fuzzy logic control designer, LabVIEW using limits for soil matric potential and ambient temperature as 0-90 and 0-60 respectively as input variables and the output variable taken here is valve opening percentage (0-100%). Several simulation tests have been conducted using the fuzzy logic controller designed and centre of maximum defuzzification method.

TABLE I. User Defined Fuzzy Rules

Rule No.	Soil Matric Potential (1st I/P variable)	Ambient Temperature (2nd I/P variable)	Open Time Duration (O/P variable)
1	WET	COLD	CLOSED
2	WET	MILD	CLOSED
3	WET	HOT	CLOSED
4	NORMAL	COLD	CLOSED
5	NORMAL	MILD	33% OPEN
6	NORMAL	HOT	33% OPEN
7	DRY	COLD	33% OPEN
8	DRY	MILD	100% OPEN
9	DRY	HOT	100% OPEN

XII. COMPARISON OF RESULTS

In the simulation process, the LabVIEW Fuzzy Logic Designer was employed to predict the anticipated outcome of the proposed system. Three input parameters were taken into account to determine the appropriate water supply for the crops. The soil moisture and ambient temperature were considered within a range of 0 to 90 and 0 to 60, respectively, as crisp input values.
When the SMP and AT values taken are 20 (22.22%) wet and 15 (25%) cold respectively, the valve opening is 30 (30%) closed that corresponds to fuzzy rule 1.
When the SMP and AT values taken are 50 (55.55%) normal and 30 (50%) mild respectively, the valve opening is 70 (70%) 33% open which corresponds to fuzzy rule 5.
Similarly, if the SMP and AT values take are 70 (77.78%) dry and 40 (66.67%) hot resp., the valve opening is 90 (90%) 100% open which corresponds to fuzzy rule 9.
Upon taking SMP and AT values as 30 (33.33%) normal and 8 (13.33%) cold, the output is 15 (15%) closed that corresponds to fuzzy rule 4 whereas while the SMP and AT being 55 (61.11%) normal and 27 (45%) mild resp. produces 80 (80%) 33% open corresponding to the fuzzy rule 5. Thus, below given is the plot for these 5 simulation tests on the Fuzzy system designed.

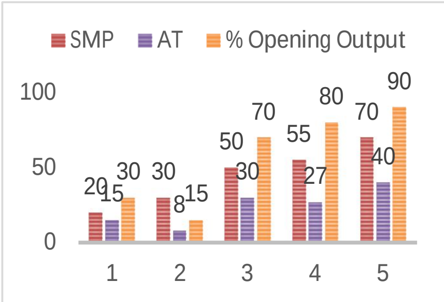
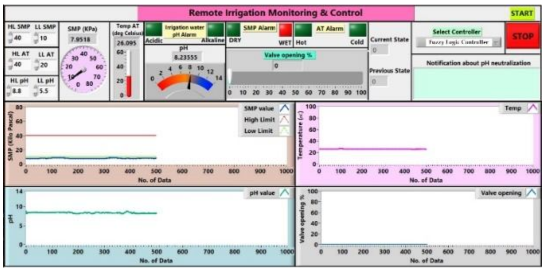


Fig. 6 (a) Fuzzy Inference System Simulation Test Plot



(b) GUI Front panel of Monitoring and Control on LabVIEW

XIII. JUSTIFICATION OF THE RESULTS

The results obtained through the simulation tests conducted using the FLC are aligned with the results of another paper where rain sensor was the extra sensor employed and 3rd input variable considered for FLC designing [18]. The fuzzy system thus developed tracks the actual soil moisture level effectively and contributes towards water wastage minimization. The above shown GUI shows the real-time monitoring results of the proposed model discussed. Here, as the SMP value is still below the set limits, hence the control valve hasn't opened yet and the system keeps on tracking the other parameters.

XIV. CONCLUSION

This proposed model can improve the watering scheduling due to the fuzzy algorithm utilized here. The fuzzy system takes two input parameters namely soil matric potential and ambient temperature for decision making for the duration of irrigation valve opening in irrigating the plantation. The LabVIEW fuzzy logic controller Designer is used for testing and simulation of the input data for analysing the system efficiency and accuracy. It is evident from the results that the fuzzy mechanism does increase the efficiency of minimizing water wastage. The LabVIEW program also notifies the users about the pH of irrigation water for taking required action to control its pH by either acidification or lime action. The controller designed monitors the parameters and when the SMP value crosses the low limit, it switches the valve on proportional to the percentage as designed with the FLC and effectively irrigates the plant system.

FUTURE SCOPE

For future work, another input variable soil temperature near root instead of ambient temperature can be included along with humidity and the developed fuzzy controller would show even better results. Even soil pH parameter can be integrated for the most accurate results but with the risk of a big budget of the industrial soil pH sensors. Another supply can also be incorporated for valve control of liquid fertilizer connecting directly with the irrigation water.

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