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RESEARCH ARTICLE

Development Of Artificial Intelligence Algorithm For Smart Irrigation Using Internet Of Things (IOT) (A BASC Automated System for Improved Agricultural Irrigation)

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Abstract

Artificial Intelligence (AI) is the most recent agricultural technology. In agriculture, water is used to irrigate the plants so that they can flourish. Due to the scarcity of water in most parts of the world, the watering process is one of the most significant and crucial procedures. To address the issue, a smart irrigation system based on the Internet of Things (IoT) was developed, utilizing AI technology, an Arduino Uno microcontroller, and sensors. The objective of this study is to develop a modified ANFIS (Adaptive Neuro-Fuzzy Inference System) AI algorithm for improved automated irrigation system decision control and to reduce the computing complexity of ANFIS architectural layers. It also seeks to develop an integrated system for monitoring and managing irrigation to increase agricultural output using MANFIS and the Internet of Things. Lastly, is to determine the difference in algorithmic complexity between the conventional ANFIS and the modified ANFIS. As a result, architectural layers were reduced into 3 layers: input, process and output. It also waters the plant automatically and sends signals regarding smart irrigation system information such as the tank's water level, the plant's soil moisture content, and the trigging factor, or the quantity of water to be released which enables the farmers to monitor and manage their irrigation system using the IoT. The simulations were carried out using MATLAB software. A fuzzy logic controller was used to control the whole system by providing its input, rules, and output. To determine the computational complexity of each method, the ANFIS and modified ANFIS were examined.

KEYWORDS:
ANFIS, Artificial Intelligence, algorithm, MANFIS, MATLAB, sensors, microcontroller, smart irrigation

1 | INTRODUCTION

Introduction Agriculture plays a vital role in the growth of the country's economy. There are a lot of modern technologies to make agricultural work very easy. Due to the shortage of water in most areas of the world, the watering process is one of the most important and critical processes in modern farming [1]. Hence, there is a need for automatic, intelligent, and smart systems that can make smart utilization of the available amount of water to feed plants for maximum time of farming [2].

A lot of research has been conducted on irrigation systems. An integrated irrigation system was developed by [3] to assist and monitor irrigation using Bluetooth technology. A microcontroller system was designed to monitor the soil temperature within the crop fields with suitable sensor devices [3]. SMSs are sent to organize irrigation schedules whenever there is a possibility of rain based on the environmental conditions in the agriculture field [4]. Weekly irrigation evaluation is performed using measurement of soil and environmental changes based on sensor nodes [5]. Automating farm irrigation allows you to apply an appropriate amount of water regardless of the availability of labor to your own valves on or off and to know the plant growth status. Nowadays, automation has been implemented in all fields like industries, home automation, agriculture, etc. [6]. Distributed field sensor-based irrigation systems offer an eventual solution to support irrigation supervision that produces maximum yield with water-saving systems [7].

Crop water requirements (CWR) are defined as the depth of water, usually measured in mm, needed to meet the water consumed through crop evapotranspiration (ETc) by a disease-free crop, growing in large fields under non-restricting soil conditions including soil water and fertility, and achieving full production potential under the given growing environment [8]. It always refers to a crop grown under optimal conditions, i.e. a uniform crop, actively growing, completely shading the ground, free of diseases, and favorable soil conditions (including fertility and water). The crop thus reaches its full production potential under the given environment.

The crop water needed mainly depends on:

- the climate: in a sunny and hot climate, crops need more water per day than in a cloudy and cool climate
- the crop type: crops like maize or sugarcane need more water than crops like millet or sorghum
- the growth stage of the crop; fully grown crops need more water than crops that have just been planted.

Before applying irrigation water, the exact amount of water and the schedule of irrigation should be identified first. A calculation should be made in order to come up with this. Otherwise, there will be a harmful effect on plants, a waste of water and irrigation that will not be efficient.

Emerging Internet of Things (IoT) technologies offer a great potential for novel solutions and smarter application development that can improve all aspects of the agricultural sector [9]. IoT has already been at the center of smart farming research efforts for several years. The majority of papers focus on the benefits and challenges of IoT in agriculture [10] and [11] or analyze IoT architectures, technologies, and practices for smart agriculture [4] and [12], focusing on hardware, platforms, sensors, and wireless communication protocols [13] and [14].

Machine learning methods are implemented in agricultural areas for getting precision data and positive yields [15]. Machine learning methods are implemented in agricultural areas for getting precision data and positive yields [15]. Machine learning also provides systems with the potential to automatically learn, program, and get better without external stimuli and programming. Data is collected and transferred for decision-making using IoT. A Neural Network provides the required intelligence to the device that considers current sensor inputs and masks the irrigation schedule for efficient irrigation [3]. Many researches about smart irrigation uses neural networks and deep learning like fuzzy logic and adaptive neuro-fuzzy inference systems.

ANFIS (Adaptive Neuro-Fuzzy Inference System) is an efficient combination of an Artificial Neutral Network (ANN), piece of a computing system designed to simulate the way the human brain analyzes and processes information, and fuzzy logic for modeling highly non-linear, complex, and dynamic systems. It has been proved that, with the proper number of rules, an ANFIS system is able to approximate every plant. Even though it has been widely used, ANFIS has the major drawback of computational complexities [16]. ANFIS models with large inputs have not been implemented due to the curse of dimensionality, and many researchers have used meta-heuristic algorithms to tune the parameters of ANFIS. This study focuses on modification of the ANFIS architecture to reduce its complexity and improve the accuracy of the classification problem.

2 | METHODOLOGY

The proposed algorithms (MANFIS) use a Top-Down Design approach, which depends on problem solving by dividing large problem into smaller problems. It can be solved separately by using modules that initially started from high-level details and work their way down to the lower levels of problems. The sum of the smaller solutions will be the solution to the overall problem.

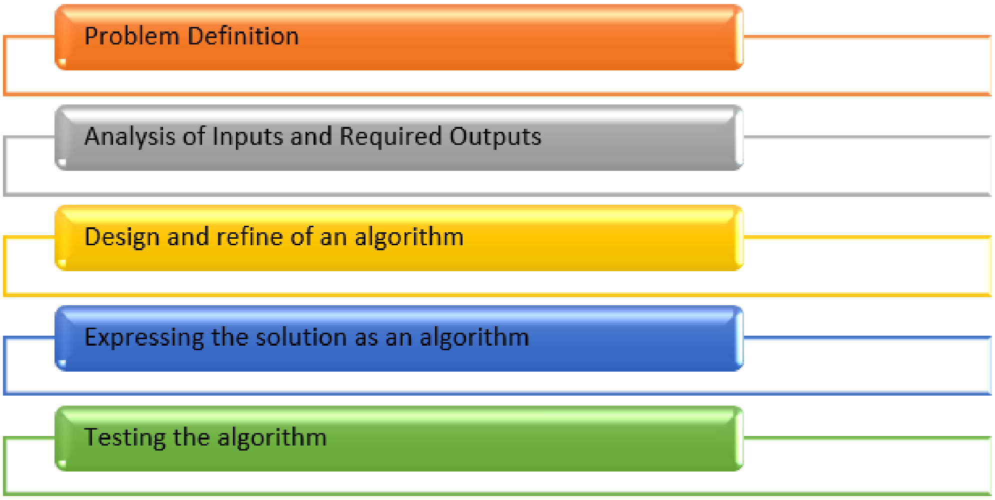

FIGURE 1 Framework of a structured algorithm process

Step 1: Problem definition:

- How to compare the Computational complexity of ANFIS to MANFIS
  - How to reduce the computational complexity of ANFIS
  - How to make a truth table
  - How to make equations
  - How to simplify the equation
- How to compare the Architectural layer of ANFIS to MANFIS
  - How to reduce the architectural layers of ANFIS
- How to monitor and control irrigation to improve productivity in agriculture based on MANFIS by means of IoT?
  - How to assemble Arduino Uno controllers, sensors, and SIM module
  - How to simulate in MATLAB software.

Step 2: Analysis of Inputs and Required Outputs. In this step, the input, processing details, and required output that relate to the problem are necessary. Here are some of the questions that will help the developer in analyzing the inputs and required outputs.

- Output analysis (by asking and answering such questions as:)
  - What is required of the algorithm?
  - What format should the output take?
  - How will the output be presented?
- Input specification (by asking and answering such questions as:)
  - Where does the data come from?
  - What is required to achieve the desired output?
  - What is the nature of the data?
  - What quantity of data will be input?

- Processing rules (by asking and answering such questions as:)
  - What formula or rules are used to transform the data?
  - What decisions need to be made about the data and the flow of logic within the algorithm?

TABLE 1 Shows the soil moisture percentage and type of soil basis for the algorithm development

Soil Moisture	Type of Soil
0% to 35%	Soil needs to be irrigated or Dry
36% to 45%	Soil is irrigated moisture
46% to 100%	Soil is “soggy” or too much water content

Step 3: Design and Refinement of Algorithm, Designing the solutions can only begin once the input, output, and processing rules have been clearly defined and clarified. Algorithms will be designed using the Input-Process-Output (IPO) method.

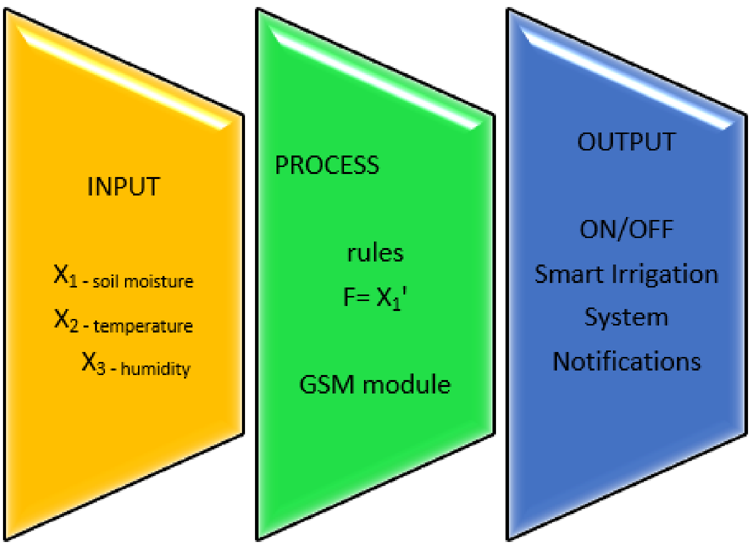

FIGURE 2 IPO Conceptual Framework

Step 4: Expressed the solution as an algorithm, Transformed the solution to its mathematical equations or formula. This solution is an algorithmic solution that will be converted into mathematical equations.

TABLE 2 Truth table for the rules of the MANFIS for smart irrigation system

INPUT			OUTPUT
x_1	x_2	x_3	
0	0	0	1
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	0
1	1	0	0
1	0	1	0
1	1	1	0

Where:

X_1 stands for the soil moisture
X_2 stands for the temperature
X_3 stands for the humidity

Equation:

$$F = X_1'X_2'X_3' + X_1'X_2'X_3 + X_1'X_2X_3' + X_1'X_2X_3 \qquad \text{Eq. 1}$$

Simplify:

Using Karnaugh Mapping or K-mapping Techniques

	00	**01**	**11**	**10**
0	1	1	1	1
1				

$F = X_1'$ *Eq. 2*

This means that if the X_1 (Soil Moisture) input is low or zero, smart irrigation will be triggered. If the soil moisture level is low, the smart irrigation system will release water and start watering the plants.

Step 5: Test the algorithm, Algorithms will be tested using desk-checking and walk-through. Desk-checking is the dry run of the algorithm using some test data, and walk-through is the checking of the algorithm by stepping through each line of the algorithm code. A desk check is performed manually by walking through every line in a pseudo-code to identify the bugs in logic and to ensure the algorithm works as intended. It is performed on an algorithm code using tables with columns as line number, value of variables, conditions if applicable, input-output and expected result.

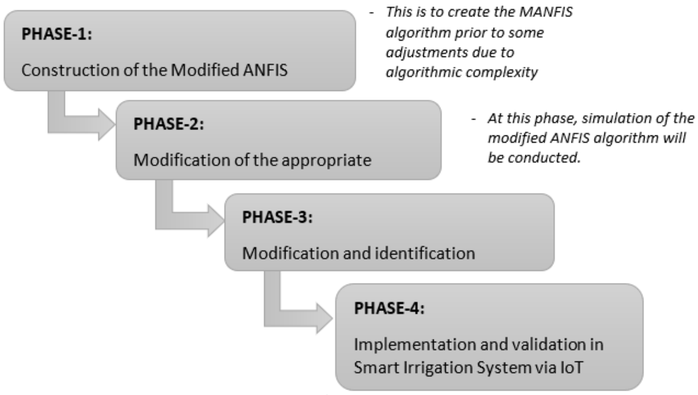

FIGURE 3 Experimental Design

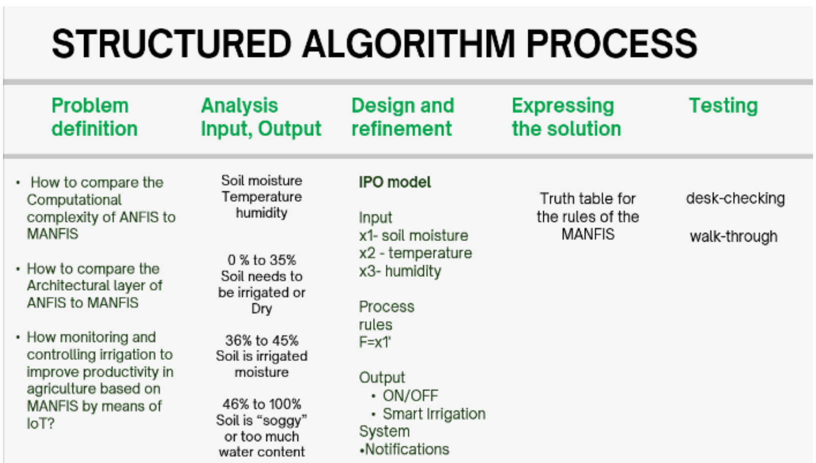

FIGURE 4 Structured Algorithm Process

Below shows the detailed description of the different phases identified by the proponent.

Phase-1. In this phase, the proponent tried to create the complete construction of the modified ANFIS algorithm. By doing this, the proponent has to search for the appropriate or related resources when constructing the algorithm. Prior to this, the proponent has to see to it that the necessary software requirements are met, like the program language to be used. Prior to proceeding to the next phase, the proponent has to evaluate the algorithm by compiling it appropriately.

Phase-2. Once the MANFIS algorithm is established, the proponent then modifies the round function by adding or subtracting some logical operations within the defined area. Proper observation on how to use the operations.

Phase-3. In this phase, the proponent has to properly analyze what to modify in the round function's parameters. Appropriate modification and identification of the parameters should be observed and simulated. Parameters such as the number of rounds, the i-th round, and the constant value of the function f(x).

Phase-4. As to the last phase, the modified ANFIS should be tested in terms of its security. The modified ANFIS will be implemented and validated in the smart irrigation system using IoT.

2.1 | Materials

Software

For the Operating System, the proponent will be using MS Windows 10 Pro in a 64-bit system type, which includes MS Office 365 for the write-up of this study. For the programming framework, MATLAB R2019b, the latest version, will be used for the implementation of the modified ANFIS. MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. MATLAB R2019b also has Simulink® Support Package for Android™ Devices that enables the users to create and run Simulink models on supported Android devices.

Hardware

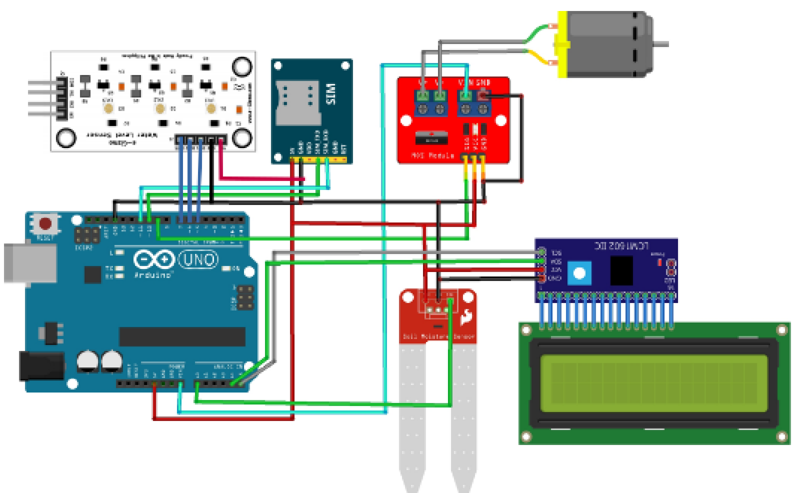

FIGURE 5 Schematic diagram Smart Irrigation System

For the hardware (Smart irrigation), the proponent would consider the following specifications:

- Arduino Uno training set
- Soil moisture sensors
- Water level sensors
- Pump
- LCD

3 | RESULT AND DISCUSSION

The architectural layers of ANFIS were reduced from five layers to three which include INPUT, PROCESS, and OUTPUT. A modified ANFIS offers a much simplier computation than ANFIS.

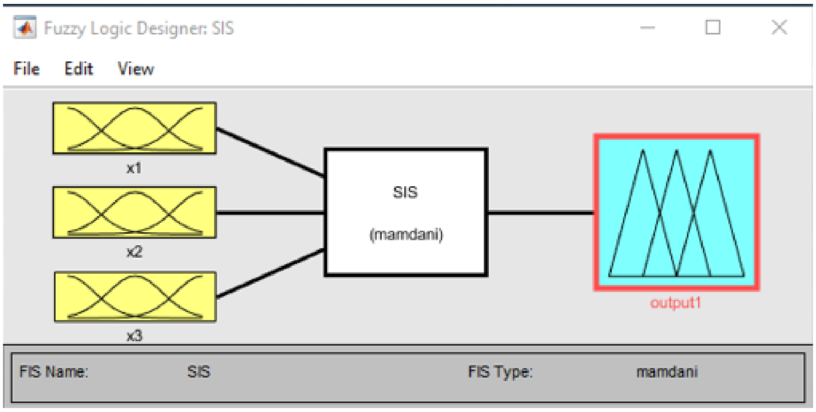

FIGURE 6 Fuzzy Logic Controller of Smart Irrigation System

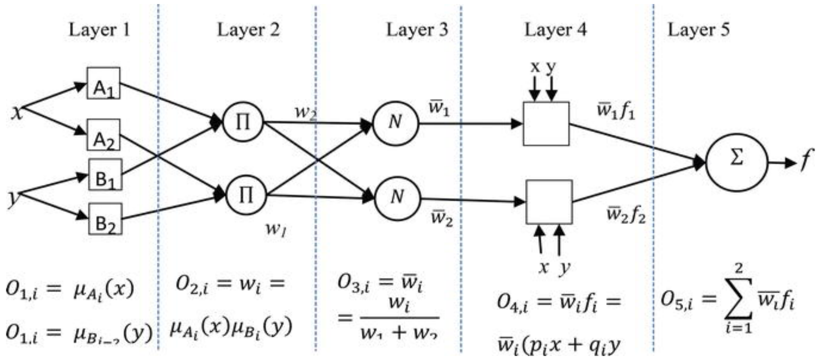

FIGURE 7 ANFIS Architectural Layers

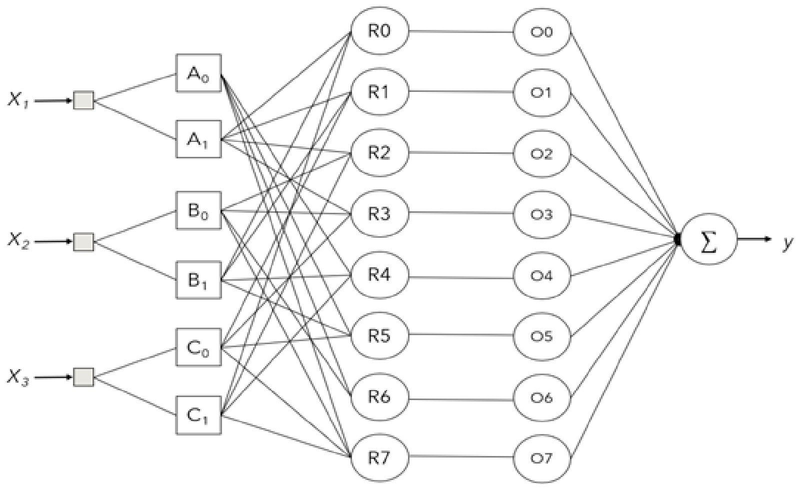

FIGURE 8 Modified ANFIS

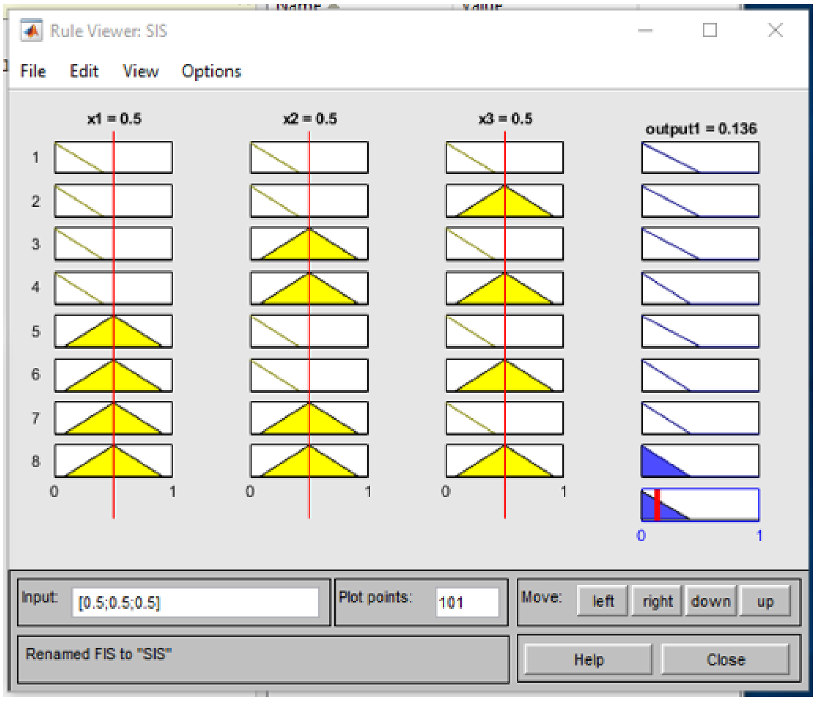

FIGURE 9 Rules of the Fuzzy Logic Controller of Smart Irrigation System

TABLE 3 Table of Rules of Smart irrigation System (SIS)

INPUT			OUTPUT
x_1	x_2	x_3	
Low	Low	Low	ON
Low	Low	High	ON
Low	High	Low	ON
Low	High	High	ON
High	Low	Low	OFF
High	Low	High	OFF
High	High	Low	OFF
High	High	High	OFF

The rules for the smart irrigation system are shown in Table 2, which are used to activate the system's ON and OFF switches. If X_1 is low, the smart irrigation will automatically irrigate the crops. A sensor moisture sensor was placed into the plot. This sensor reads the soil moisture content and sends it to the Arduino Uno microcontroller, which holds the AI controller that can decide when to switch ON and OFF the irrigation system on its own.

The functionality of the algorithms was tested using desk-checking and walk-through. Table 2 shows the desk checking of the algorithm and Table 3 shows the walk-through of the algorithm.

TABLE 4 Desk Checking of Algorithm

Line Number(P-Code)	*Soil moisture*	*Watering delay (sec)*	*SMS*	*PUMP*	*Notification*
63			Text “status”	OFF	Yes
71			Text “trig”	ON	Yes
79	0	0	1	ON	Yes
79	1	0	0	OFF	No
124	1	1000	1	OFF	Yes
110	>100	0	1	ON	Yes
124	0	1000	1	ON	Yes

TABLE 5 Walk-Through Testing of Algorithm

Walk-Through Testing	**YES**	**NO**
1. Did the Smart Irrigation System (SIS) Run when plug in?	100%	
2. Does a SMS send to the user?	100%	
3. Does the SMS contain the water level percentage of the water container, Soil moisture content of the plant and watering triggering factor?	100%	
4. Does the SIS automatically irrigate the water when the soil moisture content is low?	100%	
5. Does the SIS automatically send message to the user when irrigating?	100%	
6. Does the SIS reply when the user text ‘status’	100%	
7. Does the SIS reply contain water level percentage of the water container, Soil moisture content of the plant and watering triggering factor?	100%	
8. Does the SIS reply when the user text ‘trig’	100%	
9. Does the SIS reply contain the triggering factor	100%	
10. Does the SIS reply when the user text ‘trig’ plus percentage	100%	
11. Does the SIS reply contain the triggering factor plus percentage	100%	
12. Does the SIS meet its objective to automatically irrigate the plant?	100%	
13. Does the SIS will enable to monitor the irrigation system using IoT?	100%	
14. Does the SIS send notification to the user every time it irrigates?	100%	

To validate the whole system, the researchers conducted several trials of testing on the smart irrigation system. The system measured the soil moisture level and water level of the tank, then classified the soil type and displayed it on the LCD. The testing was done in an indoor plant setting at different times. Table 4 shows the testing results with 12 trials and shows the results were successful when the system did the expected output needed.

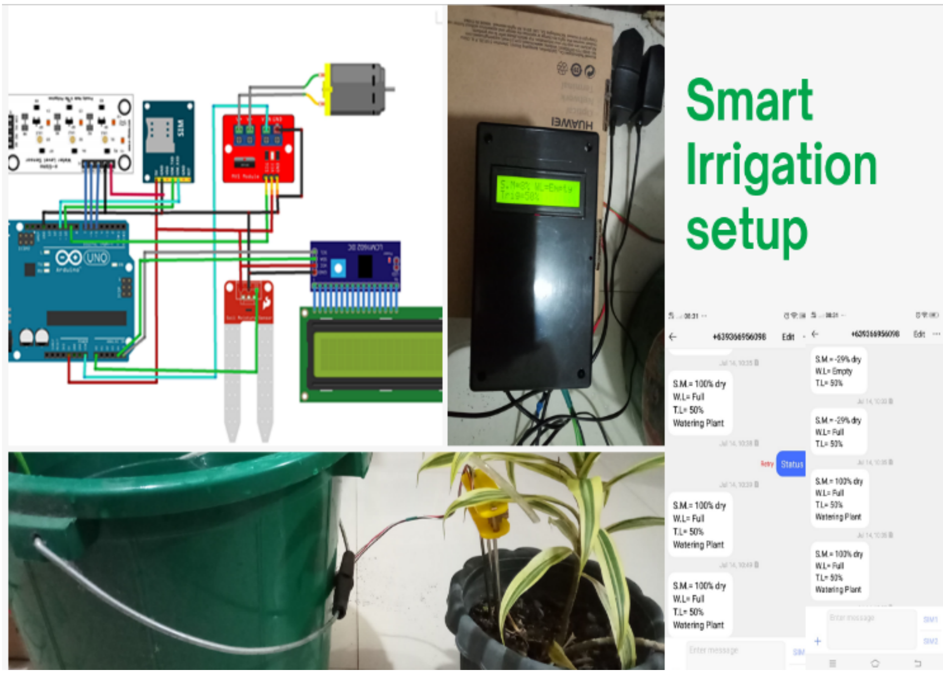

FIGURE 10 Functionality Testing of the water pump and sensors

TABLE 6 Walk-Through Testing of Algorithm

NO. OF TRIALS	TIME	WATER LEVEL	SOIL MOISTURE (DRY)	SMS NOTIFICATION	RESULT
1	10:33 AM	Empty	29%	Yes	Success
2	10:33 AM	Full	29%	Yes	Success
3	10:35 AM	Full	100%	Yes	Success
4	10:49 AM	Full	0%	Yes	Success
5	3:50 PM	Empty	0%	Yes	Success
6	3:55 PM	Empty	100%	Yes	Success
7	3:57 PM	Full	18%	Yes	Success
8	4:47 PM	Full	0%	Yes	Success
9	9:06 AM	Full	100%	Yes	Success
10	9:30 AM	Full	0%	Yes	Success
11	3:05 PM	Empty	0%	Yes	Success
12	3:06 PM	Empty	100%	Yes	Success

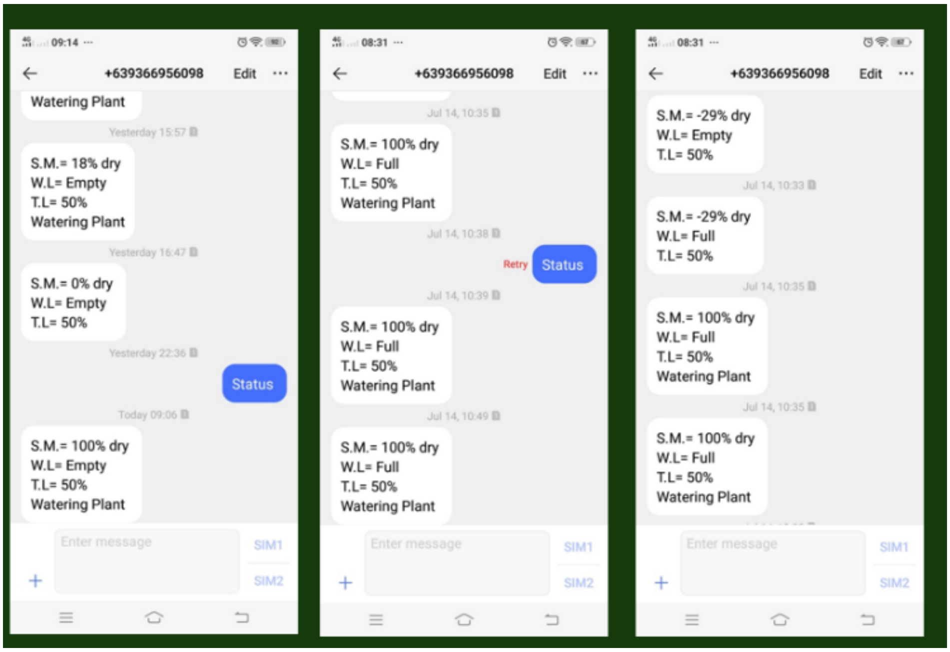

FIGURE 11 SMS Notification Testing

3.1 | CONCLUSION

In this study, the ANFIS architectural layers were reduced into three layers: input, process/rules, and output with much simplified computations. The smart irrigation system, through controlled soil moisture measurement using low-cost sensors, was able to monitor and control the irrigation to improve production in agriculture by means of SMS notifications. The system passed all validation and functionality tests with a 100% success rate. This confirmed and indicated that the method is efficient and successful when it comes to soil irrigation. The system may be improved by adding a water tank, network sensors, cloud or IoT monitoring, and deep learning.

3.2 | ACKNOWLEDGMENT

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