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# Design and simulation of an intelligent irrigation system using fuzzy logic

Peter Kibazo<sup>1</sup> · Wanzala Jimmy Nabende<sup>1</sup> · Michael Robson Atim<sup>2</sup>

Received: 10 September 2024 / Accepted: 9 January 2025

Published online: 24 January 2025

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## Abstract

Farmers in developing countries employ various irrigation methods ranging from traditional techniques such as the use of irrigation cans to modern pressurized systems while irrigating short-seasoned crops that require continuous water supply especially during the dry season. In spite of being cheap and easy to use, farmers find it challenging to optimize farming costs through the application of the necessary amount of water onto the crops, leading to crop water logging and hence rotting. Due to the growing demand for agricultural products, there was need to develop an irrigation system that considers the amount of moisture in the soil, air temperature and light intensity, which are important parameters in plants' growth. This dissertation therefore presents the design, simulation and implementation of an intelligent irrigation system, utilizing multiple sensors and a fuzzy logic controller to optimize water usage while ensuring high farming yields. The system design integrates light, temperature, and soil moisture sensors to monitor environmental conditions and soil moisture content in real-time. The operation of the irrigation system is governed by a set of one hundred twenty five (125) fuzzy rules that process the inputs from these sensors, determining the appropriate irrigation duration based on the prevailing light intensity, ambient temperature, and soil moisture levels. The fuzzy logic controller employs a combination of membership functions and rule-based inference to handle the relationships between the environmental parameters and the irrigation needs of the soil. By continuously analyzing the data from the sensors, the system dynamically adjusts the water output, ensuring optimal soil moisture levels while minimizing water wastage. Additionally, the system is equipped to send notifications in form of calls to a smartphone connected to the GSM network in case of critical conditions or system malfunctions. Experimental results demonstrate the ability of the intelligent irrigation system to dynamically adjust the amount of water being pumped into the garden basing on the prevailing soil moisture, temperature and light intensity.

**Keyword** Fuzzy logic · Fuzzy rules · Linguistic terms

## 1 Introduction

The intelligent irrigation system was built with three types of sensors: Temperature, light intensity and soil moisture sensors. Furthermore, each of these types of sensor were made three in number, with an average signal of the three sensors being considered for decision making, hence leveraging accuracy of the system. To allow categorization of the average signals, a set of linguistic levels was established for each parameter and this was done to minimize errors and

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✉ Peter Kibazo, kibazopeter256@gmail.com; Wanzala Jimmy Nabende, wanzalajimmy@gmail.com; Michael Robson Atim, mikeatim.sci@busitema.ac.ug | <sup>1</sup>Physics department, Mbarara University of Science and Technology, Mbarara, Uganda. <sup>2</sup>Physics department, Busitema University, Busia, Uganda.



hence increasing system's accuracy. The linguistic levels of the three parameters are then combined using a set of fuzzy rules, developed using the table 6.

## 1.1 Background

### 1.1.1 Agriculture

Growing consumer demand for agricultural products has been the primary drive of the technological revolution of agriculture in developing nations [1, 2]. This has led to a significant rise in the usage of modern technology, such as synthetic pesticides, conventional irrigation, and high-yielding seed varieties, which have huge productivity and poverty-reduction benefits [3]. Several models have also been developed to ensure effective land use and management [4, 5]. In Uganda, agriculture is the backbone of country's economy, employing eighty one point three percent (81.3%) of the country's population, and contributing half of Uganda's export earning and a quarter of the country's gross domestic product (<sup>1</sup>). This involves both crop growing and rearing of animals. Under crop growing, water is a crucial ingredient in plants' growth [6], and its scarcity has a negative impact on crops [7]. Plants therefore need to be watered regularly to ensure proper growth.

### 1.1.2 Irrigation

In the absence of sufficient rains, human action is required to supply water to the plants [8]. This is mainly done through irrigation which can be; surface, subsurface or pressurized irrigation [9]. Surface irrigation is commonly employed in many developing nations due to its low cost and energy need as compared to subsurface and pressurized irrigation systems (sprinkler and drip irrigation systems), which are usually more efficient than surface irrigation [10]. Current irrigation systems, including drip and spray irrigation, rely on surface irrigation, which is unreliable since it suffers soil moisture loss through evaporation [11]. Furthermore, such unautomated irrigation systems are prescribed with different challenges including; water wastage arising from farmers overwatering their crops, hence increased costs of watering a garden, inconsistent irrigation (due to manual operation of the system) leading to low crop yields, increased labour costs to run the irrigation system, and low efficiency [12].

### 1.1.3 Internet of Things (IoT)

IoT is a paradigm where everyday objects can be equipped with identifying, sensing, networking and processing capabilities that will allow them to communicate with one another and with other devices and services over the internet, to achieve specific objective relating to online data transmission and storage for analysis [13]. Under IoT, devices (things) that include mobile phones, wearables, sensors and actuators are connected together, with an aim of simplifying communication between different devices and data access [14]. This in turn offers control and automation of systems, enables real-time access to information, and guarantees efficiency of systems [15]. Therefore, the incorporation of IoT in irrigation systems helps to mitigate all the challenges common with unautomated systems, with additional benefits which include; improved agricultural output and efficient water use [8], agricultural modernization by lowering expenditures, personnel, and water, resulting in increased revenues [16]. Automated irrigation systems are of a great advantage to a farmer since they help in saving energy and resources for utilizing in a precise way, easy installation of the system on the field, aid application of the right amount of water at the right time for the sake of farmer's easiness to control farm irrigation and nursery, use of valves in automated irrigation systems to turn on/off the motor which minimizes the time spent by a farmer on ground, operation of a pump or motor by a sensor-based controller and no need for any labor to monitor the irrigation systems [17]. Furthermore, crop efficiency that includes improvement in the reduction of the overwatering from the saturated soil and avoiding the wrong time of irrigation to save more water is ensured [17].

<sup>1</sup> <https://www.ktaadvocates.com/wp-content/uploads/2023/12/Financial-Capability-Survey-2020-Report.pdf>

### 1.1.4 Fuzzy logic

Fuzzy logic is an extension of Boolean logic created by Zadeh (1965), based on the theory of fuzzy sets, which is a generalization of the classical set theory [18]. Fuzzy logic, by enabling a condition to be partially true and partly false at the same time, makes it suited for dealing with ambiguities or doubts [19]. This is as a result of assessment of the different membership functions generated from fuzzy linguistic terms, used in generation of the fuzzy rules. The use of many linguistic terms enables accommodation of small changes, minimizing possible errors and hence increasing system's accuracy [20].

## 1.2 Fuzzy membership function

Let  $X$  represent the world of discussion, with its elements represented by  $x$ . A fuzzy set  $A$  in the universe  $X$  is described by a membership function  $\mu_A: X \rightarrow [0, 1]$ . The fuzzy set  $A$  can be represented by the set of pairs of an element  $x \in X$  and its degree of membership defined by a membership function  $\mu_A(x)$  as expressed in equation (1), [21]:

$$A = \{(X, A(x)) / x \in X\} \quad (1)$$

A degree of zero (0) implies that the value is out of the range, a degree of one (1) implies that the value is fully a representative of the set, and a degree confined between zero and one means the value is not fully within the range [22]. The choice of the membership function is usually determined by statistical studies [23]. Different shapes such as sigmoid, triangular, trapezoidal, Gaussian and other types can be used [23].

In order to easily utilize fuzzy sets, the traditional set theory operators are modified to the fuzzy logic membership functions, which only allow values between 0 and 1. Typically, the extension of the union operator (OR) to fuzzy sets  $A$  and  $B$  defined over the same set  $X$  is defined as shown in equation (2) by [24, 25]:

$$\mu_A \cup B(x) = \max[\mu_A(x), \mu_B(x)] \quad (2)$$

Where  $\mu_A$  and  $\mu_B$  are the membership functions for  $A$  and  $B$  respectively. Similarly, the fuzzy intersection (AND) is defined as shown in equation (3) by ([25, 26]):

$$\mu_A \cap B(x) = \min[\mu_A(x), \mu_B(x)] \quad (3)$$

Fuzzy logic is applicable in various areas including automation of a voltage regulator [27], controlling hybrid power systems [28], models development for decision making [29–32], and smart home automation [33].

### 1.2.1 Nature of current irrigation systems

Traditional irrigation systems are less automated and therefore farmers using such systems encounter several challenges that include; application of large amounts of water to crops that would have required less water for growth, resulting into flood irrigation that causes rotting of plant roots [34]. Therefore, smart irrigation systems can greatly help a farmer to optimize water usage, maintain optimal soil moisture levels, and ensure agricultural productivity with reduced water wastage [35].

Table 1 summarizes the benefits of fuzzy irrigation to a farmer in comparison with other irrigation methods.

Light intensity, temperature and humidity are important factors that affect the rate of plant photosynthesis [36]. According to [37], soil moisture, air temperature, humidity and light intensity affect seed germination. Thus, it is important to study the trends in variation of the three parameters in plant growth.

**Table 1** Merits of fuzzy irrigation over other irrigation methods

| Fuzzy irrigation                     | Traditional irrigation methods     |
|--------------------------------------|------------------------------------|
| Shift response to weather conditions | Response is user controlled        |
| Data driven decisions                | User defined decisions             |
| Precise water distribution           | No precision in water distribution |
| Reduced pumping costs                | Less cost effective                |

### 1.3 Related work

Neha et al., 2024 in their journal, [38], designed and developed a soil moisture sensor and a response monitoring system that measures the moisture of the soil, compares it with the desired values given by the user and generates an alert if the soil moisture goes below the desired value. Norell et al. [37] in their journal, [39], developed an Okra seed germinator that controls soil moisture, temperature, light intensity and humidity, with emphasis being put on soil moisture that has a significant impact on plants' germination. Ibrahim et al. [40], in their research journal [40], developed a fuzzy logic algorithm for improvement of irrigation controller system in agriculture using multiple input parameters of temperature, relative humidity, sunshine, solar irradiation and wind speed.

### 1.4 Research problem

Inability of irrigation systems to regulate water dispensation is one of the major causes of plant yield loss. Most of these are surface irrigation systems that primarily rely on moisture content in soil for irrigation, leading to crop water-logging through unnecessary irrigation schedules. Therefore, there is a growing need to develop an irrigation system that considers several parameters that affect plants' growth hence helping farmers to optimize their crop yields while minimizing water usage.

## 2 Materials and methods

### 2.1 Design of an intelligent irrigation circuit system

To design an intelligent irrigation circuit system, fritzing software was used, following the block diagram shown in figure 1. The components to be used were firstly brought into the fritzing working environment through the use of the "search" option, followed by "routing" to ensure that they are connected to the microcontroller.

From figure 1, the microcontroller takes in signals from the multiple moisture, temperature and light sensors.

To obtain the resistance from the soil moisture sensors, equation 4:

$$y = a * x + b \quad (4)$$

was used where; y is the soil moisture, x is the sensor reading, a and b are constants that vary with the type of sensor used.

The temperature correction of the soil was also performed using the equation 5:

$$y = y_0 + (T - T_0) * k \quad (5)$$

Where;  $y_0$  is the initial soil moisture in volumetric water content, T is the temperature in °C,  $T_0$  is the reference temperature in °C and k being the temperature correction constant.

To convert the analog temperature into digital form, equation 6 was used:

$$D_{\text{value}} = V_{\text{out}} * \text{ADC}_{\text{resolution}} / V_{\text{ref}} \quad (6)$$

The digital value obtained from equation 6 was then calibrated and linearized using equation 7:

**Fig. 1** Block diagram showing the operation of an intelligent irrigation system

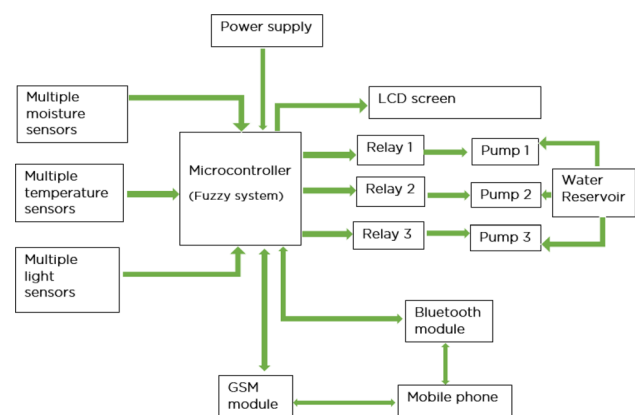


**Table 2** Linguistic terms of soil moisture

| Linguistic level | Range of values (wfv) |
|------------------|-----------------------|
| Too dry          | 0–200                 |
| Semi dry         | 200–350               |
| Normal           | 350–500               |
| Semi wet         | 500–700               |
| Wet              | 700–950               |

**Table 3** Linguistic terms of temperature

| Linguistic level | Range of values (°C) |
|------------------|----------------------|
| Cold             | 0–9                  |
| Semi cold        | 10–21                |
| Normal           | 20–29                |
| Semi hot         | 30–39                |
| Too hot          | 40–50                |

$$Lux = a * D_{value} + b \quad (7)$$

Where  $V_{out}$  is the sensor output voltage in volts,  $R_{sensor}$  is the sensor output resistance in ohms,  $D_{value}$  is the converted digital signal in bits,  $ADC_{resolution}$  is the analog to digital conversion resolution in bits,  $V_{ref}$  is the reference voltage in volts, lux is the luminous flux in lumen, a and b are calibration constants.

For accuracy, the average values of each of the input signals are computed and results displayed on the liquid crystal display (LCD) screen. Fuzzy rules were then used to control the output, in form of irrigation duration, with the most critical taking longer than the less critical conditions. The GSM sends an SMS only in critical states, with possible suggestions, to the smartphone once specific optimal values have been reached. The android application was used to control the irrigation system only under emergency conditions.

## 2.2 Simulation of an intelligent irrigation system.

The remotely controlled mobile irrigation system was simulated using ISIS, a proteus package, following the circuit diagram in figure 1. By selecting letter "P" under device selector in proteus, a dialogue box could be obtained, that allowed searching of the individual components. These were then joined using "Buses Mode", allowing interconnection of the individual components. In case a specific component wasn't integral part of proteus software, the corresponding library was downloaded from the website <sup>(2)</sup> and pasted in a folder named "bin" containing other libraries. The system was simulated with multiple temperature, light and soil moisture sensors, that provided the microcontroller with input signals. In the hardware project, the sensors were planted in different corners of the garden and the three water pumps strategically placed at different points of the garden in such a way that different pumps don't irrigate at the same point.

Tables 2, 3, and 4 quantitatively describe the five linguistic levels of soil moisture, temperature and light intensity respectively. Table 5 summarises the five outputs considered in terms of irrigation duration in seconds.

From table 2, too dry is the most critical condition of soil moisture, implying very low or no moisture content in the soil. The moisture content goes on increasing through semi dry, normal, semi wet until when it is wet. At this point, the soil is expected to have collected a significant amount of water.

<sup>2</sup> (<https://www.labcenter.com/libraries/>)

From table 3, too hot is the most critical condition of temperature and thus necessitating the extended irrigation duration. The temperatures go on dropping through semi hot, normal, semi cold upto cold, which is regarded as the less critical condition.

From table 4, the light intensity is expected to increase from no intensity through low, normal, moderate to high intensity.

From table 5, the irrigation duration increase from no duration through short, normal, moderate to very long duration. If all the conditions of soil moisture, temperature and light intensity are critical, the output is expected to be an extended irrigation duration that allows enough moisture to be collected by the soil.

Using fuzzy logic designer, the three parameters were created independently as inputs as shown in figure 2

From figure 2, the default input was renamed as soil moisture and given a range of 0–950 wfv. To add temperature and light intensity as inputs, the edit option was selected and the two added one after the other as independent input variables. These were accorded a range of 0–50 °C and 50–800 lux for temperature and light intensity respectively.

By selecting the first input as "soil moisture" and using table 2, the five linguistic terms were added to this input as membership functions. This was done by double clicking on the input, navigating to the edit option, followed by selection of "add membership functions". Since three out of the five membership functions appear by default, a total of two was added to produce the necessary linguistic terms. These were then selected one after the other, renamed and assigned the corresponding range as provided in table 2. To produce the triangular shape for each membership

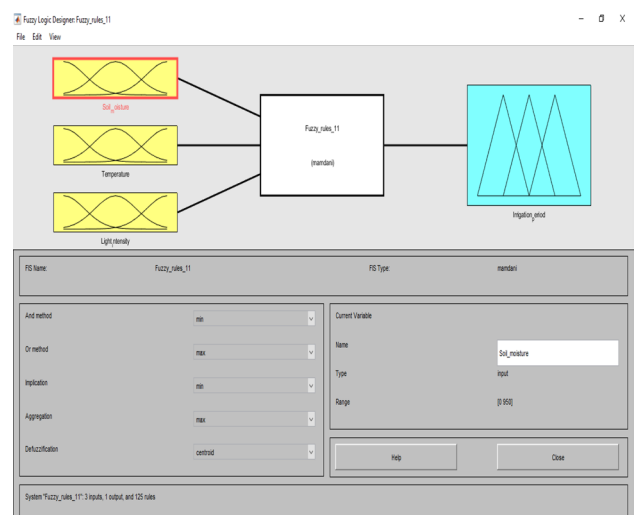
**Table 4** Linguistic terms of light intensity

| Linguistic level   | Range of values (Lux) |
|--------------------|-----------------------|
| No intensity       | 50–95                 |
| Low intensity      | 100–145               |
| Normal             | 150–195               |
| Moderate intensity | 200–445               |
| High intensity     | 450–800               |

**Table 5** Linguistic terms of output duration

| Linguistic level   | Values (seconds) |
|--------------------|------------------|
| No duration        | 0–5              |
| Short duration     | 4–10             |
| Normal duration    | 9–20             |
| Moderate duration  | 19–30            |
| Very long duration | 29–40            |

**Fig. 2** The three input parameters (yellow) used in MATLAB simulation



function, the minimum, centre and maximum values were provided under "params" and slightly reduced (for minimum) to ensure that there is a steady transition from one membership function to another. The resultant of the above procedures after saving the file with a specific name is shown in figure 3.

The above procedure was performed for the other two parameters using tables 3 and 4 for temperature and light intensity respectively, resulting into figures 4 and 5 respectively.

To add the required output, the "edit" option was chosen once again, that allowed navigation to the "add variable" option and "output" selected. This was followed by renaming of the variable to "irrigation duration" and given a range of 0–40 s. The necessary membership functions were added to it using table 5, producing figure 6.

**Fig. 3** The five rectangular membership functions of soil moisture

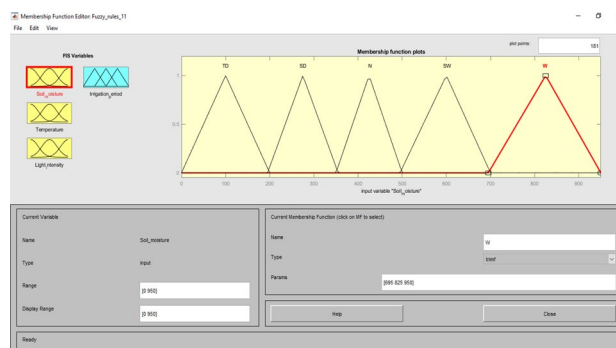


**Fig. 4** The five rectangular membership functions of temperature

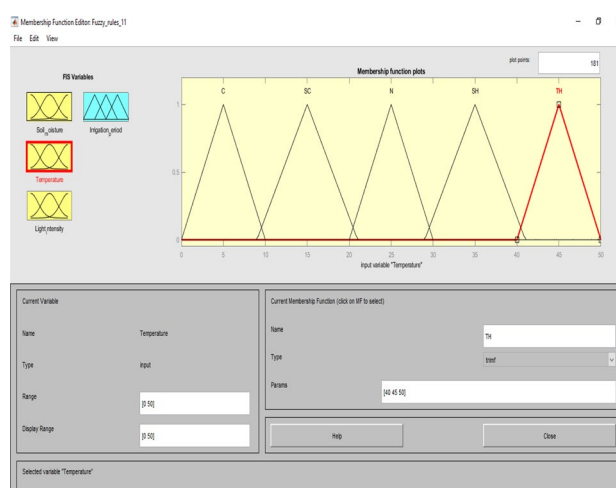


**Fig. 5** The five rectangular membership functions of light intensity

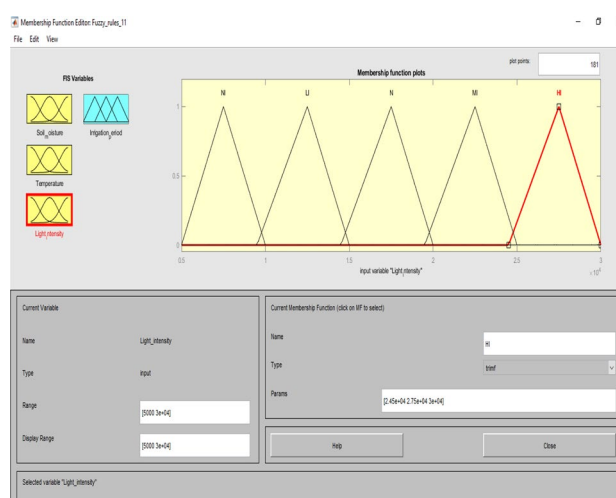


**Fig. 6** MATLAB extract showing the irrigation duration membership functions

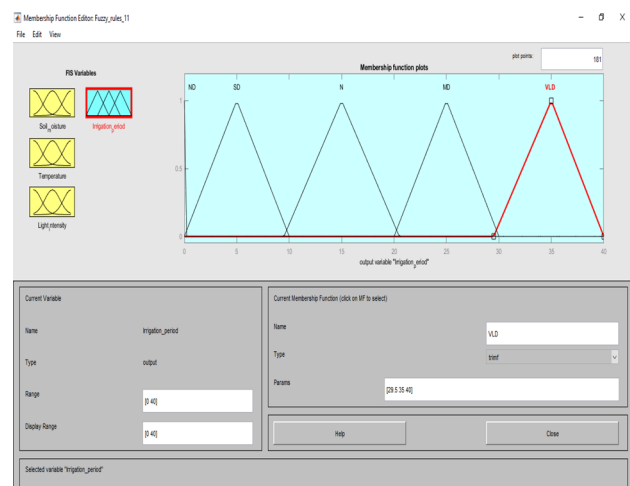


**Table 6** Linguistic terms of input and output signals

| Input    |             |                    | Output             |
|----------|-------------|--------------------|--------------------|
| Moisture | Temperature | Light intensity    | Irrigation period  |
| Too dry  | Too hot     | High intensity     | Very long duration |
| Semi dry | Semi hot    | Moderate intensity | Moderate duration  |
| Normal   | Normal      | Normal             | Normal duration    |
| Semi wet | Semi cold   | Low intensity      | Short duration     |
| Wet      | Cold        | No intensity       | No duration        |

To have the rules incorporated into the fuzzy logic designer, the square between the three inputs and the output was double-clicked, returning an interface that allows formulation of these rules. The linguistic levels of the other two parameters were altered with that of the third parameter maintained constant. The connection between the three parameters was maintained as "and", with the appropriate output being selected accordingly to the prevailing conditions.

If the conditions are too critical that is; semi dry or too dry for soil moisture, semi-hot or too hot for temperature and high light intensity, then the duration of irrigation is expected to be either moderate or very long. However if the states of the individual parameter are less critical, then the output in terms of irrigation duration is expected to be lower.

The suitable time for irrigation was determined using the available literature and controlled using the multiple fuzzy rules that were generated using the multiple linguistic terms of each of the three parameters listed in table 6.

Using table 6, multiple fuzzy rules were generated following each of the linguistic terms under the three different parameters. The generated rules were then used to control the output of the system, in form of irrigation period, with the duration varying from extended to shortest for most and less critical conditions respectively. Results of the prevailing temperature, light intensity and soil moisture were displayed on the LCD screen. Once the results of analysis of the three parameters necessitate starting of the irrigation system, the user is notified accordingly through an SMS sent to the smartphone, through the GSM module and the irrigation starting automatically. The GSM module attached to the system was connected to the smartphone wirelessly and communication established through a program code, that was uploaded to the microcontroller.

### 2.3 Implementation of an intelligent irrigation system

Each of the three types of sensors were tested to ascertain their capability of controlling the irrigation system individually, while keeping the other two inactive. All the three types of sensors were later considered to control the output signal of the system, following the set fuzzy rules. Once a signal is sent to the relay switch necessitating turning on of the water pump and the decision executed successfully, both the relay switch and water pump were confirmed to be fully operational. The communication between the smartphone and the irrigation system was established using a GSM module, that was attached to the system.

The system was then tested under various case scenarios of varying soil moisture, light intensity and temperature to find out how the irrigation duration is affected by the changes in each of the parameters.

### 3 Results and discussion

#### 3.1 Design of an intelligent irrigation circuit system.

From the circuit diagram shown in figure 7, Arduino UNO was chosen as the microcontroller and the connections made as describe below:

The three moisture sensors were connected individually to analog pins A0, A1 and A2 of Arduino UNO respectively, with the VCC terminals being supplied with a voltage of 5 V and the GND terminals grounded accordingly. Each of these sensors was connected to a variable resistor (POT-HG), to allow adjustment of the sensor's resistance in the process of running the simulation. The data pins of the three DHT11 temperature sensors were separately connected to digital pins D2, D3 and D4 of the Arduino UNO respectively. GND terminals of the three sensors were connected to a common ground and the positive voltage (VDD) supplied as 5 V to the sensor.

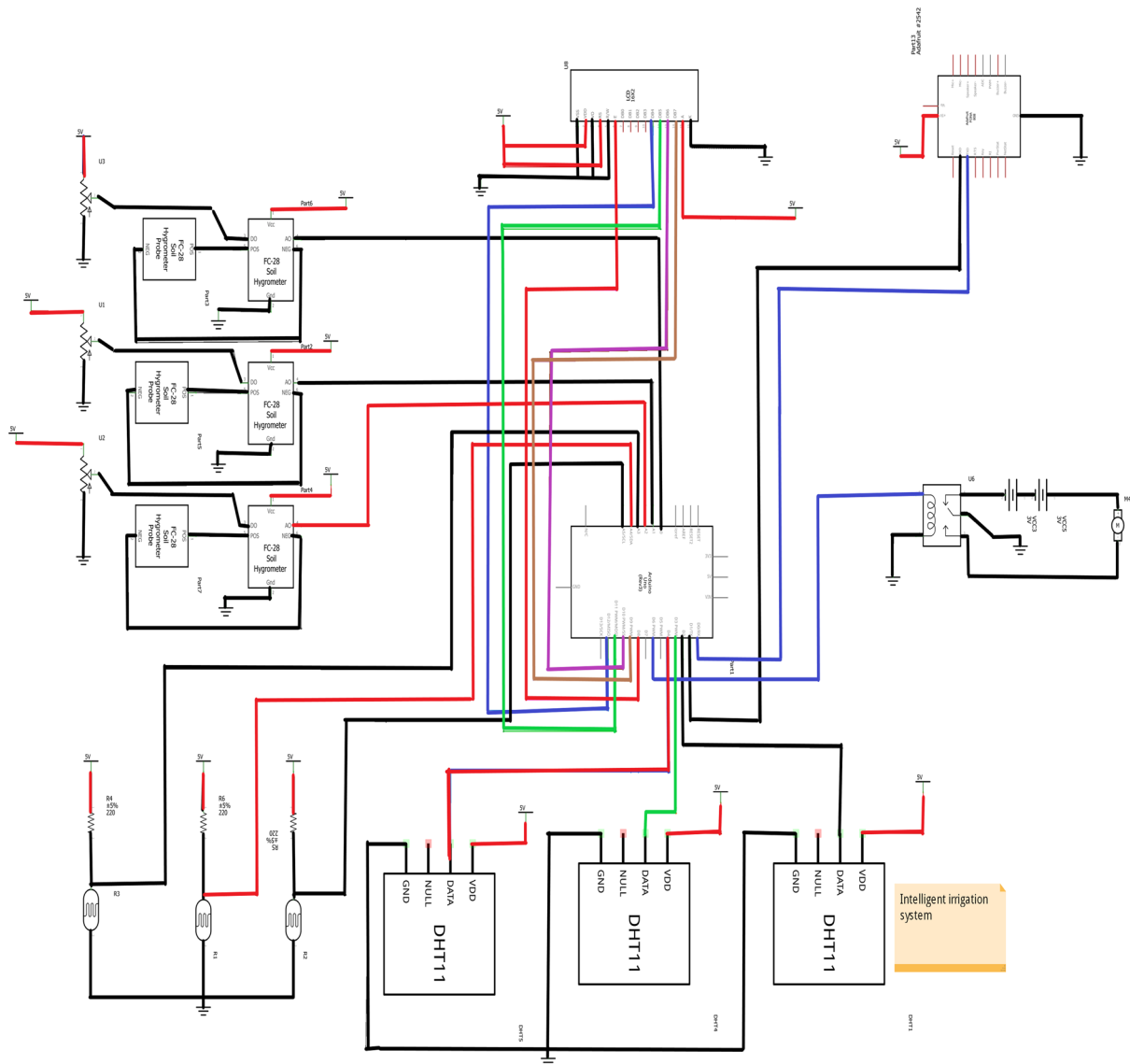


Fig. 7 Circuit diagram of a remotely controlled mobile irrigation system

**Fig. 8** Visualizing the variation of irrigation duration at low moisture, with temperature and light intensity being constant



**Fig. 9** Visualizing the variation of irrigation duration at normal moisture, keeping temperature and light intensity constant



The three LDR sensors were connected independently to analog pins A3, A4 and A5 respectively, with the same terminal being supplied with a voltage of 5 V. The GND terminals from each of these three sensors are connected to a common ground. RXD and TXD terminals of the GSM module were connected interchangeably to digital pins RX and TX of Arduino UNO, with GND and VCC terminals being connected to the ground and 5 V positive power supply respectively. The GND terminal of the relay switch attached to the coil was connected to digital pin D5 of Arduino UNO.

On the LCD screen, the VSS, V0 and K terminals were grounded, VDD, RS and A terminals connected to a positive 5 V voltage supply. The terminals E, DB4, DB5, DB6 and DB7 were connected to digital pins D8, D12, D11, D10 and D9 of Arduino UNO respectively. One terminal of the motor (serving as a water pump) is connected to the Common (COM) terminal of the relay switch and the second terminal of the motor connected to the Normally Closed (NC) terminal of the relay switch. The GND terminal of the relay switch is grounded.

### 3.2 Simulation of an intelligent irrigation system

To visualize the rules generated, the "view" option was clicked from the top menu bar of fuzzy logic designer and "rules" selected from the available options. Figure 8 shows an extended irrigation duration resulting from the soil moisture being low, while both temperature and light intensity being high, obtained by dragging the red line cutting through the linguistic terms of each parameter.

Figure 9 shows a moderate irrigation duration resulting from the soil moisture, temperature and light intensity being moderate.

The result in figure 9 was obtained by dragging the red line cutting through all the linguistic terms of each parameter so that it lies in the middle.

Figure 10 shows a low irrigation duration resulting from the soil moisture being high, while both temperature and light intensity being low.

The three figures 8, 9 and 10 show that variation of any of the three parameters directly leads to variation of the output in terms of irrigation duration.

By varying the temperature while keeping both soil moisture and light intensity constant, the results shown in table 7 were obtained. Similar tables were obtained for soil moisture (table 8) and light intensity (table 9).

**Fig. 10** Visualizing the variation of irrigation duration at high moisture, keeping temperature and light intensity constant

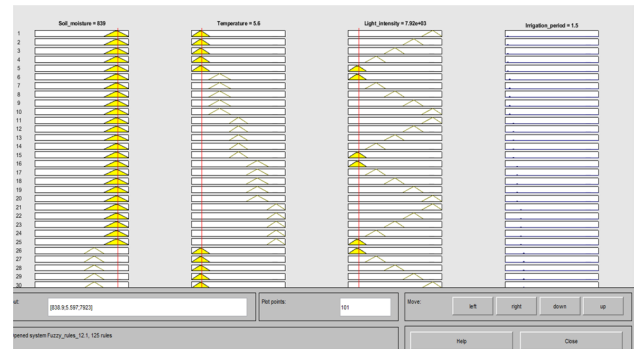


**Table 7** Variation of irrigation duration with temperature

| Temperature (°C) | Irrigation duration(s) |
|------------------|------------------------|
| 5.12             | 21.0                   |
| 15.4             | 23.0                   |
| 25.00            | 25.0                   |
| 35.2             | 27.0                   |
| 45.50            | 29.0                   |

**Table 8** Variation of irrigation duration with soil moisture

| Soil moisture (wfv) | Irrigation duration(s) |
|---------------------|------------------------|
| 85.8                | 45.0                   |
| 269.0               | 35.0                   |
| 441.0               | 25.0                   |
| 601.0               | 15.0                   |
| 830.3               | 5.0                    |

**Table 9** Variation of irrigation duration with light intensity

| Light intensity (lux) | Irrigation duration(s) |
|-----------------------|------------------------|
| 75.6                  | 24.1                   |
| 127                   | 24.5                   |
| 178                   | 25.0                   |
| 223                   | 25.5                   |
| 280                   | 26.0                   |

Soil moisture = 475 wfv

Light Intensity = 175 lux

From table 7, the irrigation duration increases with increase in the prevailing air temperature.

Light intensity = 175 lux

Temperature = 25 °C

From table 8, the irrigation duration decreases with increase in the amount of soil moisture.

Soil moisture = 475 wfv

Temperature = 25 °C

From table 9, the irrigation duration increases with increase in the light intensity.

Using tables 7, 8 and 9, plots showing the variation of irrigation duration with each of the parameters were obtained as shown in figures 11, 12 and 13 respectively.

Figure 11 shows a positive linear variation between temperature and irrigation duration. The line of best fit has a positive gradient of  $0.1989 \text{ s/}^{\circ}\text{C}$  which implies that the irrigation duration increases with increase in temperature.

Figure 12 shows a negative linear variation between soil moisture and irrigation duration. The line of best fit has a negative gradient of  $0.0547 \text{ s/wfv}$  which implies that the irrigation duration decreases with increase in soil moisture.

Figure 13 shows a positive linear variation between light intensity and irrigation duration. The line of best fit has a positive gradient of  $9.4987\text{e-}3 \text{ s/lux}$  which implies that the irrigation duration increases with increase in light intensity.

### Proteus simulation

The circuit diagram designed in figure 7 was then replicated in proteus software as shown in figure 14.

From figure 14, the  $10\text{K}\blacksquare$  resistor connected to each soil moisture sensor helps to simulate how the analog pin's voltage changes according to the signal received from the soil in form of resistance, while the capacitor helps to provide stable and accurate readings. The variable resistor called pot-Hg was connected to the same sensor from the "Test" terminal to allow variation of the sensor readings. Adjustment of the values on LDR and DHT11 sensors was done using the "plus"

**Fig. 11** Variation of irrigation duration with temperature

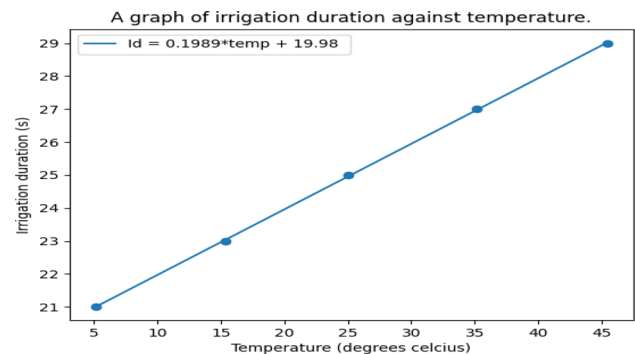


**Fig. 12** Variation of irrigation duration with soil moisture

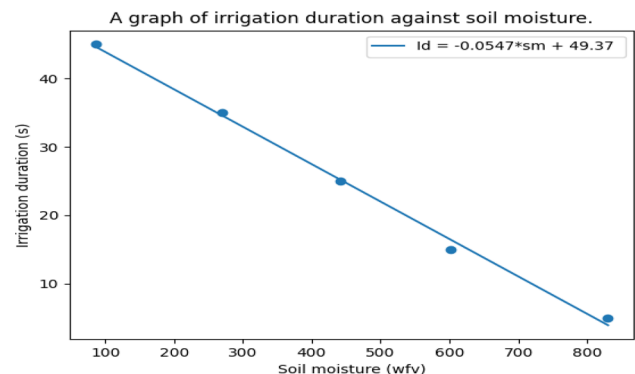


**Fig. 13** Variation of irrigation duration with light intensity

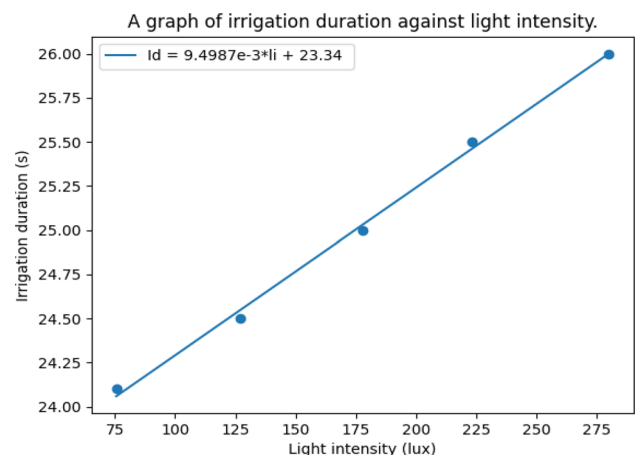




**Fig. 16** Physical circuit of the irrigation system

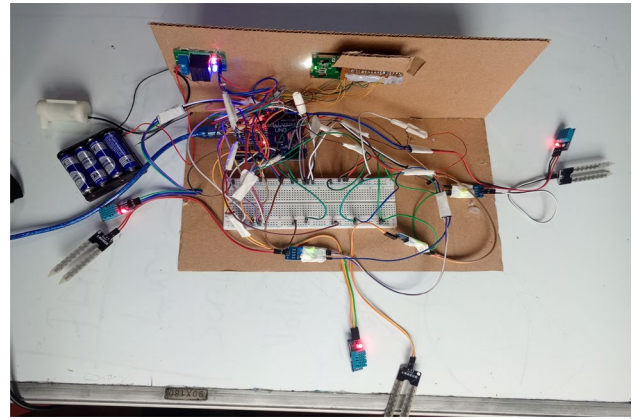


**Fig. 17** Aerial view of the project



VCC and GND terminals being connected to 5 V power supply and ground respectively of arduino UNO. The components with two probes are moisture sensors, which were connected to analog pins A0, A1 and A2, with their VCC and GND terminals being connected to 5 V power supply and ground respectively of arduino UNO. Light sensors (LDRs) were connected to analog pins A3, A4 and A5, with their GND terminals being connected to ground of arduino UNO. The RS, E, D4, D5, D6 and D7 pins of the LCD screen were connected to digital pins 6, 7, 8, 9, 10 and 11, with their VCC and GND terminals being connected to 5 V power supply and ground respectively of arduino UNO. The relay switch was connected to digital pin 5, with the VCC and GND terminals being connected to 5 V power supply and ground respectively of arduino UNO. The positive terminal of the pump was connected to normally closed (NC) while that of the extra power supply (used to toggle the relay) connected to common (COM) terminal of the relay switch. The negative terminal of the pump was connected to negative terminal of the extra power supply. To have an extension of both the 5 V and ground terminals from arduino UNO, the two terminals were connected to the bread board and the corresponding terminals from different components tapped from there.

Figures 17 and 18 show the aerial view of the irrigation system being planted in a garden setting and the pump being immersed in the water reservoir, used to supply water to the garden respectively.

#### a) Soil moisture adjustment

Figure 19 shows the sensing probes of a moisture sensor being inserted into dry soil of the garden when the temperature is normal and light intensity being low. In this case, the pump was triggered to go "on" for a given period of time as per the set of fuzzy rules listed under Appendix 1.

Figure 20 shows the intelligent system pumping water from the reservoir, through the pipe into the garden. In such a scenario, the pump is on until when a designated period is done. If the expected period for the pump to be on is over but the soil is not wet enough, irrigation of the soil continues until the garden is wet enough as displayed by the LCD screen in figure 21.

**Fig. 18** Side view of the project in a garden



**Fig. 19** Project implementation - dry soil

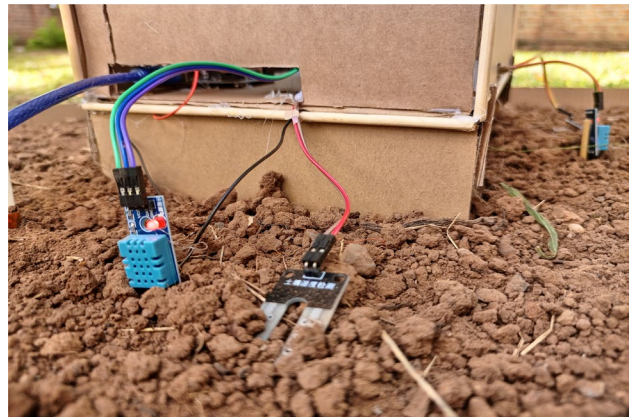


**Fig. 20** Watering of the garden by the intelligent system

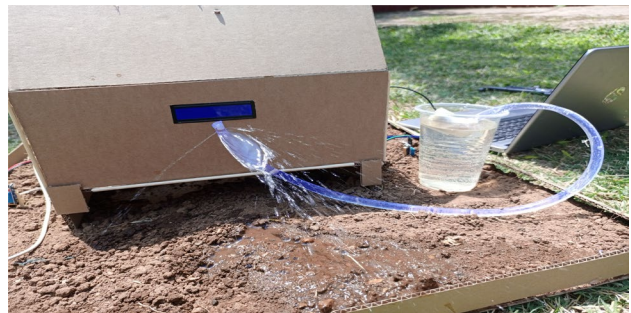


**Fig. 21** Display on the LCD screen for wet enough soil



Figure 22 shows the sensing probes of a moisture sensor being inserted into soil containing enough moisture, with the temperature being "cold" and the light intensity being "moderate". In spite of the light intensity being moderate, the water pump was kept off since the soil is wet enough, and temperatures being low.

#### b) Light intensity adjustments

Figure 23 shows the prevailing light intensity and the appropriate pump state "off" as guided by the set of fuzzy rules listed under Appendix 1. An increment in the amount of light intensity, accompanied with low soil moisture and high temperature levels trigger a change in the pump state from "off" to "on" as shown in figure 24.

#### c) Temperature adjustments

Figure 25 shows the prevailing temperature (normal) when the soil moisture is moderate. In such a case, the pump is triggered to be "on" for a given period of time as guided by the set of fuzzy rules listed under Appendix 1. In figure 26, the temperature is semi hot while the soil is wet. In spite of temperatures being high, the pump is set to be off since the soil is moist enough.

## 4 Conclusion

In the process of implementing the intelligent irrigation system, it was observed that the system automatically adjusts the amount of water being dispensed in terms of irrigation duration, as controlled by the set of fuzzy rules incorporated through the program code. The time of irrigation is seen to be extended once the prevailing states of soil moisture, temperature and light intensity are critical and shortened for less critical conditions. The dynamic adjustment of water output through continuous data analysis ensures that soil moisture is maintained at optimal levels, thereby enhancing water conservation and promoting healthier crop growth. The system's ability to send alerts to a smartphone via the

**Fig. 22** Project implementation - wet soil



**Fig. 23** Display of pump state - Moderate intensity

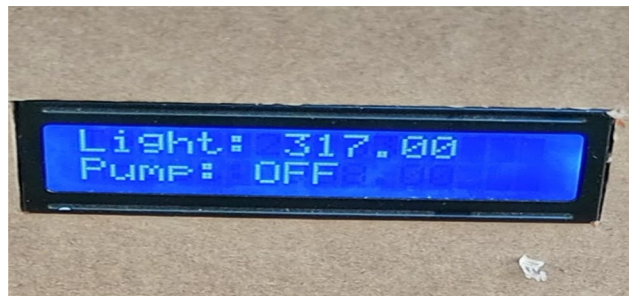


**Fig. 24** Display of prevailing pump state - High intensity



**Fig. 25** Display of prevailing temperature - Normal

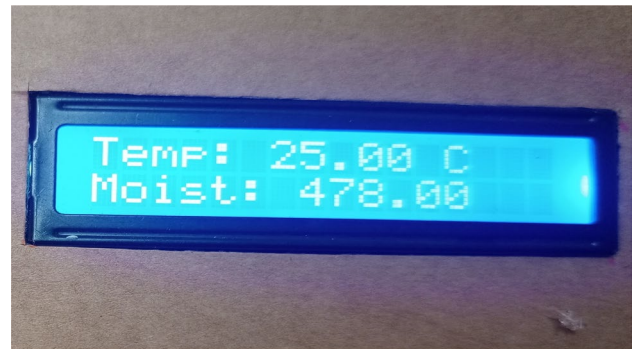


**Fig. 26** Display of prevailing temperature - semi hot



GSM network in case of critical conditions or malfunctions significantly improves its reliability and allows for prompt user intervention, preventing potential damage to crops and further conserving resources.

However, it is important to note that while this research has several strengths, it is not without its limitations and these include; particular portion of the garden (which may be too dry compared to others) being unable to receive water without irrigating the entire garden, unavailability of online data storage for future use and predictions, inability to control the irrigation system remotely, unreliability of both the water source and power supply being used to provide irrigation water and power the system respectively.

## 5 Recommendations

In order to enhance the effectiveness and applicability of the intelligent irrigation system, the following recommendations can be considered.

- (i) Independent multi-pump irrigation style: Future researchers can consider building intelligent irrigation systems with multiple pumps, with the capacity of having a single pump irrigating a particular area of the garden independent of all the others. This will help to solve scenarios of all the pumps being on, even when it is a small area of the garden that is need of moisture in soil.
- (ii) Integration with advanced communication technologies: Future developments can consider integrating the system with more advanced communication technologies such as IoT platforms, allowing for more robust data collection, analysis, and remote control capabilities. This would enable farmers to monitor and manage the system from anywhere, further increasing efficiency and ease of use.
- (iii) Development of a user-friendly interface: Creating a more intuitive and user-friendly interface for the smartphone application would enhance user interaction with the system. Features such as real-time data visualization, historical data analysis, and customizable alerts would provide users with better insights and control over their irrigation practices.
- (iv) Scalability and flexibility: Future iterations of the system can focus on scalability and flexibility to cater for various types and sizes of agricultural fields. Modular designs that can be easily expanded or adapted to different crops and growing conditions would increase the system's applicability and adoption.

- (v) **Energy efficiency and sustainability:** Investigating alternative power sources, such as solar panels, could make the system more energy-efficient and sustainable. This would be particularly beneficial for deployment in remote or off-grid areas, reducing reliance on traditional power sources and lowering operational costs.

**Author contributions** In this manuscript, P.K wrote the main text, built, designed and constructed the circuit that was implemented in the project. Both W.J.N and M.R.A did the technical roles of reviewing the manuscript, identifying loopholes and giving possible suggestions of how a particular idea can be presented better.

**Data availability** The authors declare that the data supporting the findings of this study are available within the paper.

## Declarations

**Competing interests** The authors declare no competing interests.

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## Appendix 1

### Fuzzy rules

Using table 6, a total of one hundred twenty five (125) rules were generated by keeping a given linguistic level of a particular parameter constant and varying those for the rest of the parameters as listed below.

1. if "moisture" is TD and "temperature" is TH and "light intensity" is HI then "duration" is VLD
2. if "moisture" is TD and "temperature" is TH and "light intensity" is MI then "duration" is VLD
3. if "moisture" is TD and "temperature" is TH and "light intensity" is N then "duration" is MD
4. if "moisture" is TD and "temperature" is TH and "light intensity" is LI then "duration" is NO
5. if "moisture" is TD and "temperature" is TH and "light intensity" is NI then "duration" is NO
6. if "moisture" is TD and "temperature" is SH and "light intensity" is HI then "duration" is VLD
7. if "moisture" is TD and "temperature" is SH and "light intensity" is MI then "duration" is MD
8. if "moisture" is TD and "temperature" is SH and "light intensity" is N then "duration" is N
9. if "moisture" is TD and "temperature" is SH and "light intensity" is LI then "duration" is N
10. if "moisture" is TD and "temperature" is NT and "light intensity" is HI then "duration" is MD
11. if "moisture" is TD and "temperature" is NT and "light intensity" is HI then "duration" is MD
12. if "moisture" is TD and "temperature" is NT and "light intensity" is MI then "duration" is ND
13. if "moisture" is TD and "temperature" is NT and "light intensity" is N then "duration" is NO
14. if "moisture" is TD and "temperature" is NT and "light intensity" is LI then "duration" is SD
15. if "moisture" is TD and "temperature" is NT and "light intensity" is NI then "duration" is SD
16. if "moisture" is TD and "temperature" is SC and "light intensity" is HI then "duration" is MD
17. if "moisture" is TD and "temperature" is SC and "light intensity" is MI then "duration" is MD
18. if "moisture" is TD and "temperature" is SC and "light intensity" is N then "duration" is NO
19. if "moisture" is TD and "temperature" is SC and "light intensity" is LI then "duration" is SD
20. if "moisture" is TD and "temperature" is SC and "light intensity" is NI then "duration" is SD
21. if "moisture" is TD and "temperature" is C and "light intensity" is HI then "duration" is NO
22. if "moisture" is TD and "temperature" is C and "light intensity" is MI then "duration" is NO

- [illegible]

76. if "moisture" is SW and "temperature" is TH and "light intensity" is HI then "duration" is VLD
77. if "moisture" is SW and "temperature" is TH and "light intensity" is MI then "duration" is MD
78. if "moisture" is SW and "temperature" is TH and "light intensity" is N then "duration" is NO
79. if "moisture" is SW and "temperature" is TH and "light intensity" is LI then "duration" is ND
80. if "moisture" is SW and "temperature" is TH and "light intensity" is NI then "duration" is SD
81. if "moisture" is SW and "temperature" is SH and "light intensity" is HI then "duration" is MD
82. if "moisture" is SW and "temperature" is SH and "light intensity" is MI then "duration" is NO
83. if "moisture" is SW and "temperature" is SH and "light intensity" is N then "duration" is NO
84. if "moisture" is SW and "temperature" is SH and "light intensity" is LI then "duration" is SD
85. if "moisture" is SW and "temperature" is SH and "light intensity" is NI then "duration" is ND
86. if "moisture" is SW and "temperature" is NT and "light intensity" is HI then "duration" is MD
87. if "moisture" is SW and "temperature" is NT and "light intensity" is MI then "duration" is NO
88. if "moisture" is SW and "temperature" is NT and "light intensity" is N then "duration" is SD
89. if "moisture" is SW and "temperature" is NT and "light intensity" is LI then "duration" is SD
90. if "moisture" is SW and "temperature" is NT and "light intensity" is NI then "duration" is ND
91. if "moisture" is SW and "temperature" is SC and "light intensity" is HI then "duration" is NO
92. if "moisture" is SW and "temperature" is SC and "light intensity" is MI then "duration" is ND
93. if "moisture" is SW and "temperature" is SC and "light intensity" is N then "duration" is SD
94. if "moisture" is SW and "temperature" is SC and "light intensity" is LI then "duration" is SD
95. if "moisture" is SW and "temperature" is SC and "light intensity" is NI then "duration" is ND
96. if "moisture" is SW and "temperature" is C and "light intensity" is HI then "duration" is NO
97. if "moisture" is SW and "temperature" is C and "light intensity" is MI then "duration" is NO
98. if "moisture" is SW and "temperature" is C and "light intensity" is N then "duration" is SD
99. if "moisture" is SW and "temperature" is C and "light intensity" is LI then "duration" is SD
100. if "moisture" is SW and "temperature" is C and "light intensity" is NI then "duration" is ND
101. if "moisture" is W and "temperature" is TH and "light intensity" is HI then "duration" is VLD
102. if "moisture" is W and "temperature" is TH and "light intensity" is MI then "duration" is VLD
103. if "moisture" is W and "temperature" is TH and "light intensity" is N then "duration" is MD
104. if "moisture" is W and "temperature" is TH and "light intensity" is LI then "duration" is MD
105. if "moisture" is W and "temperature" is TH and "light intensity" is NI then "duration" is NO
106. if "moisture" is W and "temperature" is SH and "light intensity" is HI then "duration" is VLD
107. if "moisture" is W and "temperature" is SH and "light intensity" is MI then "duration" is MD
108. if "moisture" is W and "temperature" is SH and "light intensity" is N then "duration" is NO
109. if "moisture" is W and "temperature" is SH and "light intensity" is LI then "duration" is NO
110. if "moisture" is W and "temperature" is SH and "light intensity" is NI then "duration" is SD
111. if "moisture" is W and "temperature" is NT and "light intensity" is HI then "duration" is MD
112. if "moisture" is W and "temperature" is NT and "light intensity" is MI then "duration" is NO
113. if "moisture" is W and "temperature" is NT and "light intensity" is N then "duration" is NO
114. if "moisture" is W and "temperature" is NT and "light intensity" is LI then "duration" is SD
115. if "moisture" is W and "temperature" is NT and "light intensity" is NI then "duration" is SD
116. if "moisture" is W and "temperature" is SC and "light intensity" is HI then "duration" is MD
117. if "moisture" is W and "temperature" is SC and "light intensity" is MI then "duration" is NO
118. if "moisture" is W and "temperature" is SC and "light intensity" is N then "duration" is NO
119. if "moisture" is W and "temperature" is SC and "light intensity" is LI then "duration" is SD
120. if "moisture" is W and "temperature" is SC and "light intensity" is NI then "duration" is SD
121. if "moisture" is W and "temperature" is C and "light intensity" is HI then "duration" is NO
122. if "moisture" is W and "temperature" is C and "light intensity" is MI then "duration" is NO
123. if "moisture" is W and "temperature" is C and "light intensity" is N then "duration" is SD
124. if "moisture" is W and "temperature" is C and "light intensity" is LI then "duration" is SD
125. if "moisture" is W and "temperature" is C and "light intensity" is NI then "duration" is ND

## References

1. Zhang Y, Wu X. Risk management effects of insurance purchase and organization participation: which is more effective? *Agriculture*. 2022;12(3):1–15.
2. Yi S, Wang J, Zhang X. Design and experiment of a fully automatic plate lifting machine for rice hard disk seedling cultivation. *Agri-culture*. 2021;11(8):1–15.
3. Salazar C, Rand J. Production risk and adoption of irrigation technology: evidence from small-scale farmers in chile. *Lat Am Econ Rev*. 2016;25:1–37.
4. Muhammad F, Minh Dang L, Hyeonjoon M. Enhancing land cover classification via deep ensemble network. *Knowl-Based Syst*. 2024;305. <https://doi.org/10.1016/j.knosys.2024.112611>.
5. Fayaz M, Nam J, Dang LM, Song HK, Moon H. Land-cover classification using deep learning with high-resolution remote-sensing imagery. *Appl Sci*. 2024;14(5):1844.
6. Gupta P. Smart irrigation systems using (iot) - a survey. *Int J Sci Res Eng Manag*. 2023. <https://doi.org/10.55041/IJSREM24900>.
7. Ahuja I, de Vos RC, Bones AM, Hall RD. Plant molecular stress responses face climate change. *Trends Plant Sci*. 2010;15(12):664–74.
8. Gupta S, Sharmila, Rai HM. Iot-based automatic irrigation system using robotic vehicle. In *Information Management and Machine Intelligence: Proceedings of ICIMMI 2019*. Springer. 2021; pp. 669–677.
9. Haile GG, Kasa AK, et al. Irrigation in Ethiopia: a review. *Acad J Agric Res*. 2015;3(10):264–9.
10. Koech R, Langat P. Improving irrigation water use efficiency: a review of advances, challenges and opportunities in the australian context. *Water*. 2018;10(12):1771.
11. Zhu H-H, Huang Y-X, Huang H, Garg A, Mei G-X, Song H-H. Development and evaluation of arduino-based automatic irrigation system for regulation of soil moisture. *Int J Geosynth Gr Eng*. 2022;8(1):13.
12. Pereira LS. Water, agriculture and food: challenges and issues. *Water Resour Manage*. 2017;31(10):2985–99.
13. Whitmore A, Agarwal A, Da Xu, L. The internet of things-a survey of topics and trends. *Inf Syst Front*. 2015;17:261–74.
14. Lynn T, Endo PT, Ribeiro AMN, Barbosa GB, Rosati P. The internet of things: definitions, key concepts, and reference architectures. In: *The cloud-to-thing continuum: opportunities and challenges in cloud, fog and edge computing*. Berlin: Springer International Publishing; 2020. p. 1–22.
15. Spanaki K, Sivarajah U, Fakhimi M, Despoudi S, Irani Z. Disruptive technologies in agricultural operations: a systematic review of ai-driven agritech research. *Ann Oper Res*. 2022;308(1–2):491–524.
16. Das A, Gupta Y, Wedhane NV, Islam MR. Smart water man-agement in irrigation system using iot. *Trends in Wireless Communication and Information Security: Proceedings of EWCIS 2020*, 2021. pp. 341–352.
17. Li W, Awais M, Ru W, Shi W, Ajmal M, Uddin S, Liu C. Review of sensor network-based irrigation systems using iot and remote sensing. *Adv Meteorol*. 2020;2020:1–14.
18. D'Aniello G. Fuzzy logic for situation awareness: a systematic review. *J Ambient Intell Humaniz Comput*. 2021;12(10):1–22.
19. Mourhir A, Rachidi T, Karim M. River water quality index for morocco using a fuzzy inference system. *Environ Syst Res*. 2014;3(1):1–2.
20. Atim M, Anguma S, Wanzala J. Classification of fuzzy logic linguistic terms for accurate load balancing in electric power distribution system. 2021. pp. 1–6.
21. Zadeh LA. Fuzzy sets. *Information and control*. *Inf Sci*. 1965;8(3):338–53.
22. Bhandari P. Levels of measurement - nominal, ordinal, interval and ratio. *Scribbr*. 2023.
23. Jun G, Yao J, Chen L. The statistical methods of membership function in structural serviceability failure criterion. *KSCE J Civ Eng*. 2021. <https://doi.org/10.1007/s12205-021-2089-z>.
24. Pedrycz W, Gomide F. An introduction to fuzzy sets: analysis and design. Cambridge: MIT press; 1998.
25. Samanta D. Fuzzy set theory and its applications. Berlin: Springer; 2017.
26. Carter J, Chiclana F, Khuman AS, Chen T. Fuzzy logic. Berlin: Springer; 2021. <https://doi.org/10.1007/978-3-030-66474-9>.
27. Chakraborty S, Mondal A, Das C. Fuzzy fractional order PID controller design for AVR system, IEEE 3rd international conference on control, instrumentation, energy and communication (CIEC), 2024. 31–36.
28. Chakraborty J, Susmit Mondal, Arindam B, Soumen. Application of FUZZY-3DOF-PID controller for controlling FOPTD type communication delay based renewable three-area deregulated hybrid power system. *Evol Intel*. 2024;17(4):2821–41. <https://doi.org/10.1007/s12065-024-00914-x>.
29. Chakraborty S, Mondal A, Das C. Fuzzy fractional order PID controller design for AVR system. 2024; 31–36. 10.1109/CIEC59440.2024.10468513.
30. Alamin A, Rahaman M, Mondal S. Geometric approach for solving first order non-homogenous fuzzy difference equation. *Spectr Operat Res*. 2024. <https://doi.org/10.31181/sor2120257>.
31. Kangarajan K, Singh Payal, Salahshour Soheil, Mondal Sankar. Analysis of second-order linear fuzzy differential equation under an innovative fuzzy derivative approach and its application. *J Uncert Syst*. 2024. <https://doi.org/10.1142/S1752890924500223>.
32. Singh Payal, Gazi Kamal Hossain, Rahaman Mostafijur, Basuri Tripti, Mondal Sankar. Solution strategy and associated results for fuzzy mellin transformation. *Franklin Open*. 2024;7: 100112. <https://doi.org/10.1016/j.fraope.2024.100112>.
33. Fabiana F, Jammilly F, Ayton J, Eliomar G. Advancements in smart home automation through fuzzy logic systems. 2024;5(14):1209–13.
34. Kumar N, Chhokar R, Meena R, Kharub A, Gill S, Tripathi S, Gupta O, Mangrauthia S, Sundaram R, Sawant C, et al. (2021). Challenges and opportunities in productivity and sustainability of rice cultivation system: a critical review in indian perspective. *Cereal Research Communications*, 2021; pp. 1–29.
35. Gupta P. Smart irrigation systems using (iot) - a survey. *Int J Sci Res Eng Manag*. 2023. <https://doi.org/10.55041/IJSREM24900>.
36. Lü H, Niu Y, Zhang M, Li H. Analysis of variation trend of light intensity and air temperature and humidity in solar greenhouse. *Nongye Jixie Xuebao/Trans Chin Soc Agric Mach*. 2021;52:410–7.

37. Norella A, Marie R, Reboquio M, Grace P, Apoderado Z, Khaey M, Ruizol S, Majan S, Serdeña M, Bautista J, Galay-Limos J, Norella A, Reboquio M, Apoderado Z, Ruizol P. Automated okra (*abelmoschus esculentus*) seed germinator using arduino uno r3 automated okra (*abelmoschus esculentus*) seed germinator using arduino uno r3. *Int J Res Stud Manag.* 2023;11:127–34.
38. Neha K, Gurmohan S, Jain DK, Manjit K. *International Journal of Latest Research in Science and Technology.* 2014;3(6):142–5.
39. Fuseini SI, Konditi D, Musyoki S. Smart irrigation system using fuzzy logic method. *Int J Eng Res Technol.* 2018;11(7):1417–36.
40. Ibrahim Fuseini S, S. M., Dominic Konditi,. Smart irrigation system using a fuzzy logic method. *Int J Latest Res Sci Technol.* 2018;9(11):1417–36.

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