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Proposed Intelligent Irrigation System for Riyadh City Using Fuzzy Logic

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Abstract: Considering the insufficient rainfall and rapid evaporation of soil moisture in desert regions, irrigation becomes very challenging in Riyadh. Automation is therefore required for optimum productivity and water conservation. According to the vision of the Green Riyadh project, recycled water will be used in the irrigation system to irrigate all green lands. The method of irrigation and the quantity of water being used must both be considered. Since drought inhibits plant growth and excessive moisture limits plants' ability to absorb nutrients and raises the possibility of disease development, only the amount of water needed by plants should be used. Artificial intelligence and fuzzy logic are increasingly seen as solutions to be implemented in smart drip irrigation systems. The fuzzy logic control system will aid in water conservation given its shortage, which has become a major worldwide concern. The system also has the advantage of conserving moisture to counteract inadequate rainfall, saving electricity and reducing labor costs. For such advantages, an intelligent irrigation control system based on fuzzy logic adapted to the climate of Riyadh will be proposed. Based on the measured soil moisture, ambient temperature, air humidity and solar irradiance, the fuzzy controller calculates the necessary irrigation duration. The features of the fuzzy logic toolbox in MATLAB are used to create the proposed system.

Keywords: Smart irrigation, Control system, Fuzzy logic

Introduction

The advantages of afforestation go far beyond the aesthetic value they add to the environment. Afforestation aids in improving air quality, reducing soil erosion, providing habitat for wildlife and helping to mitigate climate change (Ghosh, 2023). Based on that, the Custodian of the Two Holy Mosques, King Salman Bin Abdulaziz, launched the Green Riyadh project in March 2019, which aims to plant more than 7.5 million trees throughout Riyadh city (Abdelrahman, 2022). The project will represent a turning point in achieving one of Saudi Vision 2030’s main objectives, which is to elevate Riyadh to one of the world’s top 100 most livable cities. Moreover, King Salman Park, with an area of more than 16 square kilometers, was launched to become the largest urban park in the world providing both city inhabitants and tourists with a wide choice of options and high-quality activities (Abdelrahman, 2023). In Riyadh, irrigation becomes highly challenging due to inadequate rainfall and the quick evaporation of soil moisture. Therefore, automation is necessary for optimal efficiency and water saving. The method of irrigation and the quantity of water being used must both be considered. Since drought inhibits plant growth and excessive moisture limits plants’ ability to absorb nutrients and raises the possibility of disease development, only the amount of water needed by plants should be used (Mohammed et al., 2021). Smart irrigation systems are increasingly using fuzzy logic and artificial intelligence as potential solutions (Khatri, 2018). The fuzzy logic control system will aid in water conservation given its shortage, which has become a major worldwide concern. The system also has the advantage of conserving moisture to counteract insufficient rainfall, saving electricity and reducing labor cost waste (Singh et al., 2022). For such advantages, a fuzzy logic irrigation controller suitable for the aforementioned projects in Riyadh will be suggested.

Types of Irrigation Controllers

Irrigation controllers fall into two main categories (Mohammed et al., 2021; Ross, 2009):

1.Open-loop controllers:

In this type, the irrigation decisions are made by the user manually. Based on the user's knowledge, the time to start and time to end are determined by him as well as the volume of water to be dispensed, irrigation speed and watering periods. Since it is easy to use and does not require any sensors, this technique is commonly employed. Nevertheless, it can result in some areas being over-irrigated while others are under-irrigated, which could lead to unfavorable water stress.

2. Closed-loop controllers:

They are the type of controllers that use feedback to maintain control. The decisions are typically based on sensor data. So, when the condition changes, the output changes as well. Closed loop controllers have great irrigation efficiency because they are event-driven, which allows them to react automatically to changes in the environment and climate. Hence, it offers an alternative and efficient solution to traditional irrigation techniques. Our goal is to develop an intelligent irrigation system that employs a fuzzy logic-based closed-loop controller.

Fuzzy Logic Control System

There are three significant blocks used to create a fuzzy logic control system (Bai et al., 2007; Ross, 2009). A block diagram of a general fuzzy logic control system is shown in Figure 1.

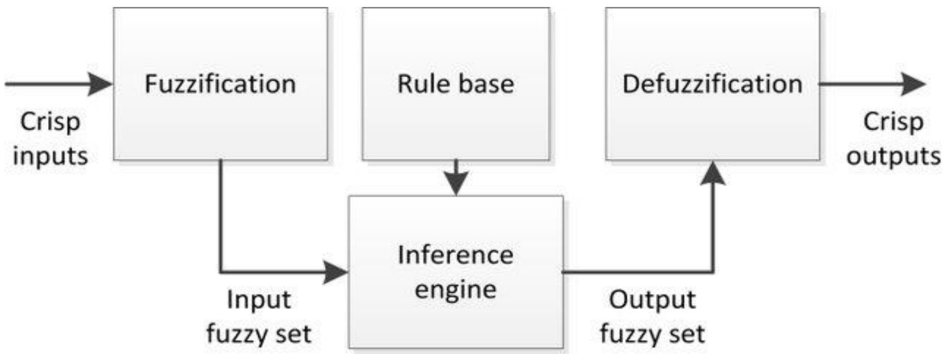

Figure 1. Block diagram of a fuzzy logic control system

Fuzzification includes two steps: deriving the membership functions for input and output variables and then representing them with linguistic variables. The fuzzified inputs and outputs are divided into several sets based on membership functions. Thus, the crisp input variables convert to fuzzy in this stage.

Fuzzy Inference Engine decides the best decision for each given situation and deduces the fuzzy result from fuzzified inputs using the "IF-THEN" rules as a foundation. The fuzzy IF-THEN rules are the rule base that contains all the pertinent input-output combinations that are designed by the user to indicate a mathematical relationship between them. The rule links a condition specified by linguistic variables and fuzzy sets to an output or conclusion. With the use of elastic conditions, the "IF" section is primarily used to capture knowledge and the "THEN" part can be used to provide the conclusion or output in linguistic variable form. The law to create a collection of fuzzy IF-THEN rules is reliant on each individual application and is based on human knowledge or experience.

Defuzzification is the last step in the fuzzy controller, this process is required in order to make the conclusion or fuzzy output applicable to practical applications. Keep in mind that the fuzzy conclusion or output is still a linguistic variable that needs to be defuzzified to be transformed into the crisp variable, so its goal is to convert the output from fuzzy to crisp.

Fuzzy Controller of Riyadh Irrigation System

The proposed fuzzy controller determines the necessary irrigation time based on the detected soil moisture, air humidity, ambient temperature and solar irradiation. It was created by the features of the fuzzy logic toolbox in MATLAB using the Mamdani fuzzy inference technique. The fuzzy inference system is illustrated in Figure 2.

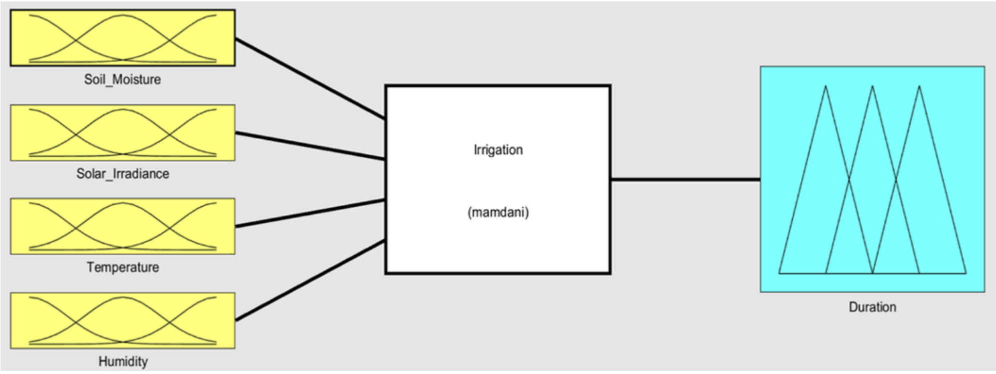

Figure 2. Fuzzy inference system in MATLAB

Membership Functions

Soil Moisture

An essential consideration before irrigation is the soil's moisture content, the drier the soil, the more water we need. On the other hand, adding extra water can harm the plants. As seen in Table 1, three linguistic variables—dry, normal and wet—define the soil moisture input variable. It ranges from 0 to 100 to represent the percentage of moisture content in the soil.

Table 1. Soil moisture membership function description

Fuzzy Set	Membership Function Type	Parameters (%)
Dry	Trapezoidal	[-30 -3 20 35]
Normal	Triangular	[20 40 60]
Wet	Trapezoidal	[45 60 103 130]

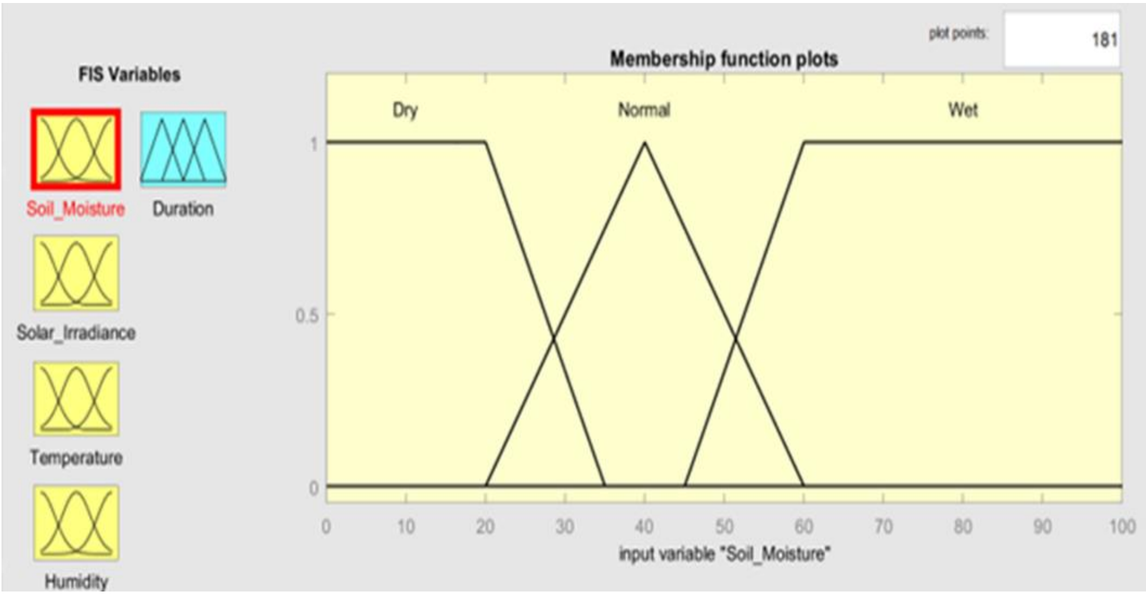

Figure 3. Soil moisture membership function plot

Solar Irradiance

Solar irradiance has a direct effect on evaporation, so it is one of the most important variables for calculating the amount of water required for irrigation. The unit of measurement for solar irradiance is watts per square meter and the amount of solar irradiance incident on the soil will range from 0 to 1000.

Table 2. Solar irradiance membership function description

Fuzzy Set	Membership Function Type	Parameters (W/m^2)
Low	Trapezoidal	[-375 -40 400 550]
Moderate	Triangular	[400 550 700]
High	Trapezoidal	[550 700 1050 1200]

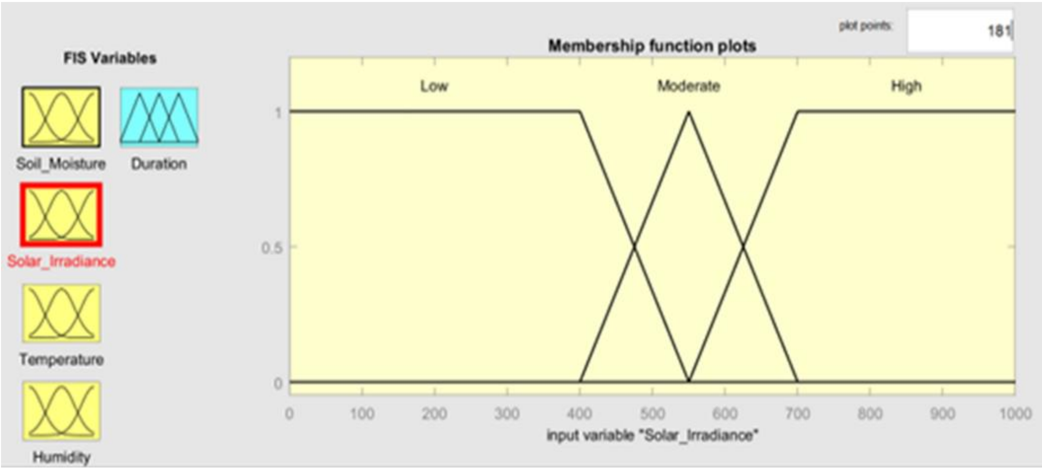

Figure 4. Solar irradiance membership function plot

Temperature

The moisture in the soil will evaporate faster at a high air temperature, which will change the water balance. Thus, in fuzzy logic control, temperature is an important factor to be considered during irrigation. Temperature is expressed as degrees Celsius and approximately ranges from 0 to 50 in Riyadh.

Table 3. Temperature membership function description

Fuzzy Set	Membership Function Type	Parameters (℃)
Cold	Trapezoidal	[-17.5 -3 17 22]
Worm	Triangular	[17 22 27]
Hot	Trapezoidal	[22 27 51 60]

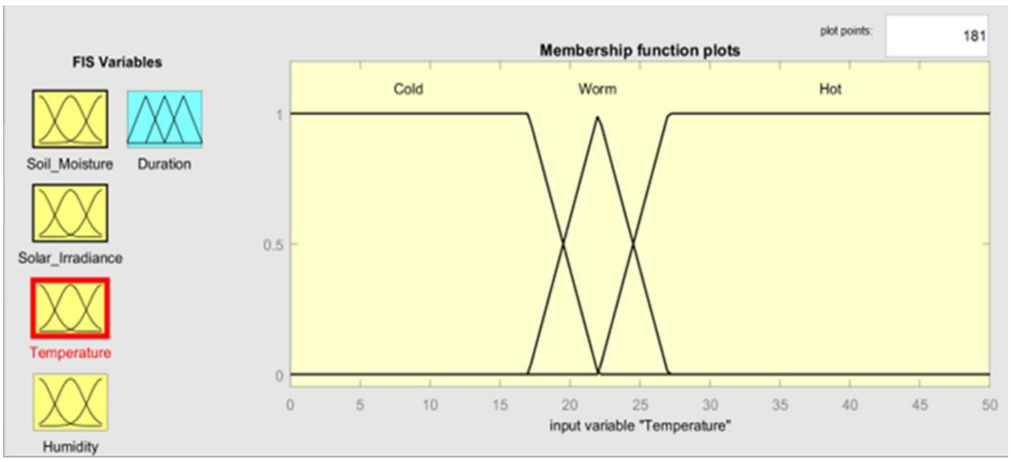

Figure 5. Temperature membership function plot

Air Humidity

Humidity is expressed as a percentage of moisture in the air around the soil surface. Although air humidity is considered very low in Riyadh city, it is nevertheless important to take it into account because it affects evaporation.

Table 4. Air humidity membership function description

Fuzzy set	Membership function type	Parameters (%)
Low	Trapezoidal	[-37 -5 35 50]
Moderate	Triangular	[35 50 65]
High	Trapezoidal	[50 65 105 138]

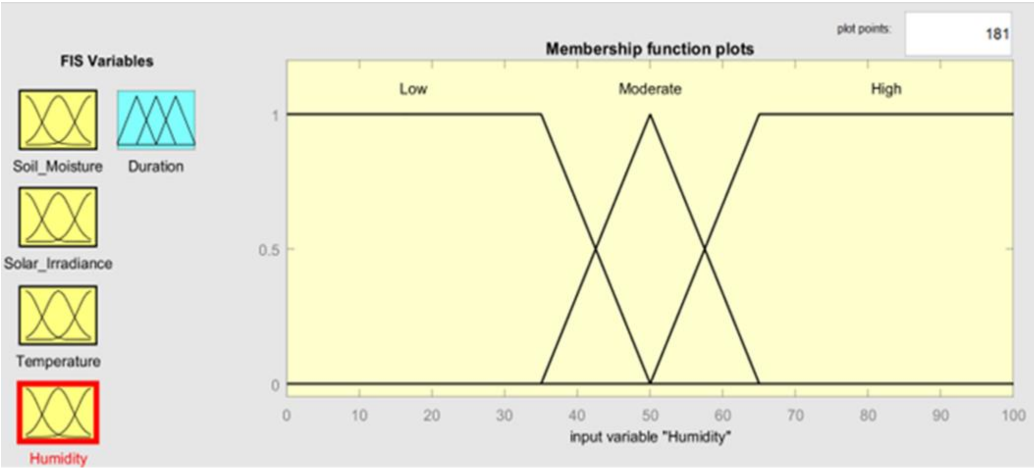

Figure 6. Air humidity membership function plot

Duration

The output of the proposed fuzzy controller is the necessary irrigation duration, which will be defined by five linguistic variables and measured by minutes ranging from 0 to 10.

Table 5. Duration membership function description

Fuzzy Set	Membership Function Type	Parameters (min)
Very Short	Triangular	[-1 0 2.5]
Short	Triangular	[0 2.5 5]
Medium	Triangular	[2.5 5 7.5]
Long	Triangular	[5 7.5 10]
Very Long	Triangular	[7.5 10 11]

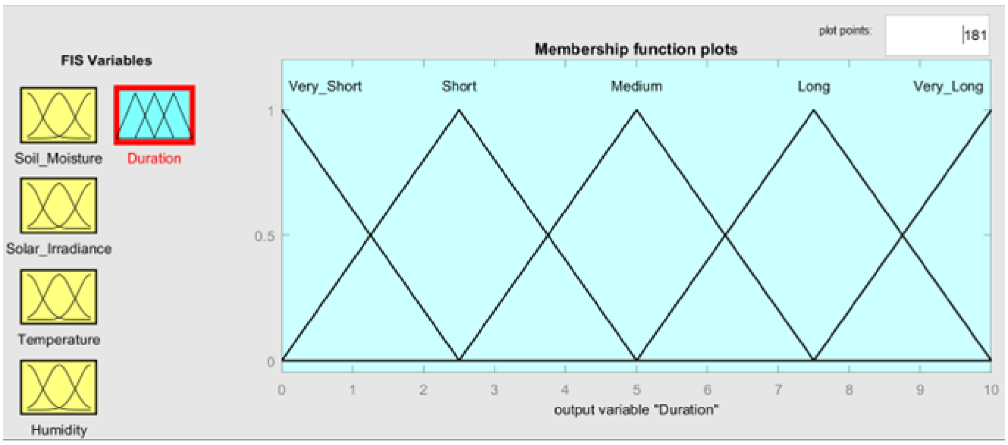

Figure 7. Duration membership function plot

Fuzzy Rules Analysis

By considering the impact of each input variable on the quantity of water required by plants, fuzzy rules can be generated. The relationship between the output variable and the input variables, which are soil moisture, solar irradiance, temperature and air humidity, can be expressed as follows:

- The need for water decreases with rising soil moisture content, indicating an inverse relationship between soil moisture and duration.
- As a result of the increased rate of evaporation caused by rising solar irradiance, irrigation duration increases in order to maintain soil moisture levels. Consequently, a direct relationship is created.
- Since temperature influences soil moisture content in a manner similar to how solar irradiance does, there is a direct relationship between irrigation duration and temperature.
- The evaporation rate of water in the soil increases when the air's moisture content is low because dry air tends to absorb moisture from the surface, hence there is an inverse relationship between duration and air humidity.

As a result, the irrigation duration required for the plant is directly proportional to solar irradiance and temperature, whereas it is inversely proportional to soil moisture and air humidity. The total number of fuzzy rules that must be created can be calculated by multiplying the number of membership functions for each input variable, which is 3×3×3×3 = 81 rules. The first considered case is the minimum. When the soil is wet, solar radiation is low, the temperature is cold and the humidity is high, then the irrigation duration is minimal. Then by changing soil moisture from dry to wet, solar irradiance from low to high, temperature from cold to hot and humidity from high to low, we can claim that the required time for irrigation is increasing. Some rules are indicated in Figure 8.

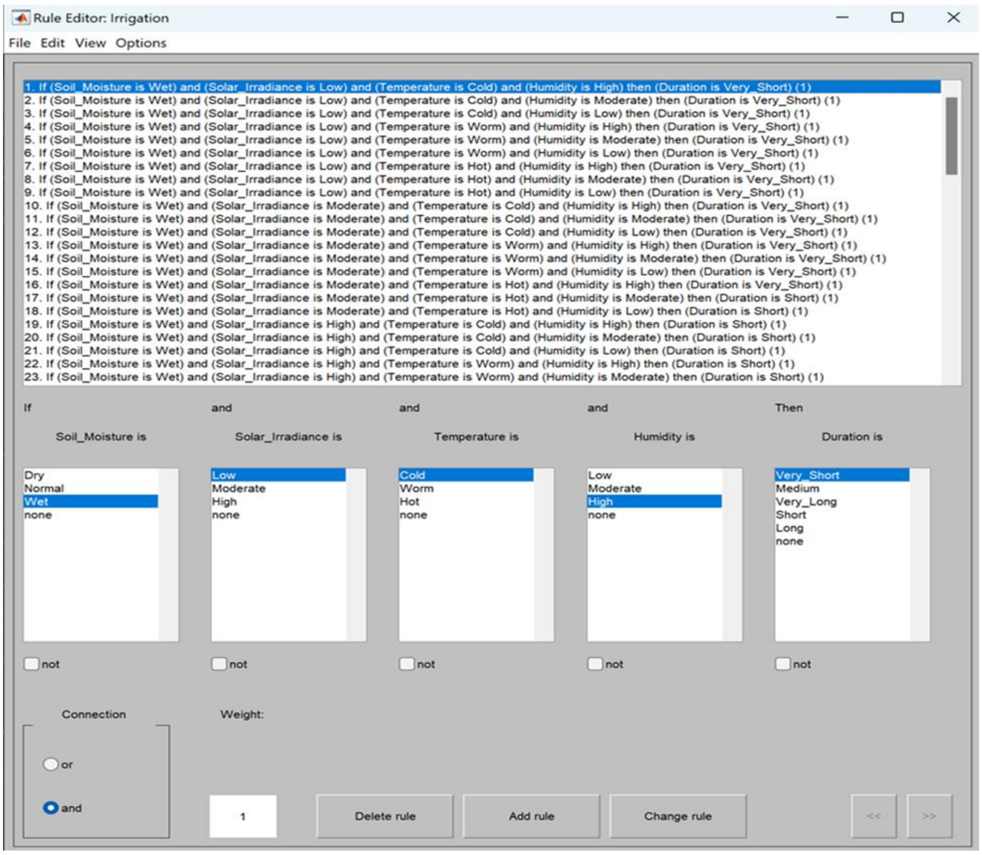

Figure 8. Rule base editor

As illustrated in Figure 9, the surface shows that the irrigation duration decreases with increases in soil moisture and air humidity.

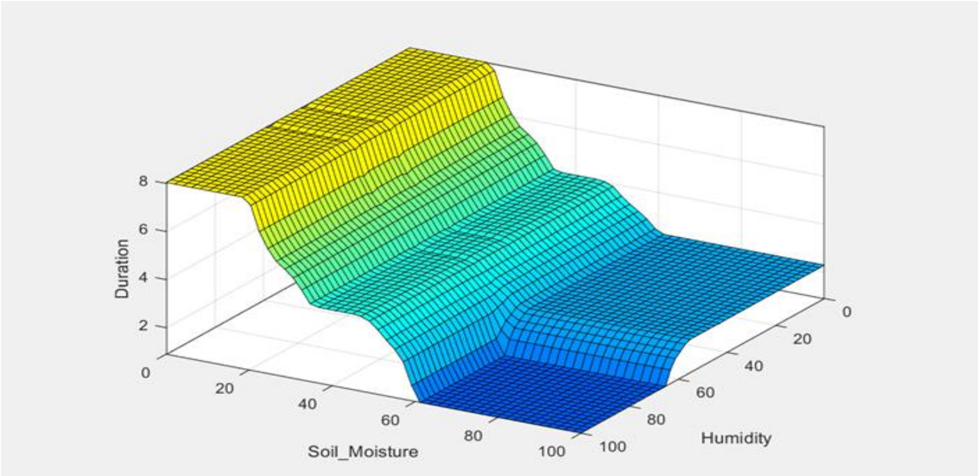

Figure 9. Surface graph of soil moisture and humidity vs duration

In contrast, the irrigation duration increases directly with solar irradiance and temperature as shown in Figure 10. Moreover, Figure 11 displays that solar irradiance and soil moisture have different proportions with irrigation duration, which almost confirms that the given rules are accurate.

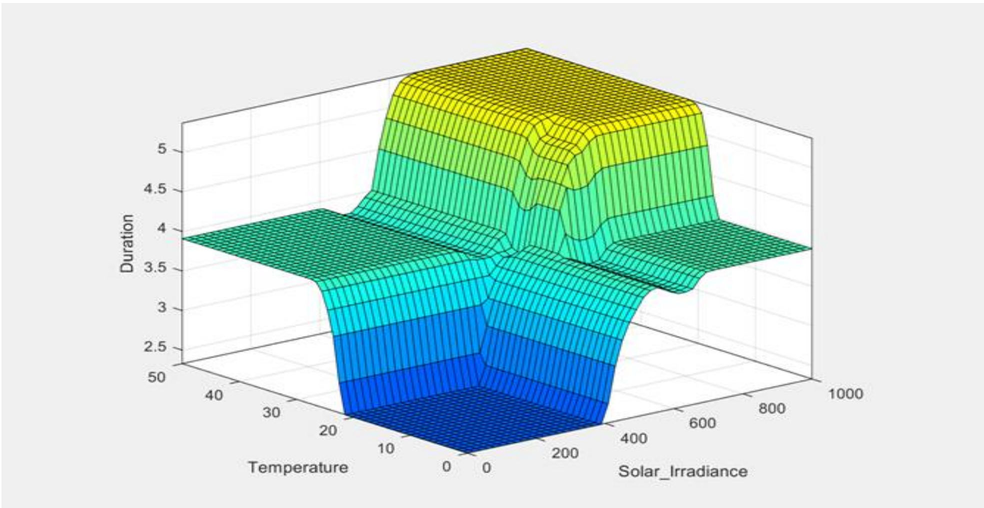

Figure 10. Surface graph of temperature and solar irradiance vs duration

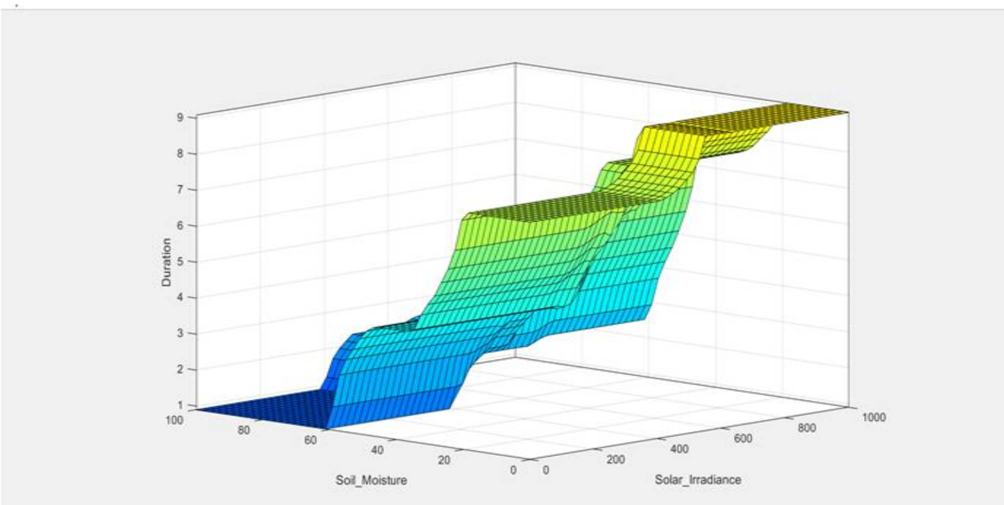

Figure 11. Surface graph of soil moisture and solar irradiance vs duration

Results

In Figure 12 , a set of crisp values have been implemented to the fuzzy logic control system. The values of 20, 250, 43 and 25 have been applied to the input variables of soil moisture, solar irradiance, temperature and humidity. The Centroid method is applied to compute the corresponding crisp output on irrigation duration which is 7.5 minutes

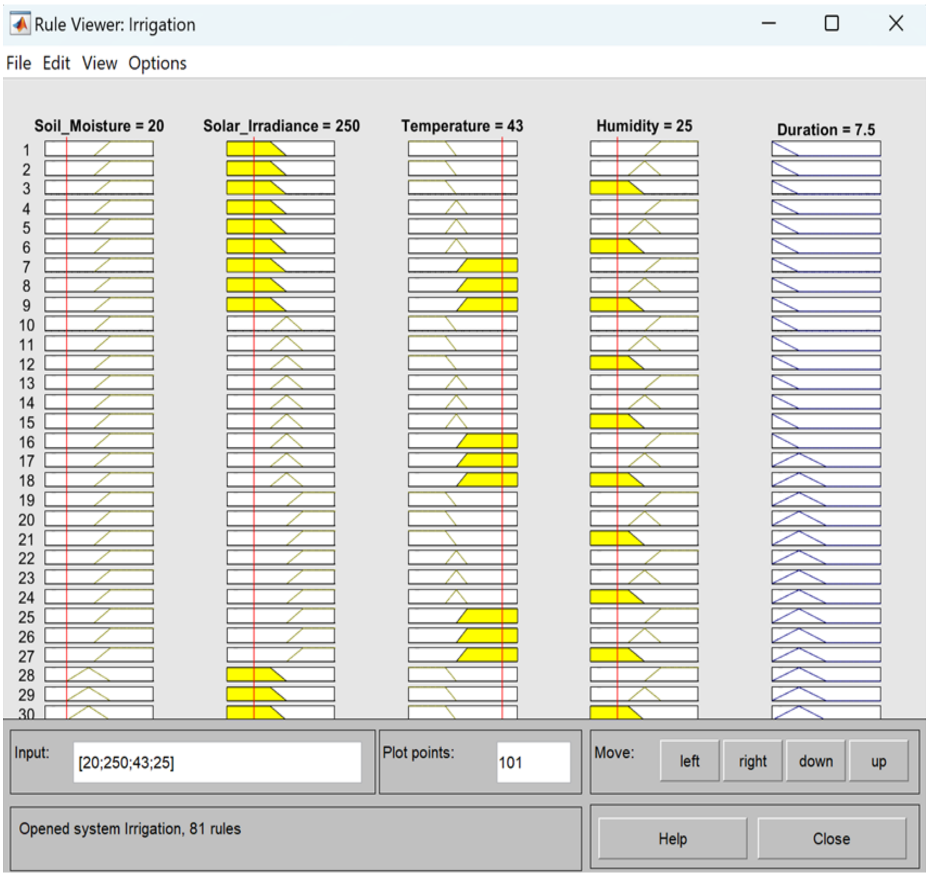

Figure 12. Rule viewer

Multiple cases have been applied using the proposed fuzzy irrigation logic controller. Some results are shown in Table 6 where the effect of all inputs on the irrigation duration was observed. When comparing the first and second rows, soil moisture and air humidity are constant, but solar irradiance decreased from 900 to 500 and air temperature decreased from 50 to 20, which led to a decrease in irrigation duration from 9.2 to 7.97. Additionally, the soil moisture and solar irradiance in the third and fifth rows remained constant, while the air temperature dropped from 40 to 10 and the air humidity rose from 20 to 100, resulting in a decrease in the irrigation duration.

Table 6. Results

Serial No.	Soil Moisture (%)	Solar Irradiance (W/m^2)	Temperature (℃)	Humidity (%)	Duration (min)
1	15	900	50	50	9.2
2	15	500	20	50	7.97
3	30	900	40	20	7.67
4	30	400	40	20	6.03
5	30	900	10	100	6.09
6	40	500	20	50	4.05
7	50	700	30	20	5.37
8	80	800	30	50	2.5
9	80	300	30	30	0.8

Simulation

To evaluate the ability of the fuzzy controller, a prototype model was created in Simulink. For each input variable, this model can be used to evaluate the fuzzy controller over a wide range of input values. Each input variable is subjected to a sine wave function block with various parameters in order to permute every possibility as specified in the fuzzy rule base. To obtain every possible permutation of the values of all the input variables, each wave is designed to engulf the others in every manner.

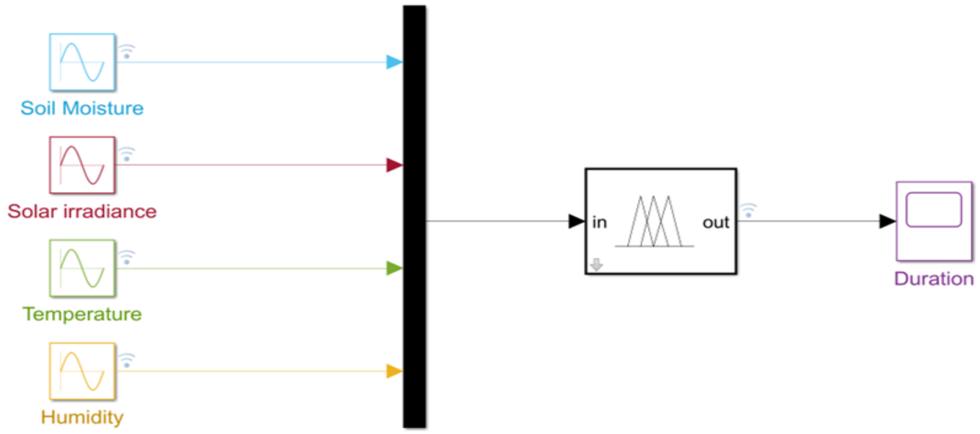

Figure 13. Simulink model

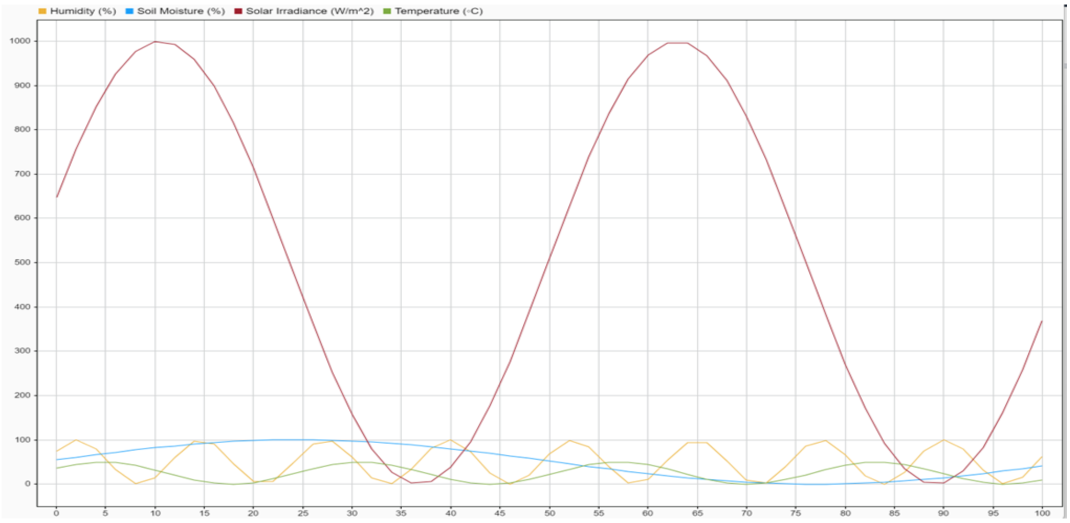

Figure 14. Inputs in simulink model

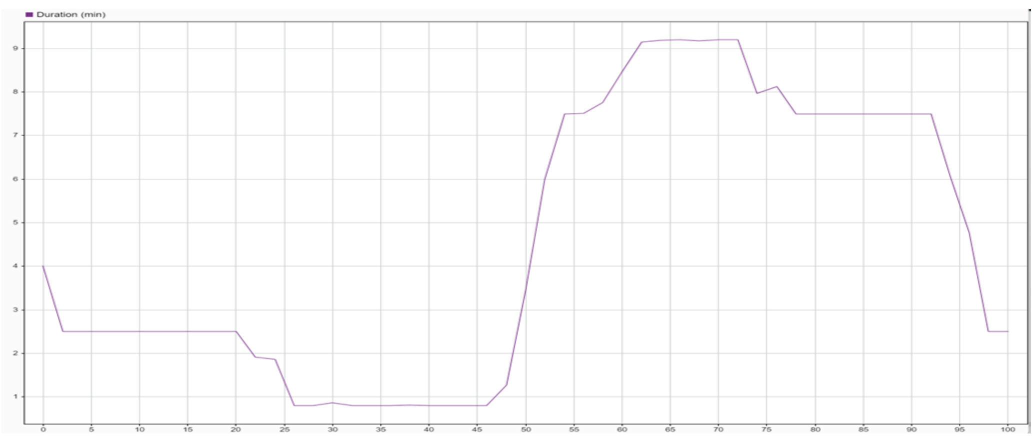

Figure 15. Output in simulink model

According to Figure 14 and Figure 15, the x-axis represents the simulation time, while the y-axis represents the value of the corresponding variable with respect to its unit of measurement. Every variable is denoted by a distinct color as shown at the top of the figures. Hence, Figure 14 displays how the input variable values changed during the simulation and the output result is shown in Figure 15. The following findings were noted:

- We can observe that the duration decreases as we move from 20 to 26 on the x-axis. This is due to a decrease in solar irradiation at the same time when soil moisture was at its peak and humidity was increasing. The need for more water was eliminated and the duration decreased to the minimum.
- The duration increases when we move from 46 to 64 on the x-axis, which coincides with an increase in solar irradiation to its highest and a decrease in soil moisture. This implies that in situations where soil moisture is low and solar radiation at its peak, the duration increases to the maximum.

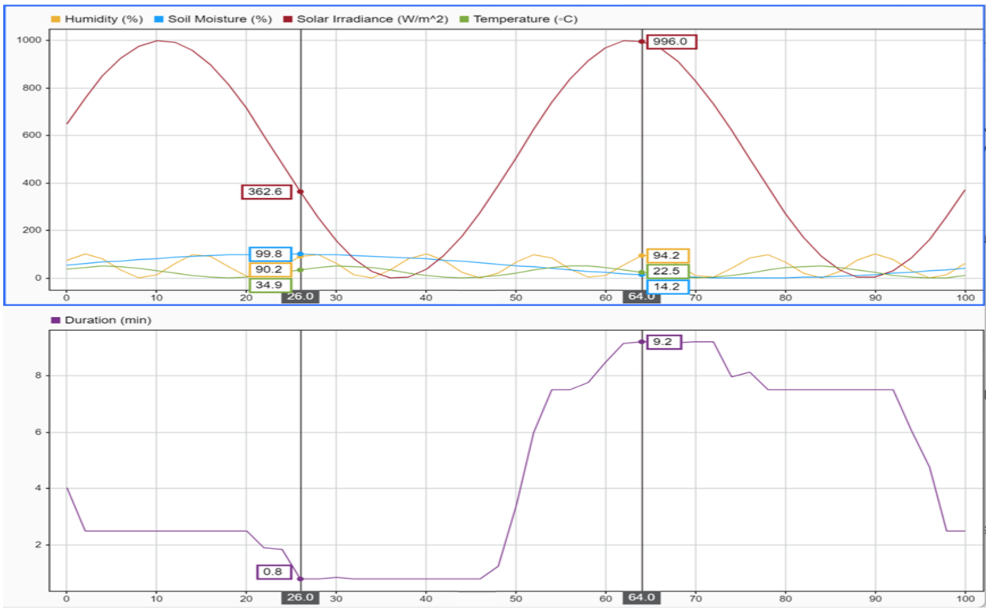

Figure 16. Simulink model with two cursors

Conclusion

In this paper, a smart irrigation control system based on fuzzy logic adapted to the climate of Riyadh was suggested. The theoretical part of the irrigation controller has been proposed, but the irrigation system could be tested and then implemented in the field by engineers. To collect data, the use of different types of sensors is necessary to gather real-time measurements for each input variable. Along with sensing the moisture level of the soil and climatic factors, determining the type of plant can also help to interpret the need of water for irrigation. Finally, to achieve the best performance of the system, we need an expert's knowledge to ensure the accuracy of the rules.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgments or Notes

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