Design a solar system for fuzzy control of intelligent irrigation system

Mohammad Younesi Alamouti[1*], Hamid Khafajeh[2], Arzhang Javadi[3], Hossein Dehghanisanij[4]

(1 .Imam Khomeini Higher Education Center, Agricultural Research, Education and Extension Organization (AREEO), Karaj, Iran;
2. Biosystems Engineering Department, Tarbiat Modares University, Tehran, Iran;
3 . Agricultural Engineering Research Institute, Agricultural Research, Education and Extension Organization (AREEO), Karaj, Iran;
4. Agricultural Engineering Research Institute, Agricultural Research, Education and Extension Organization (AREEO), Karaj, Iran.)

Abstract: Restriction of water resources requires optimal use of agricultural water resources. In this regard, the use of new technology may increase irrigation efficiency. In arid and extremely arid regions such as Iran, the time and duration of irrigation is the key to achieving sustainable irrigation. Therefore, in this research, after constructing a garden in Iran, Karaj, Imam Khomeini Higher Education Center with an area of 0.05 ha, and installing equipment related to irrigation and fertilization, a fuzzy control system was designed to optimize water consumption and inputs, intelligent irrigation and fertilization system. The present study presents a practical solution based on artificial intelligence in which all stages of design and implementation are described. In this system, a microcontroller was first used to process and store data on soil moisture, ambient temperature and solar radiation. The fuzzy logic controller then takes these three inputs and based on the table of rules created for a specific product, produces the desired irrigation time and duration. Experimental results showed that, the developed system accurately compensates for the amount of water lost through evapotranspiration. It seems that the use of fuzzy control has a great impact on irrigation management and planning in the near future.

Keywords: solar system, fuzzy control, irrigation system, artificial intelligence

Citation: Alamouti, M. Y., H. Khafajeh, A. Javadi, and H. Dehghanisanij. 2023. Design a solar system for fuzzy control of intelligent irrigation system. Agricultural Engineering International: CIGR Journal, 25(1): 14-26.

1 Introduction

In recent decades, due to the lack of water in the Iran, farmers have realized the value of this vital substance due to its limitations and with hard work and great effort in distributing water on the farm, they are more successful. Night flood irrigation in Iran has shown the hard work of our ancestors in better water management. This type of irrigation has been done in Iran not so long ago with the following goals: maximum use of water due to lower evaporation from the soil surface, adoption of strict rules by the government among farmers in order to adapt the cultivation pattern to the existing water capacity and creating small water tanks in gardens and farms to store excess water and this shows the hard work of our ancestors in managing better water consumption (Zargan and Waez-Mousavi, 2016). Restrictions on production resources, especially water resources, limit the increase in production by increasing the area under cultivation. Recent droughts have exacerbated the problem. As the water shortage increases, the risk of reducing the area under cultivation also increases day by day. In other words, in the current

Received date: 2022-04-08 **Accepted date:** 2022-09-09
***Corresponding author: Mohammad Younesi Alamouti,** Agricultural Engineering Research Institute, Agricultural Research Education and Extension Organization (AREEO), Karaj, Iran, P.O. Box: 31585-854. Email: mohamadyounesi@yahoo.com.

situation, first of all, maintaining and then increasing the area under cultivation of agricultural products requires the optimal use of agricultural water resources. To increase irrigation efficiency, it is necessary to use new technologies (Mousavi Seyedi et al., 2018). Due to the water crisis in the country and the lack of optimal water consumption in the agricultural sector, an attempt was made to take an effective step in preserving water and soil resources as well as increasing agricultural efficiency by establishing an intelligent irrigation management system. Fuzzy logic is close to human language with the aim of examining the indirect experiences of knowledge and reasoning. Fuzzy logic provides a control law that is often effective and independent of major theoretical developments. In fact, fuzzy controllers perform more powerfully than traditional techniques and this is in the case that the mathematical example of this process is not well known or the behavior of the nonlinear process is different (Khafajeh et al., 2020).

In this research, a new irrigation and fertilizer system was developed using fuzzy logic technique and using the knowledge and experience of the farmer. Among agricultural institutions, balanced addition of chemical fertilizers is more effective than other inputs in increasing agricultural production. On the other hand, increasing production per unit area and improving the quantity and quality of crop and horticultural crops requires special attention. Intelligent irrigation systems and their conversion from common methods of farmers (surface) to pressurized systems (diameters), can play an important role in this issue. Because the use of these systems increases the efficiency of water consumption, in other words, increases the production of the product per unit of water. The combination of these two factors (water and fertilizer) or the so-called fertilization with irrigation has special advantages. Success in this method requires sufficient knowledge about the water needs and fertilizer needs of each product. Water and fertilizer integration technology integrates the irrigation process and fertilization process to realize water-saving and fertilizer saving in the agricultural process, which is one of the development directions of modern agriculture. Through fertilizer mixing tank, water pump, and drip irrigation pipe network, the irrigation and fertilizer application system adds water-soluble fertilizer to irrigation water and delivers it to the roots of crops to achieve the purpose of water supply and fertilizer on-demand and water-saving irrigation.

In the process of irrigation and fertilization, the irrigation and fertilization device precisely controls the water supply and fertilization amount within the optimal control range to facilitate the development of the crop root system and crop growth. In addition, the uniformity and stability of water and fertilizer flow in irrigation and fertilization system are related to the control precision of crop fertilizer amount. Therefore, precise control of water and fertilizer regulation according to crop water and fertilizer requirements is the key to realizing water-saving irrigation. Since the water and fertilizer regulation process of irrigation and fertilizer system has problems of nonlinearity, time-varying, and hysteresis, which can affect the accuracy and stability of water and fertilizer control irrigation and fertilizer system, a control method with high control accuracy and good stability is needed. In this method, due to the optimal use of water and fertilizer, environmental pollution is minimized and the division of fertilizer consumption in the sensitive and required stages of the plant is done easily. Also, fertilizer wasting is prevented due to controlling the concentration of nutrients in the soil and it is provided according to the plant growth needs. On the other hand, due to the uniform solubility of fertilizers in irrigation water, its absorption is better.

Therefore, due to the problem of water scarcity and understandable sensitivities that have been created in recent years on the issue of environmental protection and conservation of energy resources and considering that traditional agricultural systems with improper water management and on the other hand improper use of fertilizers, herbicides and chemical pesticides have been the most important sources of environmental pollution, in this study, in order to optimize water consumption and inputs, an intelligent irrigation and fertilizer system was designed.

2 Materials and methods

The main goal in establishing an orchard is to develop maximum fertility in the minimum time per hectare of land. In this case, the climatic conditions of the region, soil type, base type and agricultural operations are effective. Implementation of intelligent irrigation includes land preparation, planting of seedlings, installation of sensors, design and construction of control system, fuzzy control system. The system was then evaluated Figure 1. In this research, first a land with an area of 0.05 ha was selected. The land of this research, from the field of Imam Khomeini Higher Education Center, in the Karaj, Iran with the longitude and latitude 46˚ 30' 12" and 32˚ 12' 28" respectively with a height of 1297 meters above sea level was provided. Tree seedlings were in 5 rows and 6 in each row were planted at standard intervals.

2.1 Central control unit

The central control unit consists of devices that inject the pumped water into the main pipe of the drip irrigation network after adding fertilizer (if necessary) and with precise control. In this study, sensor-based micro-variable rate (drip) irrigation was used to irrigate the tree variable rate. In this method, irrigation scheduling is based on the amount of water in the soil and climatic information. Figure 1 shows the system structure consisting of blocks. Control system inputs include: temperature and humidity sensors, ambient light and soil moisture sensor and water solenoid valve actuators and fertilizer tank solenoid valve. The purpose of this system is to apply the intelligent irrigation and fertilization and record data related to sensors of soil moisture, temperature, relative humidity and light.

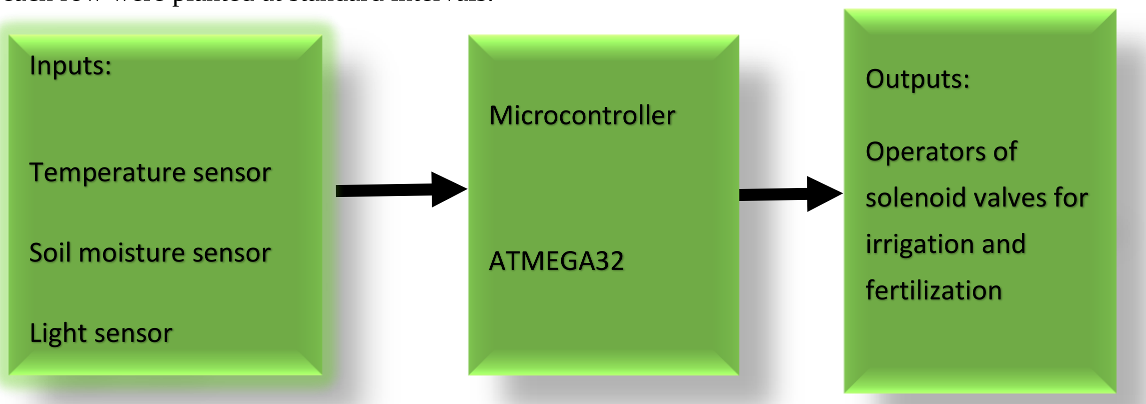

Figure 1 Control system diagram block

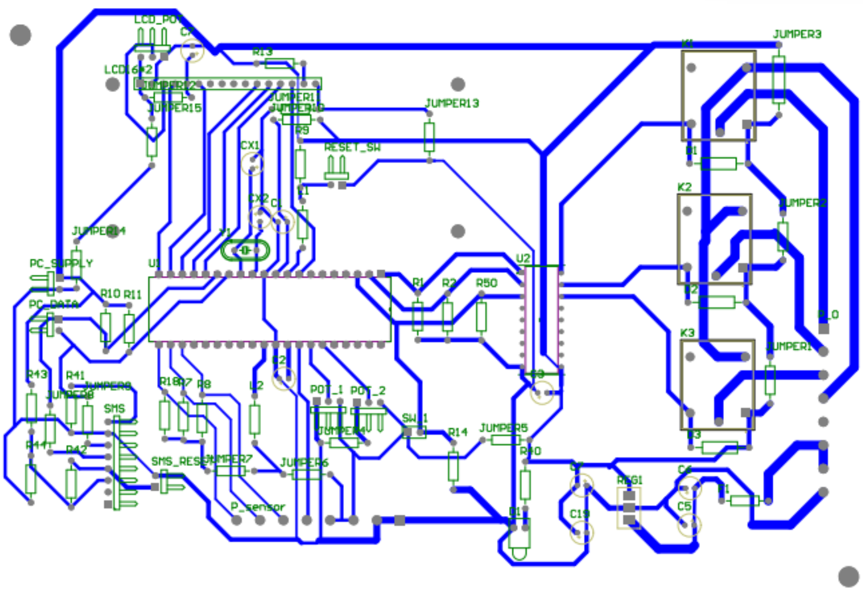

Figure 2 PCB control board

The control system board includes the power supply board, the sensor input board, the relay board and the main processor board. Figure 2 shows the designed control board. This board was first written with C ++ program and also simulated by Proteus program and then made.

In this system, a 12-volt adapter is used to convert 220 V Alternating Current (AC) voltage to 12 V Direct Current (DC). The control board includes the relay board for disconnecting and connecting the actuators. The command is issued from the microcontroller by the fuzzy system. An ATmega32 microcontroller from Atmel was used in the main processor. This board reads temperature, humidity, light and soil sensors and is responsible for the USB connection to transfer data from the board to the computer to send data to the fuzzy program and apply the appropriate commands to the relay board to disconnect and connect the control system operators.

Also, another function of this board is to connect the character Liquid crystal display(LD) screen keyboard (4 × 20). The keyboard can set the control system in automatic or manual mode. LCD display shows data related to temperature sensors, relative humidity, light and soil moisture. In this study, we used three sensors to measure ambient temperature, radiation (cooling) and soil moisture. Temperature and radiation sensors collect the information needed to calculate the rate of evapotranspiration. The soil moisture sensor provides a signal when irrigation is needed (humidity <20% in this case study). These analog signals are converted to digital data by Analog to Digital Converter (ADC). FLC makes a fuzzy rule and a fuzzy decision based on the information received from the sensors. The time and duration of irrigation will be decided. Fuzzy logic is written in C language and is transmitted to the microcontroller in machine language (hex file).

2.2 Sensors input board

This board includes a connection of three sensors, DHT22 temperature and humidity, GY_302 light sensor and one capacitive soil moisture sensor.

2.3 Soil sensor humidity meter

A proper place to put the device should be where it is in a position similar to most other places on earth. Or otherwise have the majority of local conditions. Intelligent soil moisture sensors have received a great deal of attention in recent decades for their rapid method of determining soil moisture for irrigation scheduling. By measuring the amount of soil moisture, irrigators can decide when, how much water to use to achieve maximum plant production and minimum water consumption (Cardenas-Lailhacar and Dukes 2010). Intelligent soil moisture sensors take instantaneous and continuous measurements of soil moisture therefore used in intelligent irrigation system. Numerous studies have been performed on the performance of various sensors (Winter et al., 2006). Capacitive Soil Moisture Measurement Module A module with a probe approximately 7 cm long allows you to measure the amount of soil moisture (Figure 3).

In capacitive soil moisture measurement modules, unlike resistance modules, there is no need for the copper surface to come into contact with the soil; Therefore, it is more resistant to rust and oxidation. This module is compatible with voltages of 3.3 volts to 5 volts. This module has a three-pin connector, two of which are power supply and one analog output pin. The output of this sensor is analog and its output voltage is between zero and 3 volts. The numbers that this sensor shows are between 260 and 520 and the percentage of humidity is between zero and one hundred. After calibration, this interval was divided into three parts: dry, moist and wet. If the number obtained is in the range of 430 to 520, the soil is dry. If the number obtained was in the range of 350 to 430, the soil is moist. If the number obtained was in the range of 260 to 305, the soil is wet.

2.4 Ambient temperature and humidity sensor

The temperature and humidity sensor used in this research is DHT22. The DHT22 sensor, also known as the AM2302, is one of the most popular temperature and humidity sensors, which has a single-wire calibrated digital output with high accuracy. AM2302 has the ability to send information up to a range of 100 meters. Humidity measurement range is between 0 and 100%, humidity resolution is 2% -5% and humidity response is 2 seconds. The temperature measurement range is between -40 ℃ to 125 ℃ with a resolution of 0.5% and a response time of 2 seconds.

2.5 Light sensor

GY-302 was used to measure the amount of light inside and outside the light sensor module (GY-302 BH1750 Digital light intensity detection). Brightness data output range is 0 - 65535 lux and its output is digital. Sensors (Lin) and (Lout) were installed to measure the amount of sunlight. The sensor was calibrated and evaluated before use.

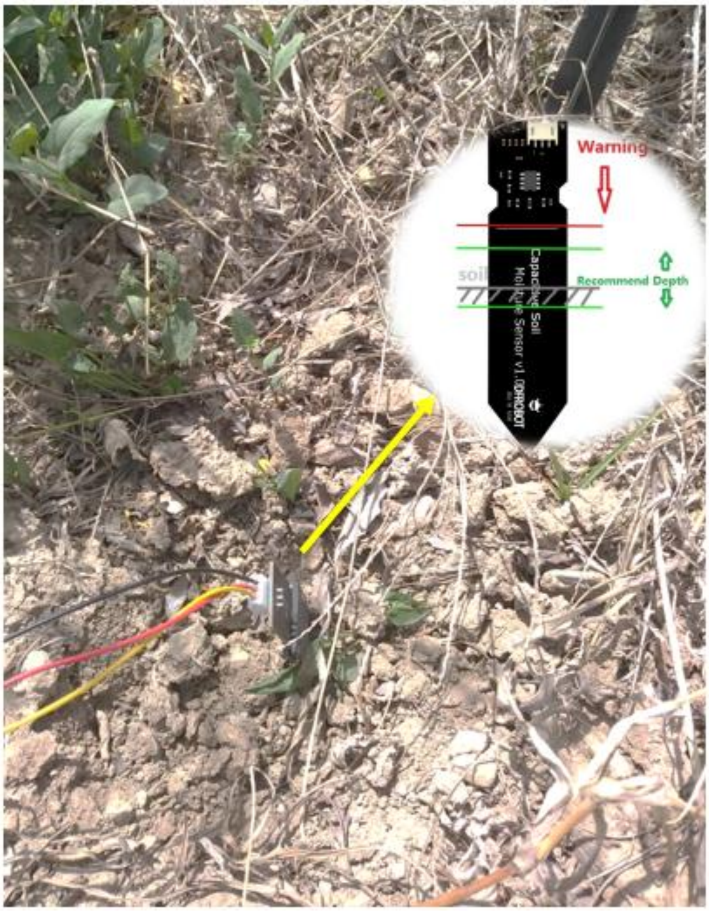

Figure 3 Location of soil moisture sensor in the garden

2.6 How the control system works

In this system, the amount of water consumption was calculated by measuring the flow rate of the inlet pipe and recording the duration of irrigation. The solenoid valves are controlled by a microcontroller. This is to turn water on and off and is connected to a drip irrigation pipeline.

Fuzzy method was used to irrigate the variable droplet rate to the humidity sensor. Also, among the factors affecting the irrigation period, soil texture factor was considered as the most important parameter affecting the amount of fertilizer in the system. For soil texture factor, different rows of trees were constructed in advance by preparing soil texture map. In this design, the irrigation rate of the trees is based on the amount of soil sensor moisture and the amount of fertilizer on the trees according to the separated areas of the soil texture map. In a variable rate fertilizer system, the amount of fertilizer is prepared based on the map and also the annual time period is tree fertilization. In the fertilizer system, after sending a signal to the control system, the processor sends the command to open the fertilizer tanks according to the written rules. After opening the tank lid, the fertilizer is poured into a larger tank containing water. Once dissolved in water, drip irrigation will be injected into the trees.

2.7 Development of fuzzy control for irrigation system

In this study, irrigation and fertilization times are controlled. The design of a fuzzy controller begins with the selection of language variables, process status, input and output variables. The next step is to select a set of linguistic rules and the type of fuzzy reasoning process. Once the rules are set, after inference, the fuzzy set and output value must be determined; a non-phase strategy must also be developed. The rules obtained in this study are based on the water consumption chart of biennial tree seedlings.

2.8 Collecting data

In the first stage of fuzzy control design with respect to biennial tree seedlings, information about the amount of water required and fertilization conditions were extracted.

Figure 4 Garden irrigation and fertilizer system

2.9 Determining the inputs and outputs of the controller

Irrigation control system was designed and implemented for irrigation and fertilization using fuzzy controller. The purpose of this system is to control the humidity and the amount of fertilizer. A fuzzy controller system was used for this purpose. Fuzzy rules consist of two parts, introduction and conclusion. The inputs of the sensors are control systems that enter the fuzzy rules database after fuzzy construction.

According to Figure 5, the block diagram of the soil moisture control system is a garden according to the desired conditions of moisture content and fertilization. The output of the fuzzy control system includes solenoid valves for irrigation and fertilization. The fuzzy program is executed according to the pre-written fuzzy rules. All sensor data is saved as a text and Excel file every two minutes. The written program can be executed manually and automatically in fuzzy (Krishnan et al., 2020).

2.10 Assign membership functions to each of the inputs and outputs (Fuzzy instruments)

In this study, Mamdani method was used for fuzzy inference. The Mamdani method was invented by Mamdani (Mamdani and Assilian., 1975). In this system, both the first part of the rules and the last part (result) are fuzzy rules. The form of Mamdani method is as follows.

$$R_i: If\ x_1\ is\ \tilde{A}_{i1}\ and(or)\ x_2\ is\ \tilde{A}_{i2}\ and(or)$$
$$\ldots x_m is\ \tilde{A}_{im} Then\ y_i = \tilde{B}_i (i = 1,2, \ldots., c)$$

The antecedent involves a fuzzy conditional proposition "If x is A then y is B", with A and B being fuzzy concepts.

2.11 Membership functions defined

For input variables are "temperature, humidity and light" and output variable is "irrigation duration of fuzzy trapezoidal type" (Souza et al., 2020).

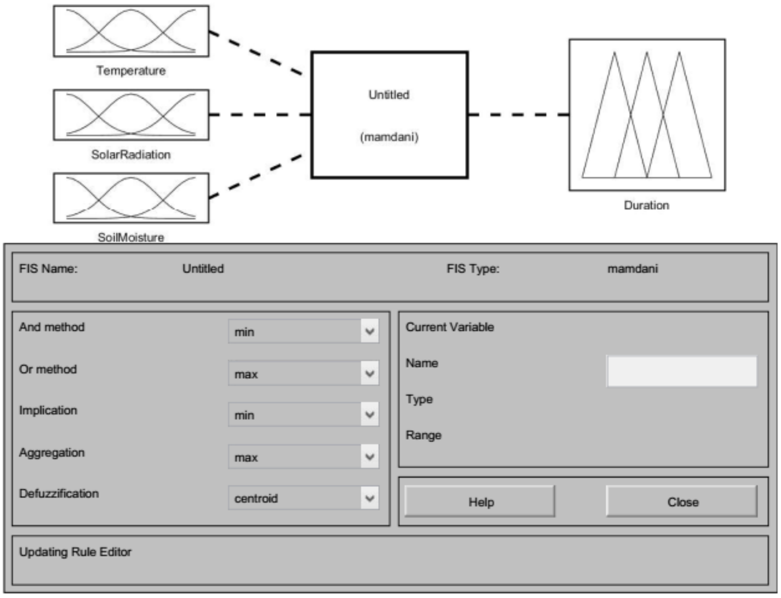

Figure 5 Fuzzy control system

2.12 Fuzzy rules

The rule block includes a fuzzy control strategy. The "If" section of the rules describes the situation for which the rules are designed. The "then" section also describes the fuzzy system response in this situation. 13 rules are written in the designed fuzzy control system. The value of all these rules is considered equal to one. The law of fuzzy control is given below. Fuzzy rules are shown in Tables 1, 2 and 3 for different soil moisture.

Table 1 Rules for irrigation time (per minute) in soil moisture

(Temperature ℃)	Lux(Radiation)		
	Light	Medium	Dark
Cold			
Medium		zero	
Hot			

Table 2 Rules for irrigation time (per minute) at medium soil moisture

(Temperature ℃)	Lux(Radiation)		
	Light	Medium	Dark
Cold		Low	
Medium	Very Low		Low
Hot	Zero	Very Low	high

Table 3 Rules for irrigation time (per minute) in dry soil moisture

(Temperature ℃)	Lux(Radiation)		
	Light	Medium	Dark
Cold		High	
Medium	Low		high
Hot	Zero	Very Low	Very high

An example of a fuzzy control rule implemented in MATLAB is given below:

If (Temperature is Medium) and (SolarRadiation is not light) and (SoilMoisture is Meduime) then (Duration is Short) .

2.13 Fuzzy inference engine

In this study, the minimum inference engine of Mamdani was used. In this inference engine, first the output of each rule was calculated by calling the minimum Mamdani (logical min operator) Then the community operator (max) was used to implicate the results to produce the final output (Jaiswal and Ballal, 2020).

2.14 Design of photovoltaic system

Whereas independent photovoltaic systems are mostly used in rural areas and where there is no electricity network, and also because the purpose of this study is to use the potential of solar energy in Iran in the system of intelligent irrigation and fertilization; therefore, an independent photovoltaic system was selected to provide the required electricity in this system. In the following, its design steps are discussed (Eltawil et al., 2021).

2.15 Assess system energy needs

One of the first things you need to do when designing a stand-alone photovoltaic system is assess your energy needs. This is usually done in the required watt-hours per day (W h day^{-1}).

2.16 Solar source evaluation

The optimal inclination angle for the photovoltaic array for the month of system design at the desired location must be considered. Then, according to the solar radiation data at that angle and during the design month, the photovoltaic array is measured (López-Luque et al., 2015).

2.17 Independent photovoltaic array measurement

The following equation is used to measure an independent photovoltaic system.

$$W_{PV} = E/(G \times \eta_{sys}) \quad (1)$$

Where, W_{PV} is the maximum power of photovoltaic array in terms W_P, E is the *energy* required per day in watts-hours(W h), G is the average peak hours of the sun per month (h) for design the slope and orientation of the photovoltaic array. η_{sys} is the overall efficiency of the system, which is generally considered to be 0.6 (60%).

$$\eta_{sys} = \eta_{PV} \times \eta_{PV-BATT} \times \eta_{CC} \times \eta_{BATT} \times \eta_{DIST} \times \eta_{INV} \quad (2)$$

where, η_{PV} is 80% (20% losses in photovoltaic modules that do not work at maximum power point), $\eta_{PV-BATT}$ is 97% (3% losses due to voltage drop in cables from photovoltaic array to battery), η_{CC} is 98% (2% loss on a good controller charge), η_{BATT} is 90% (10% battery loss), η_{DIST} is 97% (3% losses in distribution cables from photovoltaic batteries to consumers) and η_{INV} is 90% (10% loss in a good quality inverter).

2.18 Battery measurement

Batteries need to be measured to not only store the energy needed daily, but also the energy needed for several days (power supply on cloudy days). Battery measurement is obtained from the following equation:

$$Q = (E \times A)/(V \times T \times \eta_{INV} \times \eta_{DIST}) \quad (3)$$

where, Q is the minimum required battery capacity in ampere-hours (A h), E is the daily energy required in watts (W h), A is the number of days required for storage, V is the system DC voltage (V) and T is the maximum allowed depth of discharge (DOD) battery.

3 Results and discussion

One of the first things you need to do when designing a stand-alone photovoltaic system is assess your energy needs. This is usually done in the required watt-hours per day (Wh/day). In order to determine the daily watt-hour, it is necessary to prepare a list of all electrical appliances that are to be used in the system. Table (4) and table (5) show the equipment used in the system along with their rated power (W) and the number of hours used every day (h). In this research, the energy needed for the smart irrigation system is provided through the design of an independent photovoltaic system. In this design, two 120 watt solar panels, a 40 A charge controller, and a 50 watt inverter with 12 DC V input were used and according for calculations made to store energy in three days, the minimum battery capacity required is 110 amps. The selected battery for this system is 12 volts 100 amps. Therefore, 2 types of these batteries are needed to start the system.

3.1 Fuzzy control system performance

How fuzzy sets work for different inputs of temperature, humidity and light, under the influence of fuzzy rules and fuzzy inference motor, was obtained in the form of graphs and is shown in Figures 6 to 8.

Table 4 AC loads used

AC consumers	Rated power (W)	Number	Total power required (W)	Number of hours of daily use (h)	Daily energy requirement (W h)
Irrigation pump	372	1	372	1	372
Fertilizer pump	372	1	372	0.1	37.2
Solenoid valves	2	5	10	1	10
Electric mixer	200	1	200	0.1	20
Total					439.2

Table 5 DC loads used

DC consumers	Rated power (W)	Number	Total power required (W)	Number of hours of daily use (h)	Daily energy requirement (Wh)
Control system power supply board	5	1	5	24	120
Total					120

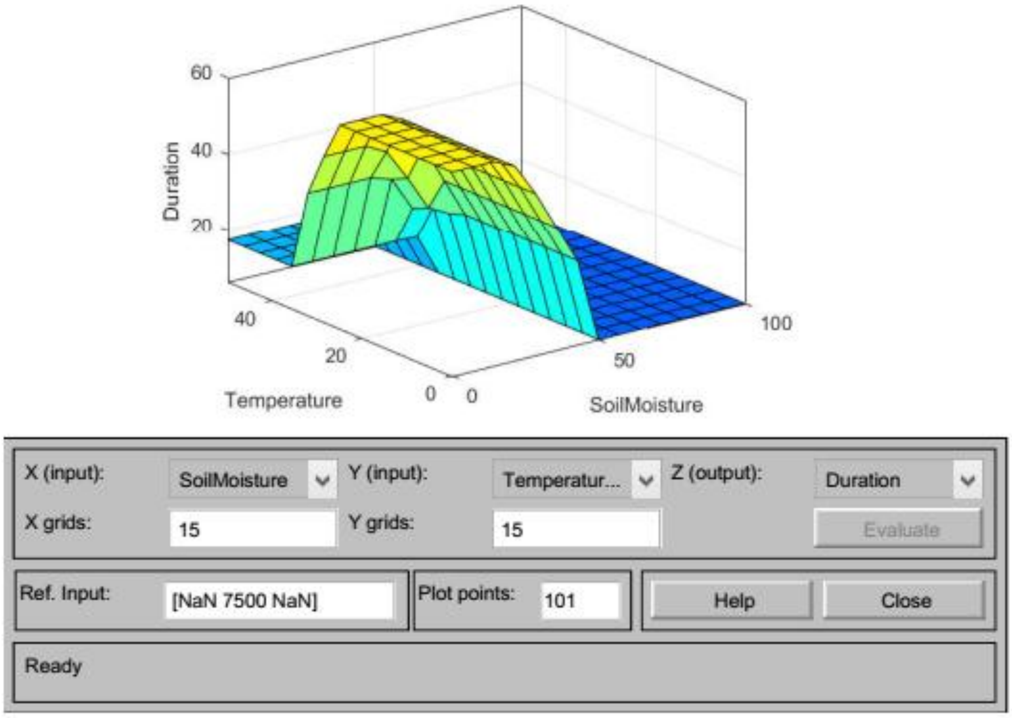

Figure 6 Output control level proportional to changes in soil moisture and temperature

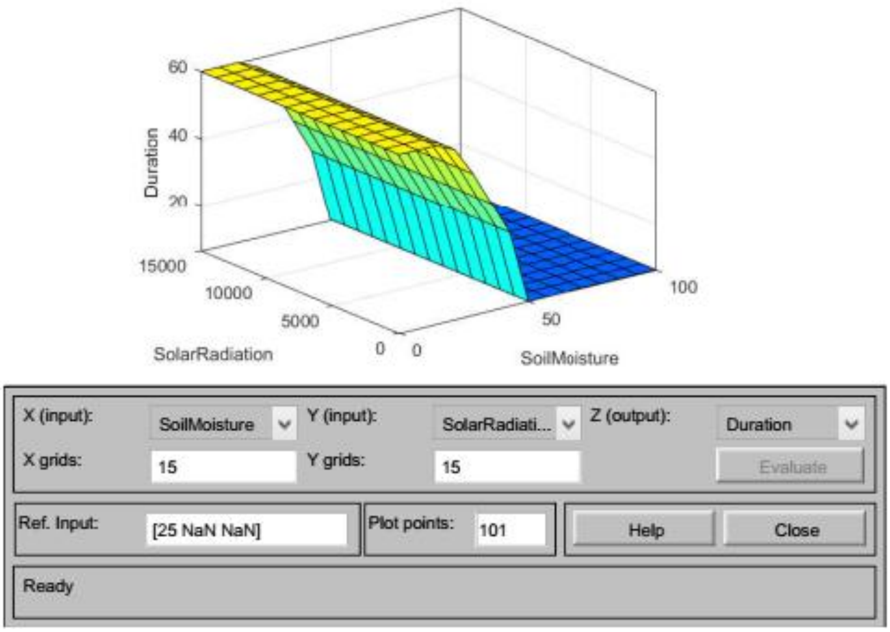

Figure 7 Output control level proportional to soil moisture changes and light

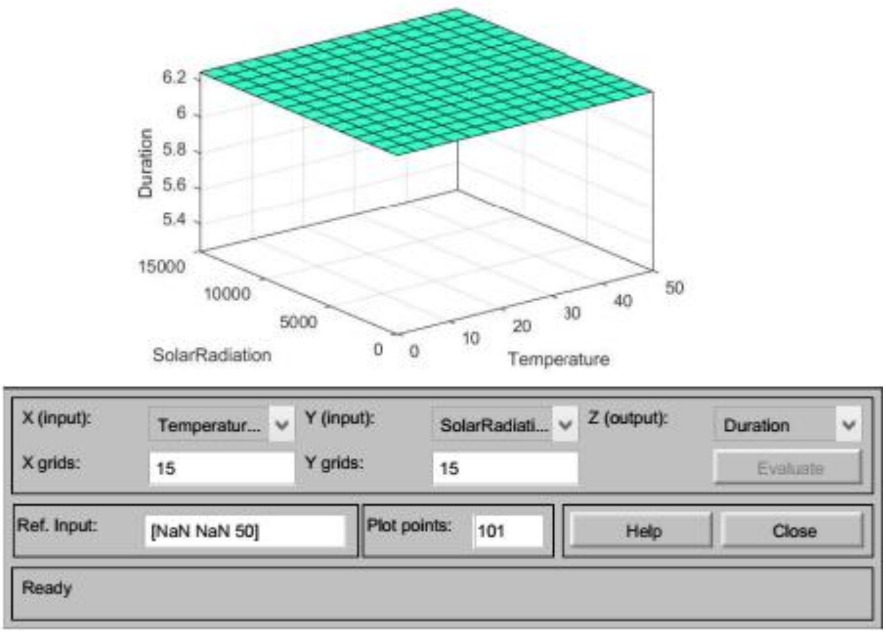

Figure 8 Output control level proportional to temperature and light changes

3.2 Experimental results

After designing, the control system is implemented on the printed circuit board and is connected to various sensors. This system worked continuously for 30 working days. Actual measurement of parameters was performed in the garden. The evaluation results of the fuzzy control system showed that the system prevented the reduction of evapotranspiration at high temperatures during the day. It also selects the appropriate time by referring to the fuzzy rules database. One of the parameters of tree growth is soil moisture. Soil moisture varies during different days. This humidity is adjusted according to the water needs of the tree. Maximum, minimum and average soil moisture were 88.92%, 40.84%, and 61.3%, respectively. The soil moisture diagram is shown in Figure 9. According to the diagram, by reducing the humidity of the control system, this humidity is compensated by opening the solenoid valves and continues until the moisture reaches saturation.

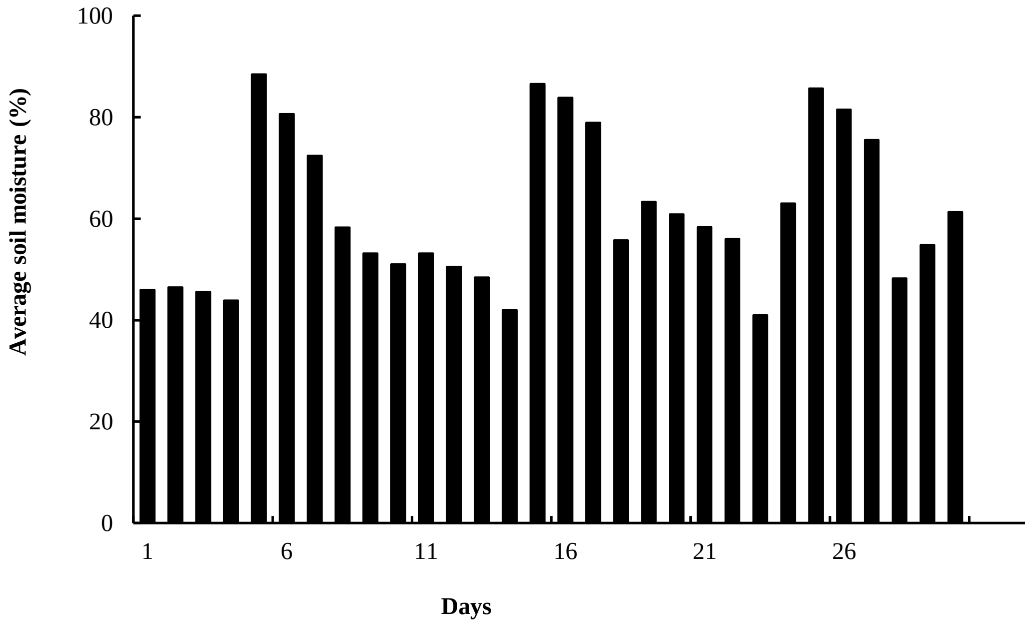

Figure 9 Soil moisture in different days

Figure 10 shows the amount of air temperature on different days. Maximum, minimum and mean ambient temperature were 40.95 ℃, 31.92 ℃ and 31.37 ℃, respectively. Fuzzy rules are written in such a way that irrigation operations are not performed at times when the temperature is high.

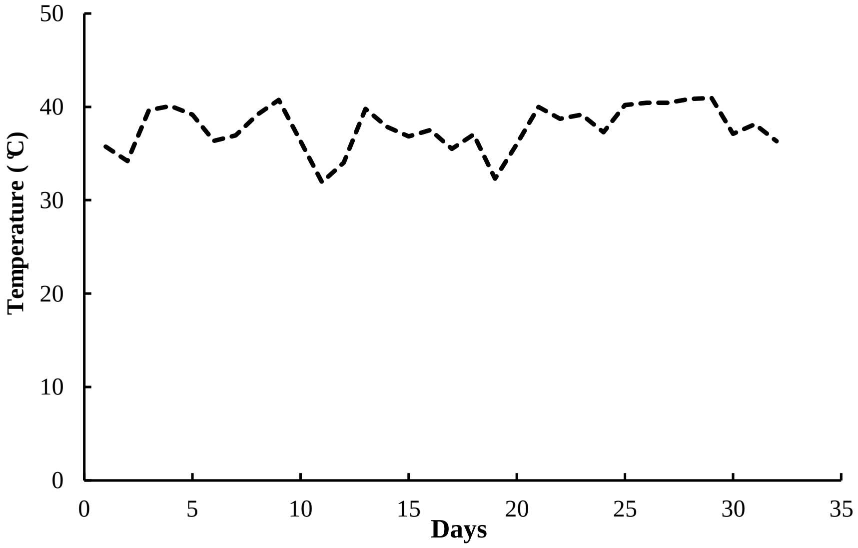

Figure 10 Temperature on different days

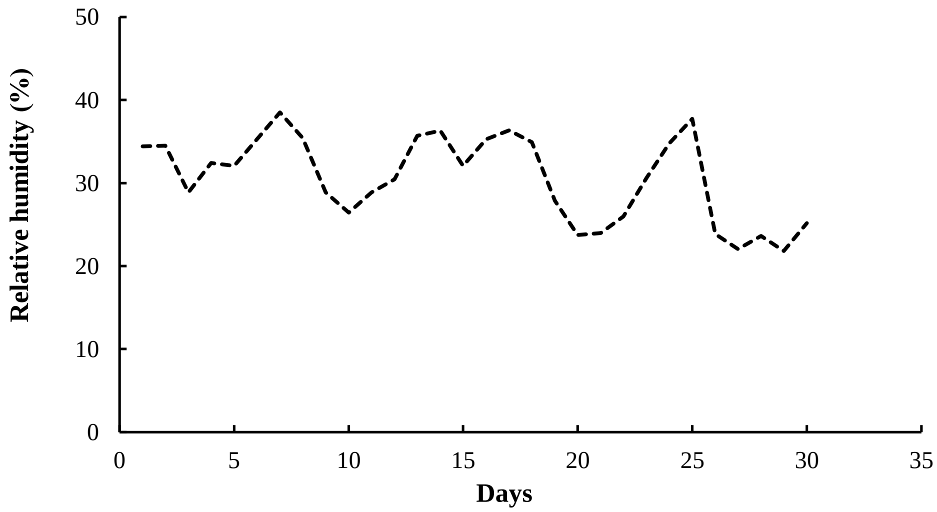

Figure 11 Relative humidity of the environment on different days

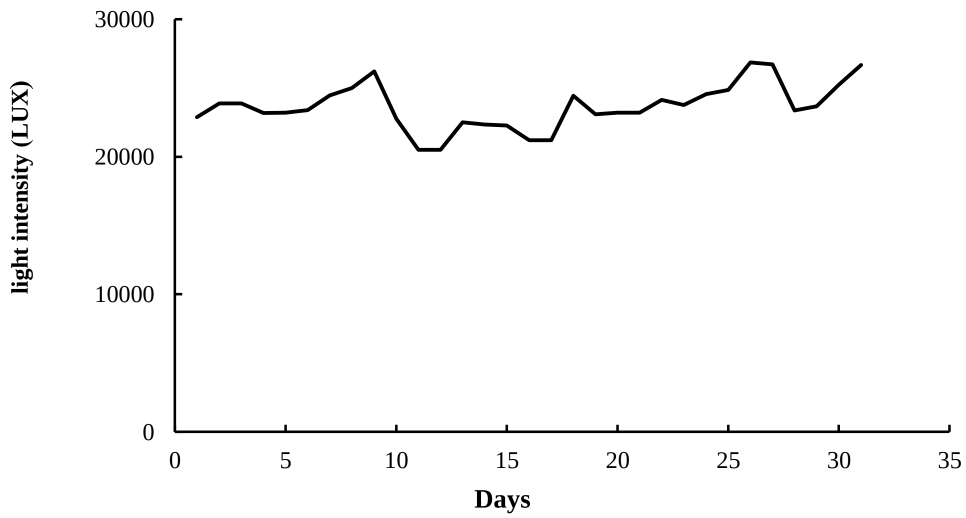

Figure 12 Average light intensity on different days

Figure 11 shows the amount of humidity on different days. Maximum, minimum and average humidity were 38.51%, 21.81% and 30.59%, respectively. Figure 12 shows the average amount of light intensity on different days.

In 30 days, the total amount of water consumed is 3960 liters. That is, an average of 132 liters per day is consumed in an area of 0.05 ha. This amount is for 30 seedlings. Also, the consumption for each seedling was 4.4 liters. This shows that the fuzzy control irrigation system created here completely compensates for the water that the soil and crop lose due to evapotranspiration.

4 Conclusion

In this research, first a garden with an area of 0.05 ha was constructed. Then irrigation and fertilizing equipment was installed. After determining the soil texture, a soil texture map was prepared and the specifications were given to the control system. In this research, the fuzzy control system was designed based on the data of soil moisture sensor and light sensor and soil texture. In this study, Mamdani method was chosen for fuzzy inference and membership functions defined for input and output variables of triangular and trapezoidal type. An irrigation and fertilizer system was designed for optimal management in maintaining moisture and fertilizer content. The design of the controller program is based on a fuzzy logic program with a rule base; therefore, the design of the control program is applicable to any type of environmental conditions and this control system can be used in various irrigation systems. This control program can also be modified and applied by calibrating the amount of moisture and fertilizer according to the needs of each garden.

After designing, the control system worked continuously for 30 working days. Actual measurement of parameters was performed in the garden. The evaluation results of the fuzzy control system showed that the system prevented the reduction of evapotranspiration at high temperatures during the day. It also selects the appropriate time by referring to the fuzzy rules database. One of the parameters of tree growth is soil moisture. Soil moisture varies during different days. This humidity is adjusted according to the water needs of the tree. Maximum, minimum and average soil moisture were 88.92%, 40.84% and 61.3%, respectively. By reducing the humidity of the control system, this humidity is compensated by opening the solenoid valves and continues until the moisture reaches saturation. In 30 days, the total amount of water consumed is 3960 liters. Also, the consumption for each seedling was 4.4 liters. This shows that the fuzzy control irrigation system created here completely compensates for the water that the soil and crop lose due to evapotranspiration. Experimental results showed that the establishment of fuzzy control approach has a great impact on irrigation sustainability through better management and planning.

References

Cardenas-Lailhacar, B., & Dukes, M. D. (2010). Precision of soil moisture sensor irrigation controllers under field conditions. Agricultural Water Management, 97(5), 666-672.

Eltawil, M. A., H. A. Alhashem, and A. O. Alghannam. 2021. Design of a solar PV powered variable frequency drive for a bubbler irrigation system in palm trees fields. *Process Safety and Environmental Protection*, 152: 140-153.

Jaiswal, S., and M. S. Ballal. 2020. Fuzzy inference based irrigation controller for agricultural demand side management. *Computers and Electronics in Agriculture*, 175: 105537.

Khafajeh, H., S. Minaee, M. Delavar, and A. Banakar. 2020. Design and construction of hydroponic greenhouse of cucumber equipped with fuzzy control system. *Journal of Researches in Mechanics of Agricultural Machinery*, 9(1): 69-80.

Krishnan, R. S., E. G. Julie, Y. H. Robinson, S. Raja, R. Kumar, P. H. Thong, and L. H. Son. 2020. Fuzzy logic based smart irrigation system using Internet of Things. *Journal of Cleaner Production*, 252: 119902.

López-Luque, R., J. Reca, and J. Martínez. 2015. Optimal design of a standalone direct pumping photovoltaic system for deficit irrigation of olive orchards. *Applied Energy*, 149: 13-23.

Mamdani, E. H., and S. Assilian. 1975. An experiment in linguistic synthesis with a fuzzy logic controller. *International Journal of Man-Machine Studies*, 7(1): 1-13.

Mousavi Seyedi, S. R., K. Laiy, and D. Kalantar. 2018. Design, construction and evaluation of an online control system for drop irrigation in greenhouse. *Iranian Journal of Irrigation & Drainage*, 12(3): 569-578.

Souza, G., P. T. Aquino, R. F. Maia, C. Kamienski, and J. P. Soininen. 2020. A fuzzy irrigation control system. In *2020 IEEE Global Humanitarian Technology Conference (GHTC)*, 9342960. Seattle, WA, USA, 29 October-01 November.

Winter, C., N. Soylemez, J. Trivedi, M. Pickens, C. Craig, and V. Vaidyanathan. 2006. Design of a sensor based smart sprinkler system. *International Journal of Modern Engineering*, 7(1): 777-780.

Zargan, J., and S. M. Waez-Mousavi. 2016. Water crisis in Iran: Its intensity, causes and confronting strategies. *Indian Journal of Science and Technology*, 9(44): 1-6.