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A Novel Approach for Crop Selection and Water Management using Mamdani's Fuzzy Inference & IOT

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Abstract— In the modern world, technology is always evolving to replace more human labour with artificial intelligence. Moreover, farmers are under constant pressure to irrigate their farms at regular intervals without even a rudimentary grasp of the rainfall pattern and soil humidity, since it is extremely difficult to cultivate any agricultural food in regions with irregular rainfall patterns and high mean temperatures.

This paper proposes a crop predictor and smart irrigation system using Mamdani's fuzzy inference and IoT. The system aims to optimize water usage and crop yield by considering various factors such as soil moisture, temperature, humidity, rainfall, crop type and season. The system consists of three modules: a crop predictor module that uses fuzzy logic to suggest the best crop for a given location and season, an IOT module that collects and transmits the environmental data from sensors to a cloud server, and a smart irrigation module that uses fuzzy logic to control the water flow to the crops based on the data and the crop predictor module. The system is implemented and tested on a NodeMCU and MATLAB platform and shows promising results in terms of water conservation and crop productivity.

Keywords- NodeMCU, Fuzzy Logic, smart irrigation, Crop predictor.

I. INTRODUCTION

Agriculture is one of the most important sectors of the economy, as it provides food and raw materials for various industries. Moreover, India is an agrarian type of economy, i.e., 55% of the labour force is involved in agriculture practices. Smart irrigation systems are an innovative and effective way to enhance water conservation and reduce the wastage of this precious commodity. The introduction of these systems has significantly transformed traditional irrigation methods by enabling customized application of water, based on factors such as weather conditions, soil moisture, and plant type.

Irrigation is a vital part of smart agriculture, as it involves applying water to the soil or plants artificially. Irrigation helps to keep the soil moist and rich in nutrients, avoid drought stress, and boost crop growth and resistance. However, irrigation also uses a lot of water, which is a rare and precious resource. The FAO estimates that irrigation takes up about 70% of the global freshwater withdrawals and 90% of the consumptive use. Furthermore, irrigation can lead to various issues such as waterlogging, salinization, erosion, nutrient leaching, and groundwater depletion. Therefore, we need to develop smart irrigation systems that can optimize water use and allocation based on crop needs and environmental conditions.

Another essential component of smart agriculture is selecting the best crop for each locality and season. This can amplify the efficacy of land utilization, diversify the origins of income, abate the hazards of pests and diseases, and conform to climate alteration. However, this is a complex problem that necessitates analysis of multiple factors such as the type of soil, climatic conditions of the region, the market demand for the crop, the characteristics of the crop, and the predilections of the farmer.

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Therefore, we need to design crop prediction systems that can address these issues correctly.

In this paper, we propose a crop predictor and IoT device for an automated irrigation system using Mamdani's fuzzy inference. The system aims to optimize water usage and crop yield by considering various factors such as soil moisture, temperature, humidity, rainfall, crop type and season. The system consists of three modules: a crop predictor module that uses fuzzy logic to suggest the best crop for a given location and season, an IOT module that collects and transmits the environmental data from sensors to a cloud server, and a smart irrigation module that uses fuzzy logic to control the water flow to the crops based on the data and the crop predictor module. The system is implemented and tested on a Raspberry Pi platform and shows promising results in terms of water conservation and crop productivity.

The rest of the paper is organized as follows: Section 2 reviews the related work on crop prediction and smart irrigation systems. Section 3 describes the proposed system architecture and design. Section 4 presents the implementation details and experimental results. Section 5 discusses the advantages and limitations of the proposed system. Section 6 concludes the paper and suggests future work.

II. RELATED WORK

Deka et al. [1] modelled water consumption estimation using the Mamdani fuzzy inference system. The models were developed by altering various structural scenarios, including membership function, rules criteria, fuzzy set, and defuzzification method. By exploring these different combinations, we aim to improve the accuracy and efficiency of water consumption estimation. Our findings have important implications for water resource management and conservation efforts.

A decision-making tool has been developed to aid in selecting the most appropriate crop for cultivation on a given agricultural land.[2][9] These tools have a good agreement rate with the results obtained from experts, making them a reliable and effective means of determining the most suitable crops for specific agricultural sites. By utilizing this tool, farmers and agricultural professionals can make informed decisions about crop selection, leading to more successful and sustainable agricultural practices.

Some research [10][15] shows different methods of maintaining optimal soil moisture levels using automated irrigation systems. Rawal et al. [10] proposed a system which utilizes a microcontroller, specifically the ATMEGA328P on the Arduino Uno platform, to monitor and regulate watering. Onyancha et al. [13] used drip irrigation along with the Thing Speak platform to automate irrigation for potted plants. By automating the watering process, this system ensures that the soil moisture content remains at the desired level without the need for manual intervention. This technology offers a reliable and efficient solution for maintaining healthy plants and crops.

III. SYSTEM MODEL

For working purposes, the proposed system has been separated into three pieces, each of which is dependent on the previous section. The first section comprises a Mamdani interference system that helps in predicting the most suitable crop for a specific region based on its local temperature range, soil moisture, soil type, and total rainfall. This system considers various factors to determine the optimal crop for the area. In the second portion, we are using our device to collect data from local climate conditions, analyse the data in real-time and make difficult decisions. The ESP8266 hosts a Mamdani fuzzy inference system that applies a set of linguistic rules to determine the optimal amount and frequency of irrigation for the crops. The fuzzy inference system also considers the crop type, growth stage, and weather forecast. The output of the fuzzy inference system is then sent to a water pump controller that regulates the water flow according to the irrigation schedule. Finally, in the last section daily data monitoring and determining the plant health is done using the Blynk IoT app. The web interface enables the user to monitor and adjust the irrigation parameters if needed.

A. System Hardware Design

The irrigation system utilizes sensors, including the DHT11, which is used for measuring humidity and temperature of the surroundings and LM 393 soil moisture sensors, to detect local environmental conditions. This data is then analyzed by the NodeMCU-based 32-bit LX106 RISC microprocessor, which is integrated into the NodeMCU ESP8266 board. The system uses this information to determine the optimal timing, duration, and amount of water required to nourish the crop plants.

By leveraging the power of the Blynk IoT app, the irrigation system can be remotely controlled and monitored, providing farmers with real-time insights into their crops' health and growth. This allows for more efficient and effective irrigation practices, ultimately leading to higher yields and healthier crops.

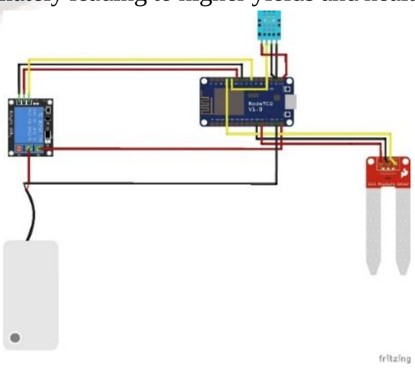

Figure 1: The architecture of a smart irrigation system that uses NodeMCU, a DHT11, and a soil moisture sensor. The device makes complex judgments using Mamdani's fuzzy inference to control the flow of water.

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B. Fuzzy Inference System Design for Crop predictor

Mamdani inference system is a type of fuzzy logic system that uses linguistic variables and rules to model complex systems and make decisions based on uncertain or imprecise inputs. Fuzzy logic is a branch of mathematics that deals with degrees of truth rather than binary logic. Linguistic variables are words or phrases that describe qualitative or quantitative aspects of a system, such as low, medium, high, cold, warm, hot, etc. Linguistic rules are conditional statements that relate linguistic variables using fuzzy operators such as and, or, not, etc. In our crop prediction model, we utilize four crisp inputs: rainfall, soil type, temperature, and soil water content. These factors are carefully analyzed to provide accurate and reliable predictions for crop yields.

The Mamdani fuzzy inference technique has been utilized to construct this system, which employs the centroid of a two-dimensional area instead of computing the weighted average/sum of input data points. This results in more efficient control of water flow. The fuzzy system has been designed using MATLAB, a powerful software tool for mathematical computation. The diagram depicts the architecture of the fuzzy inference system, giving a representation of its workings.

For smart irrigation systems, we utilize the Mamdani fuzzy inference to regulate the water flow through the motor. The system considers the soil moisture, humidity, and temperature as crisp inputs. As water loss is a slow process, these inputs are continuously sent into the microprocessor at 15-second intervals. This method also saves energy by putting the system to sleep. The sensitivity of the sensors can be adjusted to 500ms for more precise readings. To better comprehend the system's performance, we tabulated the crisp inputs and outputs, as well as their related membership functions.

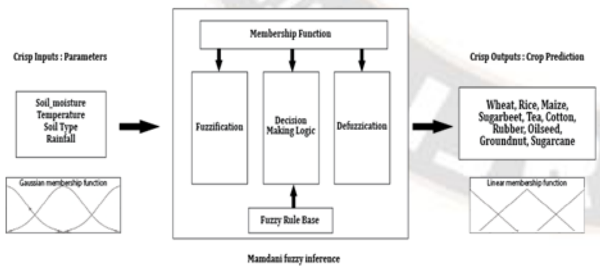

Figure 2: Mamdani's Fuzzy Logic System Architecture. Crisp input consists of soil moisture, temperature, soil type, and rainfall, which is processed as Mamdani's fuzzy inference and used to forecast crop productivity in a specific region based on crisp output.

The membership function of crisp inputs and outputs is shown in the table below.

TABLE I Membership Function Input and Output

FIS Variable	Membership Function	Membership function type	Membership function parameter
	Sandy	Gaussian	[0.3537 1]
$F_{soil\_moisture}$	Clayey	Gaussian	[0.3537 2]
(range: 1-3)	Loamy	Gaussian	[0.3537 3]
	10 to 15	Gaussian	[4.26 1.963 2.736 9.844]
	15 to 20	Gaussian	[2.156 17.2]
$F_{temperature}$	20 to 25	Gaussian	[2.266 22.15]
(range: 10-40)	25 to 30	Gaussian	[1.719 27.34]
	30 to 35	Gaussian	[1.422 31.62]
	35 to 40	Gaussian	[1.585 36.19]
	Scanty	Gaussian	[38.14 50]
$F_{rainfall}$	Small	Gaussian	[22.84 171.8]
(range: 50-400)	Moderate	Gaussian	[27.6 295]
	Heavy	Gaussian	[15.33 381.2]
F_{soil_type}	Alluvial	Gaussian	[0.3968 1.004]
(range: 1-3)	Black	Gaussian	[0.05746 2]
	Laterite	Gaussian	[0.2101 3]
	Wheat	Gaussian	[0.3708 1.675]
	Rice	Gaussian	[0.3744 2.573]
	Maize	Gaussian	[0.3631 3.341]
F_{crop}	Sugarcane	Gaussian	[0.2772 8.674]
	Tea	Gaussian	[0.4158 6.256]
	Cotton	Gaussian	[0.3717 4.301]
	Rubber	Gaussian	[0.3717 5.31]
	Oilseed	Gaussian	[0.3555 7.269]
	Groundnut	Gaussian	[0.3366 8.053]
	Sugarcane	Gaussian	[0.2799 9.407]

Our model utilizes the Mamdani fuzzy inference system to accurately predict crop yields in a specific region and help us to make informed decisions regarding watering the plants based on precise, crisp input data. By utilizing this advanced technology, we can optimize crop production and ensure the highest possible yields. This procedure is divided into three phases:

1. Fuzzification: The process involves converting precise inputs and outputs into linguistic terms using Gaussian, Triangular, and Constant membership functions. This is done to predict crisp output with greater accuracy and efficiency. By utilizing these advanced techniques, we can better understand and analyze complex data sets, leading to more informed decision-making and improved outcomes.

2. Applying Linguistic Rules to FIS Variables: To obtain a fuzzy output, the Min-Max rule is utilized to apply linguistic rules to FIS variables for both fuzzy ‘AND’ and ‘OR’ operations.

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This approach ensures that the linguistic rules are accurately and effectively incorporated into the FIS system. By implementing this methodology, the FIS system can produce more precise and reliable results.

3. The process of turning fuzzy output into numerical values using the centroid approach is known as defuzzification. This approach employs two output rules, each of which generates two values. The final fuzzy output is derived from these values. Defuzzification is the process of taking the fuzzy output and converting it into a concrete number. This is done using a method called the centroid method, which involves two rules that generate two values each. These values are then combined to give us the final output.

- z_i — The output level of the rule is either a constant or a linear function of the input values:

$$z_i = a_i x + b_i y + c_i$$

In this equation, x, and y are the values of input 1 and 2, respectively. Ai, bi, and ci are also constant coefficients. It is crucial to notice that the value of zi remains constant in a zero-order Mamdani system (a = b = 0).

- w_i — The rule firing intensity is determined by the rule antecedent.

$$w_i = AndMethod\big(F_1(x), F_2(y)\big)$$

The membership functions for inputs 1 and 2 are F1(...) and F2(...), respectively.

The final output can be calculated using centroid by utilizing the following formula, in which ($\mu(x_i)$) represents the membership value of point x_i in the universe of discourse:

$$xCentroid = \frac{\sum_i \mu(x_i) x_i}{\sum_i \mu(x_i)}$$

C. Monitoring Environment variables

We utilize Blynk app to monitor the various elements that cause water loss in plants and respond by irrigating the crop. This app is extensively used and works with the majority of PCs and mobile devices. When the system boots, the NodeMCU connects to the internet via the set Wi-Fi and then to the Blynk app via the authentication token supplied in the program.

We use the DHT 11 and LM 393 soil moisture sensors to measure local environmental factors such as temperature, humidity, and soil moisture. This information is supplied immediately to the app and shown in metered forms. Furthermore, the software gives us the option of manually watering the plant with a switch.

This innovation not only saves water but also minimizes the amount of energy required to pump water from the reservoir to the crop. As a result, the system chooses soil moisture and precipitation projection as fuzzy controller inputs and water flow from the water pump as output variables.

By utilizing the Blynk app and monitoring these variables, we can ensure that our crops receive the appropriate amount of water, leading to healthier plants and a more efficient use of resources.

D. Power Source

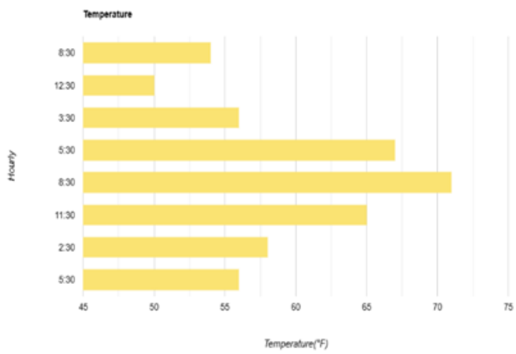
The overall device is autonomous in the sense it does not require an external power source for its operation since it uses a set of one set of lithium-ion batteries (5V) for its operation. Our model's energy demand is relatively low and hence it can be powered for almost a month with one charge. This could help in continuously monitoring data without needing any battery change or discharge time.

IV. RESULTS

By utilizing this innovative model, farmers can not only determine the most suitable crop for their fields but also conserve water and increase crop productivity. Our crop predictor results have shown that the best crops to grow in Pune, (Maharashtra) are rice and wheat.

Our study comprises monitoring 24-hour data for temperature, humidity, rainfall patterns, and soil moisture for begonia plants at Bharati Vidyapeeth in Pune, in addition to crop prediction. The motor is turned on twice a day, at 3:30 p.m. and 5:30 a.m., to irrigate the plant because these periods coincide with the greatest reduction in moisture levels. The ideal soil moisture level for begonia plants is between 60% and 80%, and water is adjusted appropriately.

Our device model offers a comprehensive solution for farmers and plant enthusiasts alike, providing valuable insights and data to optimize crop growth and plant health. With our cutting-edge technology, we aim to revolutionize the agricultural industry and promote sustainable practices for a better future.



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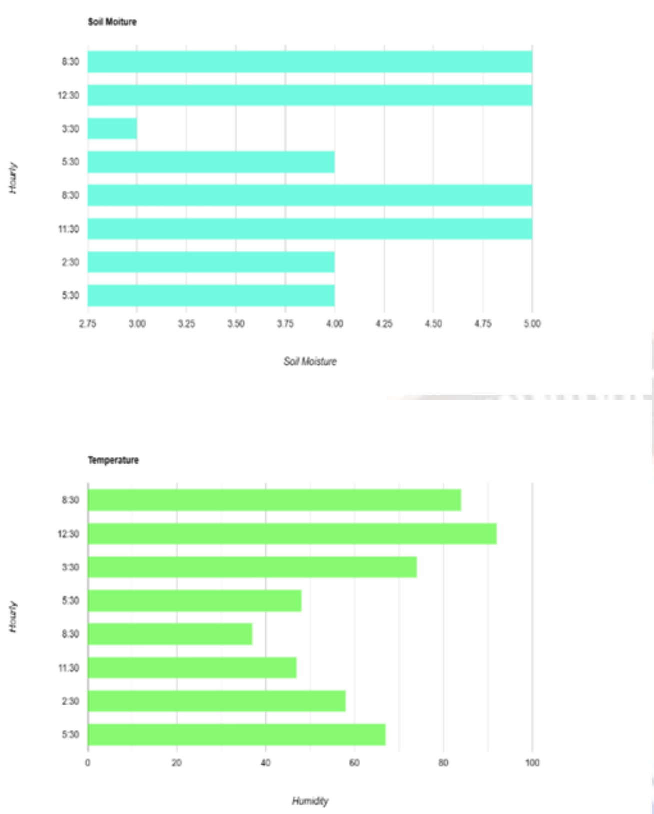

Figure 3: Graph representing temperature, humidity and soil moisture taken from our device for the begonia plant.

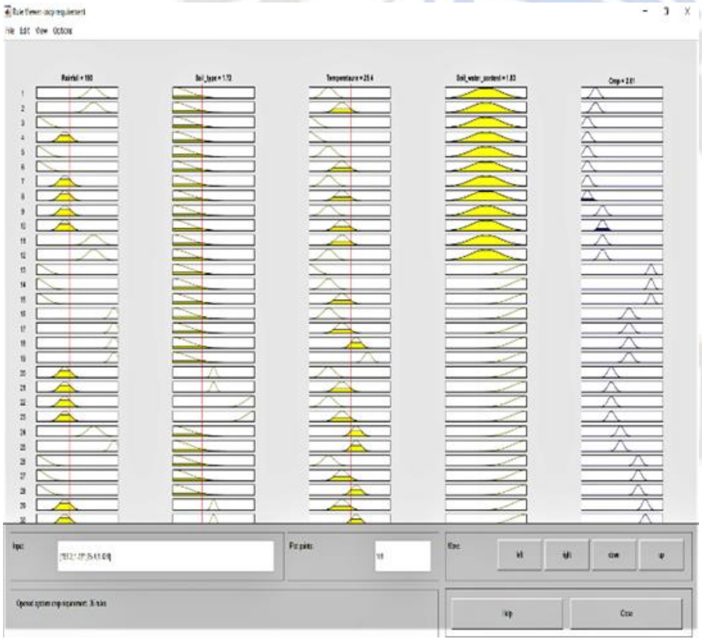

Figure 4: Dashboard for Crop prediction using Mamdani fuzzy inference. Crisp inputs taken are rainfall, soil type, temperature, and soil moisture to give the best crop suited for a particular area.

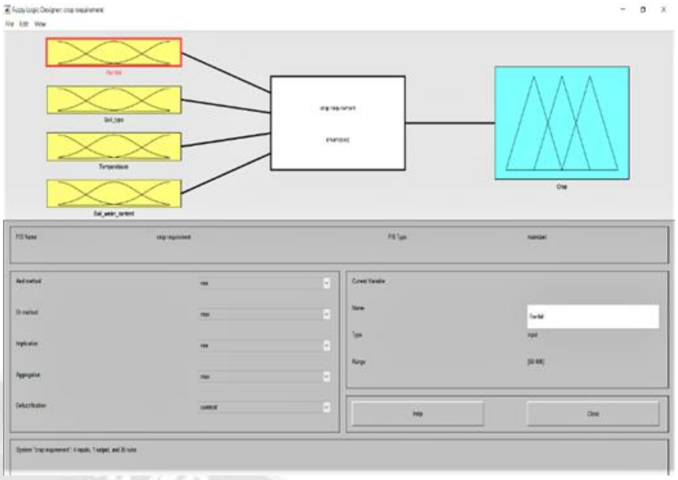

Figure 5: Different inputs and outputs of our Mamdani fuzzy logic inference

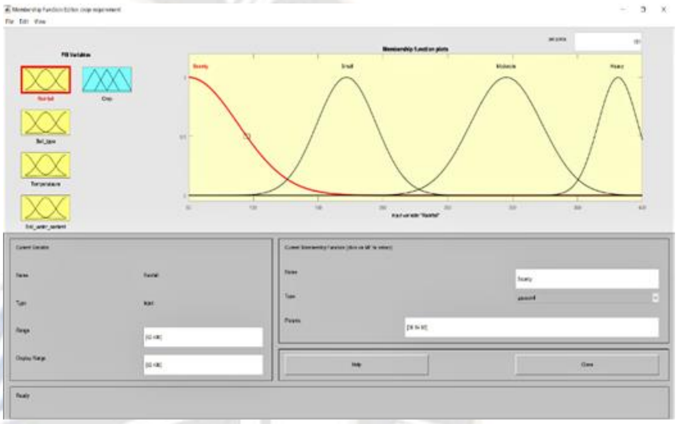

Figure 6: Memberships function for Crop predictor

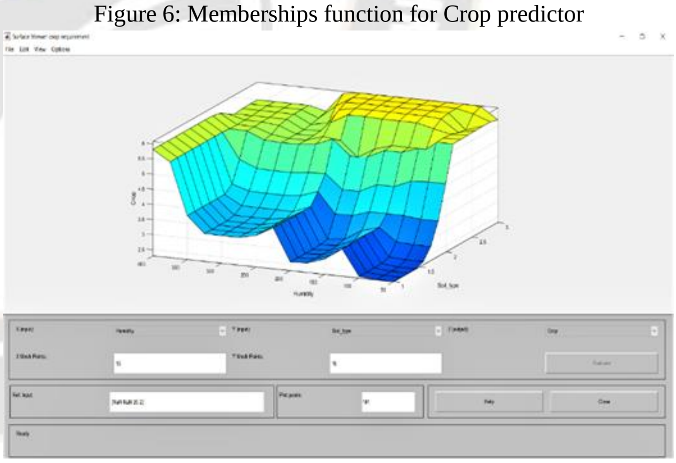

Figure 7: MATLAB simulator was used to generate the surface from fuzzy logic inference. The surface for fuzzy logic inference aids in making decisions based on numerous crisp inputs and producing a fuzzy result.

V. CONCLUSION

This study introduces Mamdani's fuzzy logic as a powerful tool for predicting crop yields and automating irrigation. The device is equipped with various sensors and crop predictors that enable farmers to accurately predict and automate the farming process. One of the most significant features of this technology is its ability to consider multiple sets of rules, which would not be possible to develop in real-life scenarios.

The smart device is small, inexpensive, and has low power consumption. It is also WI-FI enabled, removing the requirement for field installation. The only requirement for completely automated agricultural plant irrigation is a water source that which the device can pump water. One can easily link to the internet if they want to track plant development and local environmental facts. Mamdani's fuzzy logic technique, in general, is a game changer in the agriculture economy. It provides a low-cost, high-efficiency system for predicting agricultural yields and automating irrigation, resulting in greater production and water savings.

VI. FUTURE SCOPE

The use of fuzzy logic inference has the potential to transform agriculture by forecasting crop types and monitoring water requirements across wide fields with a single irrigation system. Multiple devices can function as data nodes, gathering and combining data into a single packet for field analysis. This technology can also determine the ideal plant for a certain area and moisture level, allowing farmers, gardeners, and hobbyists to produce plants without getting their hands dirty.

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