Fuzzy Internet of Things-based water irrigation system

R. B. Dhumale[1*], N. R. Dhumale[2], Amit Umbrajkaar[3], S. S. Nikam[1], P. B. Mane[1], A. N. Sarwade[2]

(1. AISSMS Institute of Information Technology, Pune, Maharashtra, India411001;
2. Sinhgad College of Engineering, Pune, Maharashtra, India-411041;
3. Dr. D. Y. Patil, Institute of Engineering, Management & Research, Akurdi, Pune, Maharashtra, India; 411035)

Abstract: The primary resource for cultivation with little storage is water. 64% of the land that is available is used for farming, which requires close to 85% of the total water storage's clean water. The development of crops and the condition of the soil are both enhanced by proper watering. The farmer must use intelligence to make realistic judgments based on the soil's state and the water resources that are available in order to prevent water waste and achieve full water utilization. This presents a challenging opportunity to apply Artificial Intelligence (AI) theory and concepts to the process of water irrigation. In this work, an intelligent strategy for agricultural irrigation with water is suggested. The Internet of Things (IoT) based Smart Fuzzy Water Irrigation System (FWIS) uses two different types of nodes: the Master Node and Sensor Nodes. Manual Mode (MM) and Automatic Mode (AM) are the two operating modes for FWIS. The IoT is used in MM to construct a web server and control the water distribution. The purpose of wireless communication is to transmit instructions that remotely regulate whether the water pump is turned on or off based on the values of soil parameters. Fuzzy Logic (FL) is utilized in AM to determine the water supply pumps' turn-on time ($TURN\_ON\_{Time}$) based on sensors that read soil characteristics such as temperature and moisture. A database is created that contains ideal soil parameter values for four types of crops: cotton, wheat, sugarcane, and rice. The technology is checked on-site, and 95.1% correctness is recorded for controlling water flow in relation to real-time soil data to prevent water waste. When compared to the traditional irrigation approach, FWIS is able to use less water while still producing the same amount of crop.

Keywords: irrigation system, fuzzy logic, Internet of Things, soil parameters.

Citation: Dhumale, R. B., N. R. Dhumale, A. Umbrajkaar, S. S. Nikam, P. B. Mane, and A. N. Sarwade. 2023. Fuzzy Internet of Things-based water irrigation system. Agricultural Engineering International: CIGR Journal, 25(2): 1-10.

1 Introduction

Humans require farming to meet their basic requirements. Farming around 85% of the fresh water and 64% of the land that is now accessible (Wang, 2022) . These numbers are consistently rising year over year as a result of globalization and population growth. Therefore, it is a challenge for every nation to build systems that would cut down on water waste and guarantee maximum water usage. A definition of irrigation is the action of supplying water to the soil (Zimmermann and Neu, 2022).

Water demand differ from one kind of soil to the subsequent and rely on a number of factors, including pH, temperature, moisture, and the variety of crops (Liu et al., 2021). Smart agriculture is a manufacturing agricultural approach that integrates intelligence. Its main goal is to maximize desired consequences with maximizing long-term, site-specific, total farm efficiency, productivity, and profitability. Sensing technologies as well as precise methods are required to enable automatic soil parameter acquisition, sensor connectivity, plus complete soil irrigation achieving maximum benefits to society (da Silva et al., 2020).

Received date: 2018-08-27 **Accepted date:** 2023-02-28

***Corresponding author: R. B. Dhumale**, Associate Professor rofessor, lecturer), *AISSMS Institute of Information Technology, Pune, Maharashtra, India*411001. Email:rbd.scoe@gmail.com.

Using the right irrigation technique is essential in the world of farming. The automated of irrigation facilities has the ability to maximize water effectiveness while maintaining optimal levels of soil moisture sensing as well as other crop factors (Phasinam et al., 2022). In a conventional irrigation system, the farmer must maintain an eye on the irrigation schedule, that varies based on the crops and perhaps other factors like the kind of soil. The farmers of today irrigate the field manually at periodic times using irrigation methods that are controlled by hand (Abdelmoamen Ahmed et al., 2021). Perhaps more water is used in this procedure, or the water arrives later than expected, causing the crop to dry out. The use of energy and water in farming in emerging economies should be maximized (Naikoo et al., 2022). The applications of water to fields unevenly and with excessive work have historically been the results of irrigation (Mou et al., 2020). Therefore, a sensing-based autonomous irrigation technology is essential to save on labor costs and provide consistent water distribution over the area.

The foundation of the entire economy is farming. Only fresh water is needed in farming for healthy crop growth. The need for fresh water will increase in the next years because of the population's well-known rapid growth (Raghuvanshi et al., 2022). As a result, there is a need for an Efficient Irrigation System (EIS) for a number of reasons, including variable weather circumstances and rising costs. The Intelligent Irrigation System (IIS) has the ability to fully utilize the available water resources and is extremely cost-effective (Dr. Nagendra Tripathi., 2021). This type of method allows for the reduction of water use while still providing the crops with the necessary quantity of water.

Apple trees that are drip-irrigated now have automatic irrigation that improves manufacturing, concentrates manufacturing costs, lowers power requirements for pumping, and enhances. The implementation of a Supervisory Control And Data Acquisition (SCADA) system's diversity of hardware and software characteristics in addition to the suitability of the irrigation scheduling algorithms for maintaining well-watered trees can be seen here (Osroosh et al. 2016). An accurate mechanistic explanation of the associated surface characterization happening throughout fertilizer application and trench irrigation can be provided by a mathematical model. One-dimensional descriptions of water flow and solute transport in the surface domain are combined in the modeling framework using the methodologies that have been suggested. The water and solute supply in the soil next to the furrow can be explained mechanically by this (Brunetti, Papagrigoriou, and Stumpp 2020). The fuzzy-based energy-efficient sensor network protocol for precision farming has already been presented applying the Fuzzy Logic (FL) method to select the best cluster head among other sensor nodes in a rigorous one which lowers the energy expenditure of nodes in each data transmission period (Varmaghani et al. 2021).

A node is made up of a variety of sensors in the proposed Fuzzy Water Irrigation System (FWIS) using the IoT that senses the parameters and transmits them to the monitoring system. The benefits of Wireless Sensor Network (WSN) system, like reliable and secure data transmission, a simple and adjustable network, affordable equipment, long battery life, etc. have led to a wide range of applications for this advanced technology in numerous fields (Anitha, Jayanthi and Chandrasekaran., 2021). One of the key approaches to increase water efficiency is to install helps in better irrigation for crops. Applications that involve actual data monitoring have shown the value of WSN (Mekonnen et al. 2020). Due to their capacity to provide actual information collected by spatially distributed sensors, wireless sensor networks potentially play a significant role in maximizing the production and usage of the available resources. Several industries, including industrial control systems, artificial intelligence, medicine, including farming, have adopted FL. Computing using real-world qualities and linguistics is made possible by FL (Mah, Skalna, and Muzam 2022). In a monitoring system, choosing a modeling approach is an important design step (Jiang et al. 2021), but in FL, the controller completes this task exactly and accurately. The FWIS's contributions are listed below:

This paper suggests a straightforward and user-friendly installation procedure.

The FWIS assists users in providing crops with the proper amount of water, thereby reducing water waste.

FWIS carries out irrigation in accordance with agricultural needs. Consequently, the soil is less likely to become worthless or saturated.

The user won't have to shell out money for labor. The irrigation is carried out by the device once it has analyzed the parameters.

2 Materials and methods

Multiple Slave Node (SN) and just a Master Node (MN) make up the FWIS using the IoT. Using numerous sensors and also the Graphical User Interface (GUI) depicted in Figure 1, so every node could be managed by an operator. As illustrated in Figure 2, each SN's corresponding parameters are sensed using a temperature sensor, moisture sensor, and pH sensor. MN and SN exchange messages, as well as MN also talks to the users. According to Figure 3, each MN is made up of sensors and a Global System for Mobile (GSM) module for control scheme.

The sensors' output is fed to the Analogue to Digital Converter (ADC). The Fuzzy Inference System (FIS) uses the temperature and moisture sensor output. The Pulse Width Modulation (PWM) uses the output from the FIS to determine the $TURN\_ON\_{Time}$ for the pump. Relay is used to operate the pump depending on the PWM's findings. The FWIS has two different modes, including: Manual Mode (MM) andAutomatic Mode (AM).

In MM, FWIS is done by hand via a web server. To physically manage water flow, this option has been included. The user is the main focus of the web server's development. Using Global System for Mobile (GSM) communication, the web server is linked to the master node, which serves as a coordinating node. The user can turn on and off the water supply via a web server. The user can check the parameters sensed by the pH, moisture, and temperature sensors in this mode. By monitoring such parameters online, the user can send commands. The process that follows after a specific request is delivered via a web server occurs at the pump, and the command that the node accepted is displayed on the display. The wireless connectivity between the MN and the SN can be confirmed by checking the display. Because of the layout of the two kinds of nodes, SNs and MNs, controls are provided for the two pumps individually instead of simultaneously both pumps to switch on and off. It is possible to reduce the amount of water that is supplied unnecessarily thanks to this automated deployment.

The Artificial Intelligence (AI) in the FIS is intended to be included into AM. In reaction to the measured soil parameters, the latest automatic irrigation technologies provide water. However, such a technology does not have a control for changing the pump's speed in response to certain common configurations of sensed values for soil characteristics. Technologies like this present challenges in decision-making for these kinds of common pairings. Therefore, the FIS is included in this mode to prevent such conflicting decisions as well as to manage the pump's speed.

A data set has been developed for four different crops. The user must make a decision based on the crop that is now growing in the field. For crops utilized in decision-making, ideal ranges of the soil parameters are maintained in the data. The inputs to the FIS are moisture and temperature readings. The rule base necessary for such $TURN\_ON\_{Time}$ of a water pump operation is stored in FIS. By taking the ideal values of the system into account, membership functions are created for both moisture and temperature. The rule basis developed for the pump's judgments is stored by FIS. The $TURN\_ON\_{Time}$ of the pump is determined by the measured values of the soil parameters and the pertinent FIS rule. In order to adjust the pump's speed with all conceivable possible combinations, including crop as well as sensor data, the FIS is used.

The FWIS is made up of similar nodes spaced apart by a specific amount. The separation between two nodes is determined by the kind of soil. The sensors will typically have the same amount of water, soil temperature, pH level, as well as moisture content if they are situated roughly five feet from one another (Sinha and Dhanalakshmi., 2022). Therefore, the intended nodes should be positioned so that they will show various values and be able to be observed.

One moisture sensor, one soil temperature sensor, one pH sensor, one level detector, and one Zig-Bee transceiver are located in each node. The FIS uses the output of the sensor to determine the $TURN\_ON_{Time}$ of the pump for all different permutations of the detected temperature as well as moisture values. The temperature and moisture of the soil are sensed. The pulse generator receives the FIS output in order to produce the pulse. Pulse Width Modulation (PWM) uses created pulses as an input. The pump is rotated based on the $TURN\_ON_{Time}$ measured by the PWM.

3 FIS Implementation

The fuzzy system for decision-making is used in AM to adjust the motor's speed in accordance with the specified perfect combination of soil parameters. Three steps make up the FIS. The input and output membership functions must first be created in accordance with the specifications. The FIS's rule base must be created next. The final level is Defuzzification. For two inputs, temperature as well as moisture, individually, three membership functions are developed in the design phase. Table 1 provides the temperature and moisture values for four distinct crops that were utilized in the development of the membership function.

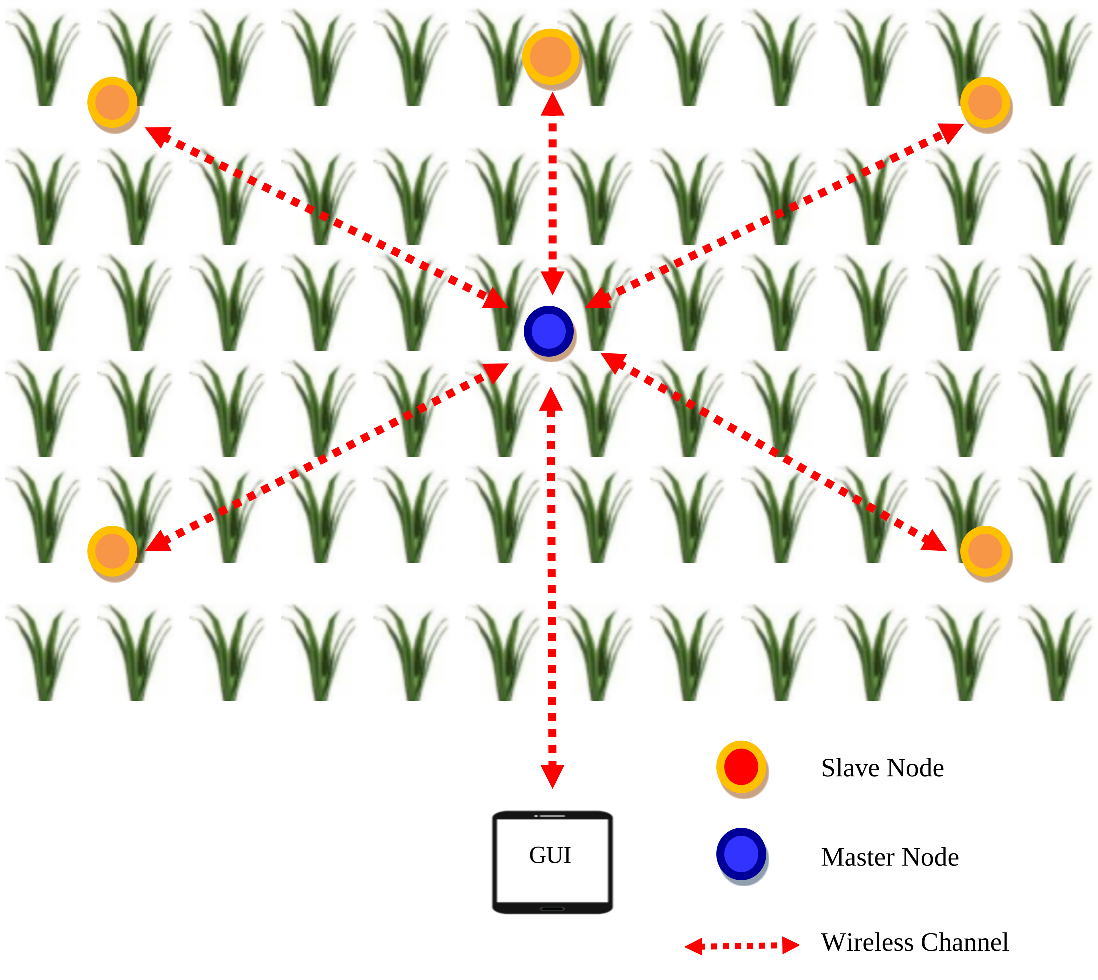

Figure 1 Wireless Sensor Network deployed for Fuzzy Water Irrigation System.

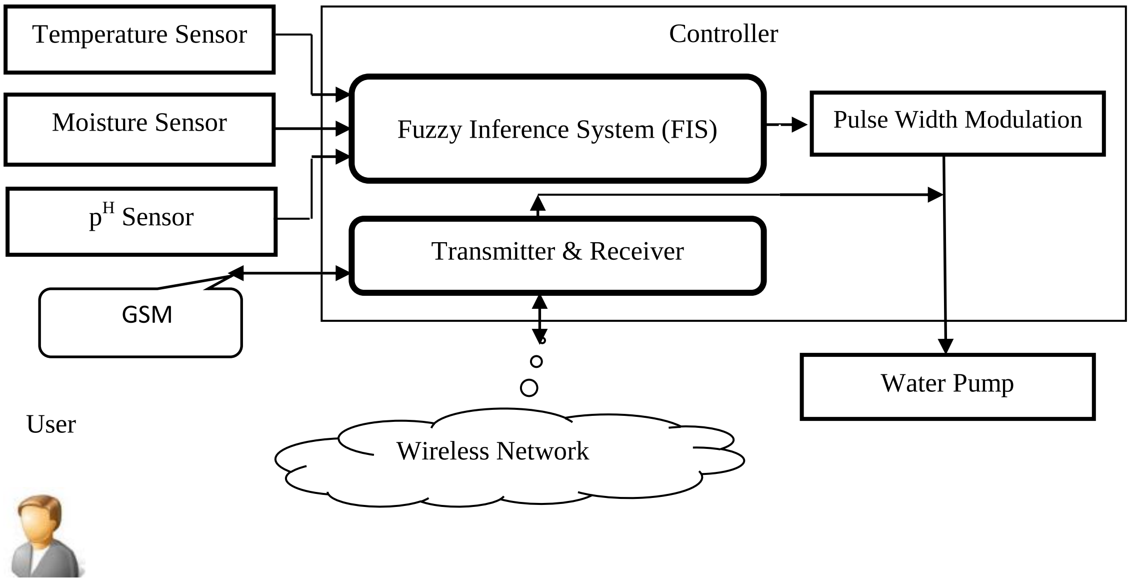

Figure 2 Architecture of Master Node

The membership's functions of temperature range are 0℃ to 40℃. Based on the values from Table 1, three trapezoidal membership functions—designated Temp_Small, Temp_Average, and Temp_Major were created. The parameters utilized for the three temperature membership functions Temp_Small, Temp_Average, and Temp_Major are, respectively, [0 0 11 18], [11 18 23 31], and [23 31 51 51]. The designed membership functions for the wheat crop's temperature are depicted in Figure 3.

The moisture membership function has a range of 0 to 100%. The creation of three membership functions with the names Mois_Small, Mois_Average, and Mois_Major is required for the moisture membership function, just as it is for the temperature membership function. Figure 4 depicts the membership functions that were created for the wheat crop's wetness. The three membership functions Mois_Small, Mois_Average, and Mois_Major of moisture have the following parameters: [0 0 45 55], [45 55 65 79], and [65 79 100 100], respectively, in the range of 0-100%.

As per Table 2, the water pump's $TURN\_ON\_{Time}$ is chosen. Five output triangle membership functions—Small, Small-Average, Average, Average_Major, and Major—have been developed. Each of these output membership functions' $TURN\_ON\_{Time}$ values is. The decision for all available possible combinations is determined using the rule base that makes up the FIS. Nine rules have been established for the developed framework, and they are listed in Table 3.

Table 1 Membership function soil parameters (Moshinsky., 1959)

Crop	Wheat	Sugarcane	Rice	Cotton
Moisture (%)	49-69	70-89	64-84	39-59
Temperature (℃)	16-23	14-29	23-29	16-29

Table 2 Triangular MFs for $TURN\_ON\_{Time}$

Output	On time of Pump (ms)
Small	[0,0,19]
Small-Average	[0, 19,49]
Average	[19,49,69]
Average_Major	[49,69, 100]
Major	[69, 100, 100]

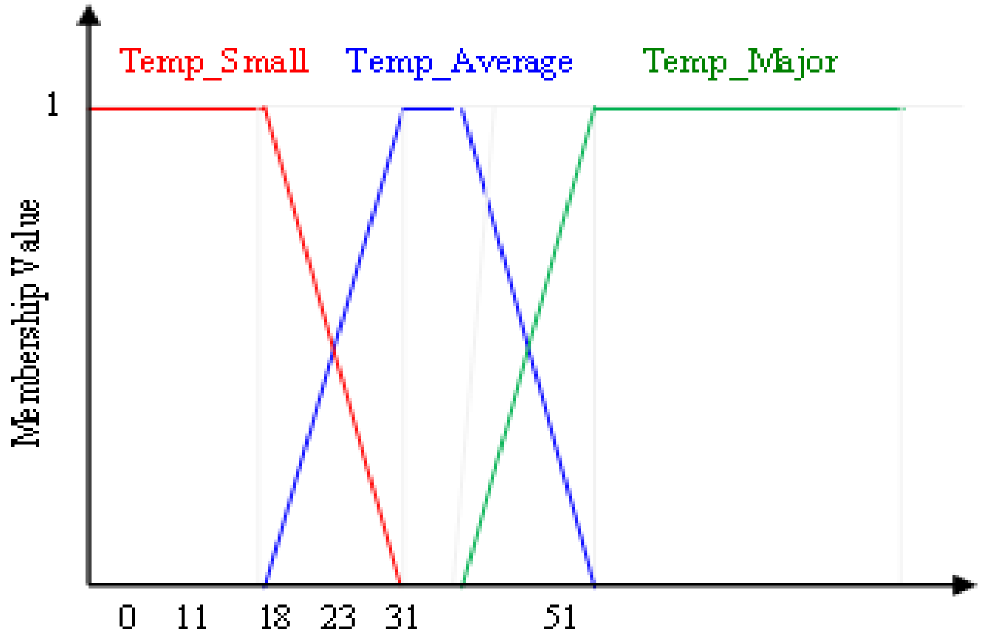

Figure 3 Temperature MFs for wheat crop

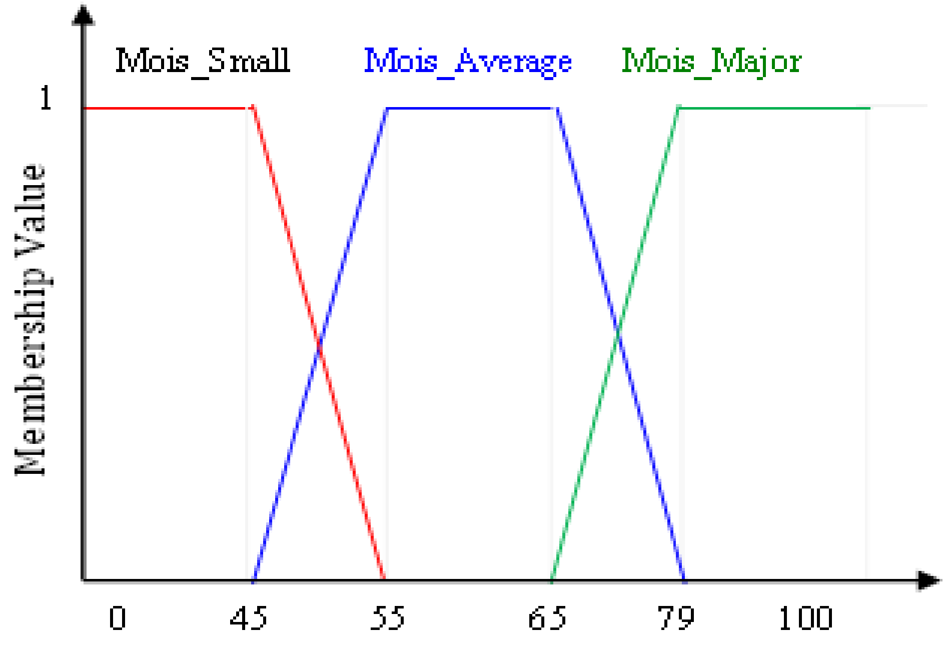

Figure 4 Moisture MFs for wheat crop

Table 3 Fuzzy rule base

Temp	Moisture	TURN_ON_Time (sec)
Small	Small	Small-Average
Small	Average	Small-Average
Small	Major	Average
Average	Small	Small-Average
Average	Average	Small
Average	Major	Average_Major
Major	Small	Average
Major	Average	Average_Major
Major	Major	Major

3 Results and discussion

The created software for the FWIS has been carried out with various input conditions and has shown high accuracy with good potential for expansion in the near future. For comparative investigations, the findings from the FWIS and predicted numerical approaches are provided.

Possible variations of temperature and moisture values can be taken into account when evaluating the rules stated in the rule base of the FIS. TURN_ON_$_{\text{Time}}$ is 40 ms away from the FIS's output whenever the temperature is 5℃ and the moisture content is 20%, which indicates that these inputs are located within the low range. It means that as there is little moisture present, not much water needs to be supplied. When the temperature and moisture are in the medium range, the FIS's result TURN_ON_$_{\text{Time}}$ is 00 milliseconds from its output. It means that the field has the appropriate degree of water and temperature when the temperature and moisture are in the middle range; therefore it is not necessary to provide the water. The best condition for temperature and moisture values is the middle range of the membership function. Therefore, it is not necessary to provide water.

The output of the FIS can also be confirmed by obtaining measured values of the temperature and moisture using the pump's TURN_ON_$_{\text{Time}}$ signal. The TURN_ON_$_{\text{Time}}$ of pumps varies with a slight improvement or reduction including both soil parameters. The database contains the ideal range of both characteristics for four distinct crops. The FIS operates for the crop of selection as well as provides the water pump TURN_ON_$_{\text{Time}}$ in accordance with that. Different configurations of inputs are tested utilizing developed FIS, and the TURN_ON_$_{\text{Time}}$ of the pump from the FIS is 60 ms when the input temperature is Major and the moisture level is small.

It is also examined how the FIS performs when the temperature is Major and the moisture level falls within the Average. It demonstrates that TURN_ON_$_{\text{Tim}}$ is 69 ms away from the FIS output under this circumstance. It means that when the temperature is excessive, it needs to lower to put it into the perfect range, whereas when the moisture level is in the middle, it needs to keep just at middle to meet the ideal situation. Water should therefore be available in sufficient quantities to satisfy the required temperature and moisture levels. As a result, in this scenario, the TURN_ON_$_{\text{Tim}}$ for supplying the water is 69 ms.

In Table 4, the real TURN_ON_$_{\text{Time}}$ as well as the TURN_ON_$_{\text{Time}}$ derived from the fuzzy system are compared. Possible variations of humidity and temperature are taken into account. The real TURN_ON_$_{\text{Time}}$ and the TURN_ON_$_{\text{Time}}$ derived via the fuzzy system are compared for varying configurations. Every combination of temperature and moisture results in a calculation of the error in the output of these two situations. Using Equation 1, the average error for the FWIS is calculated as a percentage, as well as an inaccuracy of 4.9% is found.

$$Error = \frac{\text{TURN}_{\text{ON}_{\text{Time}}}(Actual\ output) - \text{TURN}_{\text{ON}_{\text{Time}}}(Fuzzy\ Output)}{\text{TURN}_{\text{ON}_{\text{Time}}}(Actual\ output)} \quad (1)$$

Each of these four crops is examined using various temperature as well as moisture variations, as depicted in Figure 5. The T ON of the water pumps will be lowest, which indicates that the pumps will be operating in the off state, is if input values fall within the optimal range, per Tables 1 and 2. However, the T ON of the water pumps alters in accordance with the FIS rule basis when the input values start to rise or fall. The web server is built for manual operation. Laptops, smartphones, and other devices can be used to visit this website.

In MM, the role is to manage the water supply by utilizing the web server. The Pump-1 to the Pump-n can be turned ON or OFF by the web server using one of two options. The above mode was mostly created utilizing a Raspberry Pi and the "iotservers.in" domain. Designed Web page for the Manual control of water supply accessed by Smartphone is shown in Figure 6. The Raspberry Pi and the sensor nodes communicate wirelessly using ZigBee technology. It permits dissemination of communication within the other two modules and is configurable.

The display serves the purpose of test wireless communication; it shows the commands sent by the web server, enabling wireless communication's scale operations to be confirmed. Figure 7 depicts the system's actual visual. Calculating the required quantity of water numerically and utilizing a proposed FL controller are nearly equivalent. When using the FIS, the results that have previously been seen demonstrate how this method uses less water for a similar yield than the standard automatic irrigation system.

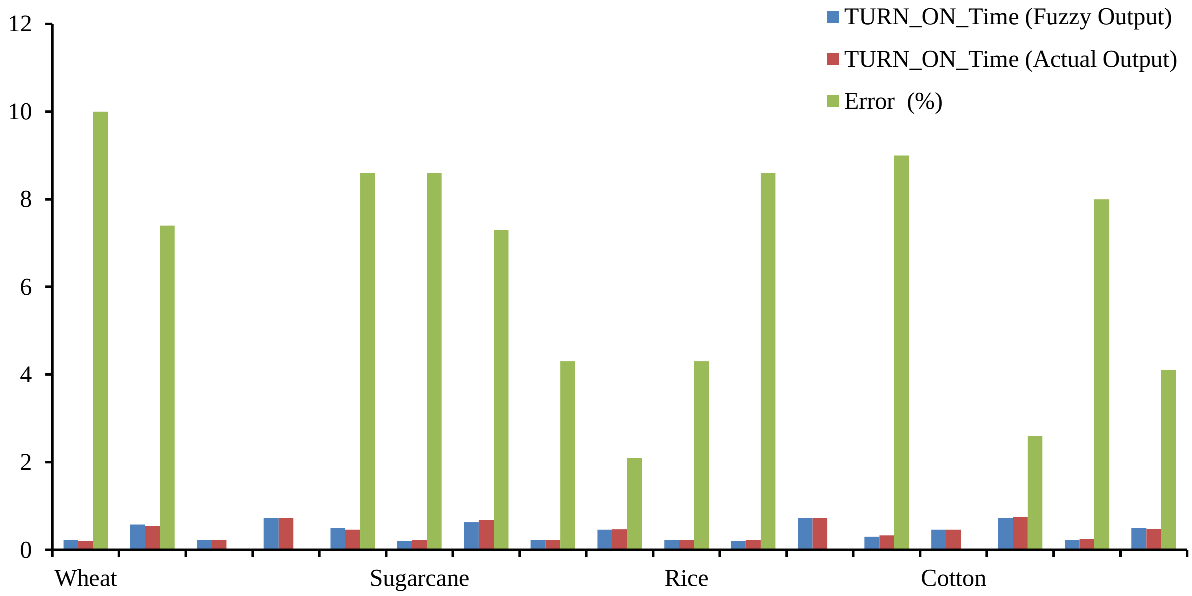

Figure 5 Comparative study of the Actual $TURN\_ON_{\_Time}$ and the $TURN\_ON_{\_Time}$ obtained from the Fuzzy System

Figure 6 Designed Web page for the Manual control of water supply accessed by Smartphone

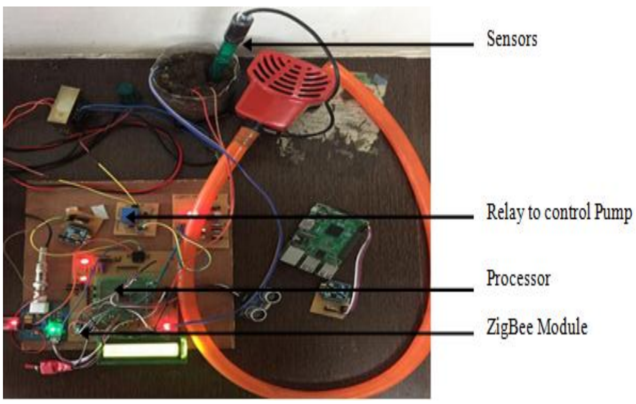

Figure 7 Internet of Things-enabled fuzzy water irrigation system in testing

The one time investment of proposed module is approximately a hectare is USD 700 considering one cluster with a GSM and 20 modules per 1 hectare. While the labor cost is not one time investment.

5 Conclusions

Mostly in world of farming, irrigated farming regulation represents the most crucial issue. Worldwide water shortages are highlighting the requirement for systems that not only regulate agricultural irrigation and moreover offer an intelligent technique to always deliver water to such locations where it is needed and in the required amount. Measuring soil moisture, temperature, and pH can help you use water more effectively. It can also help you get a better profit. This work highlights the possible benefits of using FL in intelligent irrigation systems. The outcomes give a precise understanding of the water output for the suggested agricultural field. Two modes are designed for the FWIS. Three separate sensors are employed to measure the soil properties in automatic mode. The on time of the water pump is determined by comparing the current and desired values of the soil characteristics. PWM is used to adjust the speed of the water delivery. The water system can be turned on or off using instructions in Manual mode utilizing intended web server. The FWIS's evaluation and execution, as well as a few common inputs, are confirmed. For the most effective irrigation of the field, the quantity of water provided to the crop is chosen. Consequently, it is possible to keep the land fertile. To prevent water wastage, water is only provided when it is required, and crops are given the necessary amount of water. As a result, the FWIS system offers benefits like efficient irrigation, lower labor costs, and water and electricity conservation.

References

Abdelmoamen Ahmed, Ahmed, Suhib Al Omari, Ripendra Awal, Ali Fares, and Mohamed Chouikha. 2021. "A Distributed System for Supporting Smart Irrigation Using Internet of Things Technology." *Engineering Reports* 3 (7): 1–13. https://doi.org/10.1002/eng2.12352.

Anitha, S., P. Jayanthi, and V. Chandrasekaran. 2021. "An Intelligent Based Healthcare Security Monitoring Schemes for Detection of Node Replication Attack in Wireless Sensor Networks." *Measurement: Journal of the International Measurement Confederation* 167 (May 2020):108272. https://doi.org/10.1016/j.measurement.2020.108272.

Brunetti, Giuseppe, Ioannis Aristotelis Papagrigoriou, and Christine Stumpp. 2020. "Disentangling Model Complexity in Green Roof Hydrological Analysis: A Bayesian Perspective." *Water Research* 182: 115973. https://doi.org/10.1016/j.watres.2020.115973.

Dr. Nagendra Tripathi, Prabhas Kumar Gupta,. 2021. "Regulating Water Supply and Water Cutbacks in Agriculture Using Iot Based Smart Irrigation System." *Information Technology in Industry* 9 (1): 629–33. https://doi.org/10.17762/itii.v9i1.180.

Jiang, Yuchen, Shen Yin, Jingwei Dong, and Okyay Kaynak. 2021. "A Review on Soft Sensors for Monitoring, Control, and Optimization of Industrial Processes." *IEEE Sensors Journal* 21 (11): 12868–81. https://doi.org/10.1109/JSEN.2020.3033153.

Liu, Xuezhi, Zhenhua Wei, Yingying Ma, Jie Liu, and Fulai Liu. 2021. "Effects of Biochar Amendment and Reduced Irrigation on Growth, Physiology, Water-Use Efficiency and Nutrients Uptake of Tobacco (Nicotiana Tabacum L.) on Two Different Soil Types." *Science of the Total Environment* 770: 144769. https://doi.org/10.1016/j.scitotenv.2020.144769.

Mah, Pascal Muam, Iwona Skalna, and John Muzam. 2022. "Natural Language Processing and Artificial Intelligence for Enterprise Management in the Era of Industry 4.0." *Applied Sciences (Switzerland)* 12 (18). https://doi.org/10.3390/app12189207.

Mekonnen, Yemeserach, Srikanth Namuduri, Lamar Burton, Arif Sarwat, and Shekhar Bhansali. 2020. "Review—Machine Learning Techniques in Wireless Sensor Network Based Precision Agriculture." *Journal of The Electrochemical Society* 167 (3): 037522. https://doi.org/10.1149/2.0222003jes.

Moshinsky, Marcos. 1959. "Not to Be Reproduced by Photoprint or Microfilm without Written Permission from the Publisher Transformation brackets for harmonic oscillator functions." *Nuclear Physics* 13: 104–16.

Mou, Haiyan, Wenqing Chen, Zhe Xue, Yunzhen Li, Tianqi Ao, and Hui Sun. 2020. "Effect of Irrigation Water System's Distribution on Rice Cadmium Accumulation in Large Mild Cadmium Contaminated Paddy Field Areas of Southwest China." *Science of the Total Environment* 746: 141248. https://doi.org/10.1016/j.scitotenv.2020.141248.

Naikoo, Nasir Bashir, Raihana Kanth, Mohammad Anwar Bhat, and Aijaz Nazir. 2022. "Vertical Farming: The Future of Agriculture: A Review Crop Production View Project Crop Productiom View Project" 11 (2): 1175–95. http://www.thepharmajournal.com.

Osroosh, Yasin, Robert Troy Peters, Colin S. Campbell, and Qin Zhang. 2016. "Comparison of Irrigation Automation Algorithms for Drip-Irrigated Apple Trees." *Computers and Electronics in Agriculture* 128: 87–99. https://doi.org/10.1016/j.compag.2016.08.013.

Phasinam, Khongdet, Thanwamas Kassanuk, Priyanka P. Shinde, Chetan M. Thakar, Dilip Kumar Sharma, Md Khaja Mohiddin, and Abdul Wahab Rahmani. 2022. "Application of IoT and Cloud Computing in Automation of Agriculture Irrigation." *Journal of Food Quality* 2022. https://doi.org/10.1155/2022/8285969.

Raghuvanshi, Abhishek, Umesh Kumar Singh, Guna Sekha Sajja, Harikumar Pallathadka, Evans Asenso, Mustafa Kamal, Abha Singh, and Khongdet Phasinam. 2022. "Intrusion Detection Using Machine Learning for Risk Mitigation in IoT-Enabled Smart Irrigation in Smart Farming." *Journal of Food Quality* 2022. https://doi.org/10.1155/2022/3955514.

Silva, Alexsandro Oliveira da, Bruna Aires da Silva, Claudinei Fonseca Souza, Benito Moreira de Azevedo, Luís Henrique Bassoi, Denise Vieira Vasconcelos, Guilherme Vieira do Bonfim, Juan Manzano Juarez, Adão Felipe dos, and Franciele Morlin Carneiro. 2020. "Irrigation in the Age of Agriculture 4.0: Management, Monitoring and Precision." *Revista Ciencia Agronomica* 51 (5): 1–17. https://doi.org/10.5935/1806-6690.20200090.

Sinha, Bam Bahadur, and R. Dhanalakshmi. 2022. "Recent Advancements and Challenges of Internet of Things in Smart Agriculture: A Survey." *Future Generation Computer Systems* 126: 169–84. https://doi.org/10.1016/j.future.2021.08.006.

Varmaghani, Abbas, Ali Matin Nazar, Mohsen Ahmadi, Abbas Sharifi, Saeid Jafarzadeh Ghoushchi, and Yaghoub Pourasad. 2021. "DMTC: Optimize Energy Consumption in Dynamic Wireless Sensor Network Based on Fog Computing and Fuzzy Multiple Attribute Decision-Making." *Wireless Communications and Mobile Computing* 2021. https://doi.org/10.1155/2021/9953416.

Wang, Xiukang. 2022. "Managing Land Carrying Capacity: Key to Achieving Sustainable Production Systems for Food Security." *Land* 11 (4). https://doi.org/10.3390/land11040484.

Zimmermann, Martin, and Felix Neu. 2022. "Social–Ecological Impact Assessment and Success Factors of a Water Reuse System for Irrigation Purposes in Central Northern Namibia." *Water (Switzerland)* 14 (15). https://doi.org/10.3390/w14152381.