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An Urban Based Smart IOT Farming System

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Abstract. Recent technological developments have led to the emergence of new trends in agriculture to ensure increased production through sustainable utilization of resources. One of the new trends is Precision Agriculture (PA). However, like many new emerging trends, PA is faced with a number of uncertainties and hurdles. One of the major issues and hurdles in precision agriculture is the uncertainty of optimum application of resources necessary for optimum yield production while minimizing resource wastage for sustainable agricultural production. Therefore, this paper presents a fuzzy based Decision Support System (DSS) to intelligently allocate water and fertilizer used in crop production based on the age of the plant and data collected from the soil and surrounding environment with the aid of a network of sensors. An embedded hardware system consisting of a Cartesian robot has also been implemented to ensure effective application of the fuzzy derived decisions. Two Fuzzy Inference Systems (FIS) consisting of linear, non-linear Membership Functions and a 149-rule base for the PA system have been developed in MATLAB, implemented using Arduino microcontrollers and tested on spinach plants whereby results show that the linear FIS is able to achieve more accurate results in terms of the quality of yield realized and resource utilisation. Resource utilisation comparison with other systems in literature reviewed is also done whereby the DSS is able to save up to 2031 ml and 524 ml of water and fertilizer respectively.

1. Introduction

Agriculture plays a very pivotal role in sustaining the survival of the human population around the world as a source of income and as an important source of food for both humans and animals. With the estimated global population expected to reach 9 billion by 2050, agricultural food production must double if it is to meet the increasing demands for food. Given limited land, water and labor resources, it is estimated that the efficiency of agricultural productivity must increase by at least 25% to meet that goal, while limiting the growing pressure that agriculture puts on the environment [1]. A lot of uncertainties and hurdles such as the uncertainty of optimum application of resources necessary for optimum yield production while minimizing resource wastage for sustainable production are facing agricultural food production worldwide. Therefore, there is need for integration of various technologies and management tools in order to achieve long term, sustainable and site-specific production efficiencies while eradicating/minimizing unintended consequences and impacts. In previous works reviewed, little or no significant effort has been made to utilize the complete set of collected plant, soil and environment sensor data to intelligently regulate the amount of resources allocated to the plants and the specific timing to do so. In cases where decision-making algorithms have been used, limitations



such as cost, accuracy of data retrieved from the sensors, dormancy of sensors when exposed to abrupt environment changes, over reliance on human knowledge and intelligence in application of resources thereby leading to low yields and strenuous implementation of embedded systems in real time have been highlighted [2], [3].

This research proposes the implementation of a soft computing platform based on Fuzzy Logic for decision making in order to optimize the quality of yield produced by ensuring that limited and depleting resources such as water and fertilizer are consumed in sustainable and justified quantities. In order to achieve this, collection of environment and soil data with the aid of sensors has been done, whereby sensor data collected is used by the Fuzzy inference algorithm as crisp inputs in delivering a more effective decision-making support system for effective and efficient resource utilization and crop production. The decisions made by the smart farming system include; timely application of specific quantities of water, fertilizer and sunlight to the vegetables grown based on their plant age and real time data mined from a network of sensors which include: soil moisture, sunlight intensity, soil PH, humidity and temperature. Implementation of the decision support algorithm has been done with the aid of an embedded hardware system consisting of a sustainable IOT based Cartesian farming robot which can perform a range of tasks such as seed placement and crop scouting in terms of soil sensor data collection, farm bed management, mapping, sunlight intensity control with the aid of an automated shade system and most importantly, allocation of resources such as water and fertilizer based on the decisions derived from the Fuzzy algorithm.

2. Methodology and Implementation

A Fuzzy Logic DSS, was implemented for the precision farming system with the aim of ensuring sustainable allocation of basic plant growth and development requirements such as water, fertilizer and sunlight based on data retrieved from a network of environment and soil sensors as shown in figure 1.

2.1 Decision Support System

The Mamdani Fuzzy Inference System was considered as the most conducive methodology for development of the Fuzzy algorithm due to its minimalistic and simplistic structure of minimum-maximum operations and is more tolerant of imprecise data, unlike the Sugeno approach, [2], [3], [4], [5] and [6].

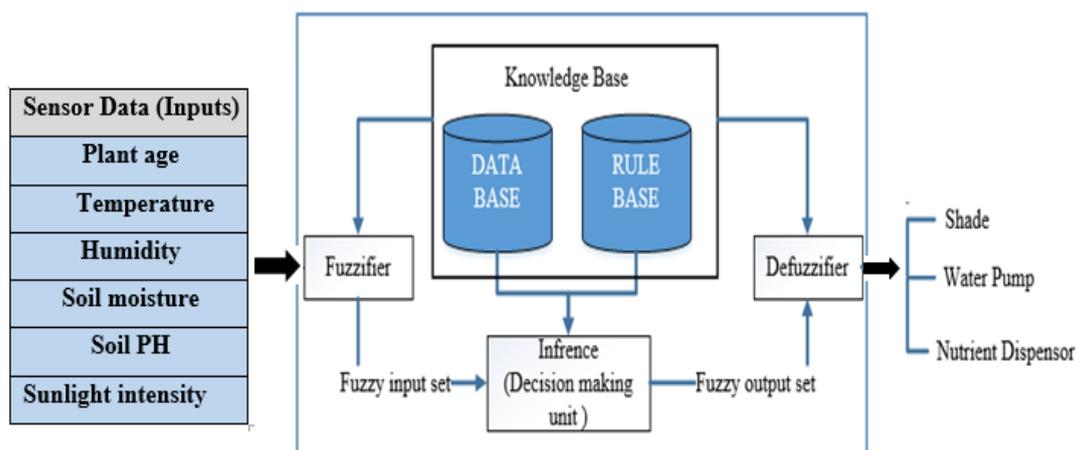


Figure 1. Proposed algorithm.

However, a couple of uncertainties must be highlighted such as, the most appropriate approach while building up the Membership Functions for the fuzzy set rules when using the Mamdani Fuzzy Inference System. According to [4], [7] and [8] inappropriate Membership Functions may interfere with the accuracy of the reasoning process, thereby leading to an input-output association with unexpected errors which might adversely affect the system's sensitivity and accuracy. Therefore a number of uncertainties were addressed when describing input and output Membership Functions for the algorithm such as:

- Which type of Membership Functions are most appropriate?
- What number of Membership Functions are required to define a single output and input variable?

- Should the Membership Functions overlap each other i.e. linear or non-linear and how do they impact the final result?

Therefore, in order to address the uncertainties listed above, two Fuzzy Inference Systems consisting of linear and non-linear input-output MF were developed with the aim of comparing the sensitivity and accuracy of each system for better result generation. The flowchart used for the development and generation of the MF and rules for the DSS is as shown in figure 2.

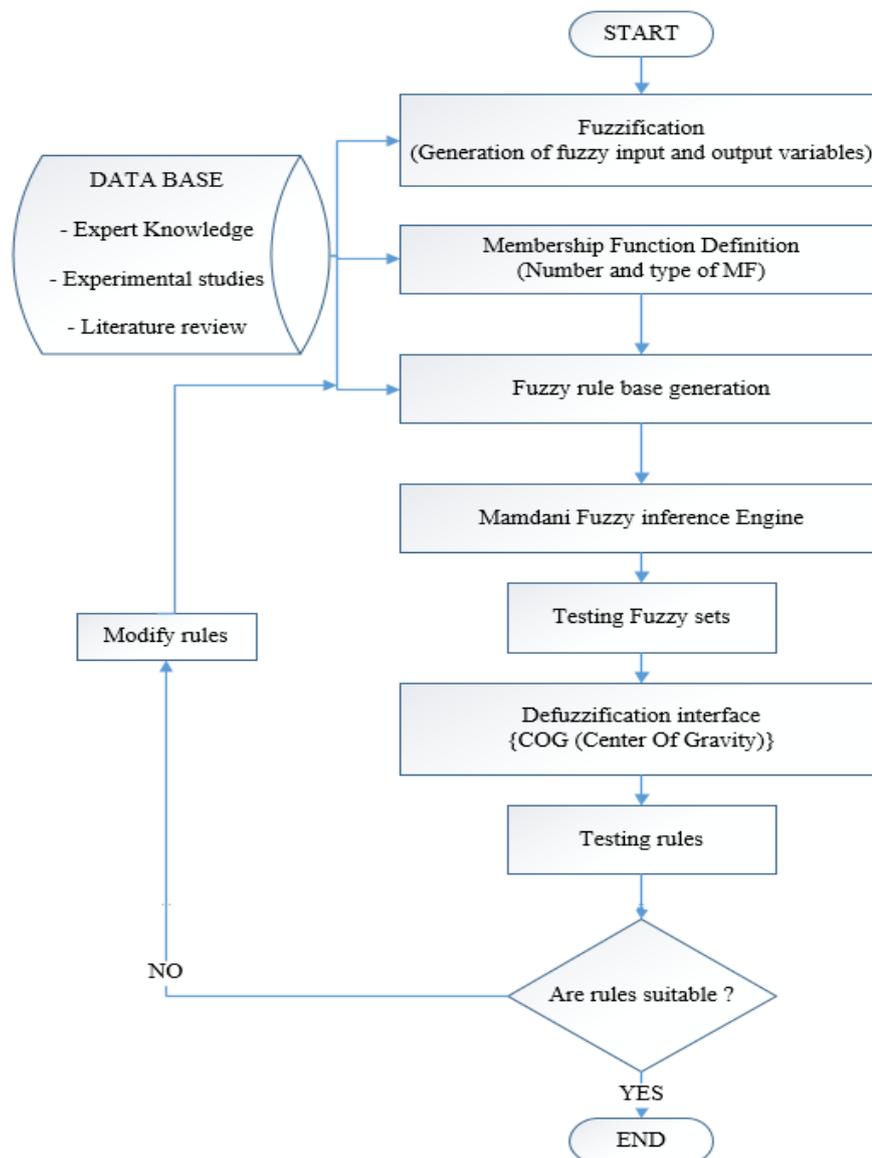


Figure 2. Fuzzy MF and rule generation process.

Generation of Fuzzy input and output MF i.e. Fuzzification, was done based on knowledge and data collected from expert databases and experimental studies reviewed, whereas the number of MF for each input and output was done based on research work sampled in the literature reviewed. The fuzzy rules generated for the decision-making algorithm were based on expert knowledge and data published for effective growth and development of spinach vegetables. The Mamdani Fuzzy inference engine which is widely used and accepted for employing expert knowledge was then used for Defuzzification of the fuzzy inputs. The inference mechanism consists of a number of symmetric and complete “IF-THEN

rules” which are modelled based on secondary data obtained from reliable literature, agricultural expert systems and publications that highlight optimum growing conditions for various vegetables.

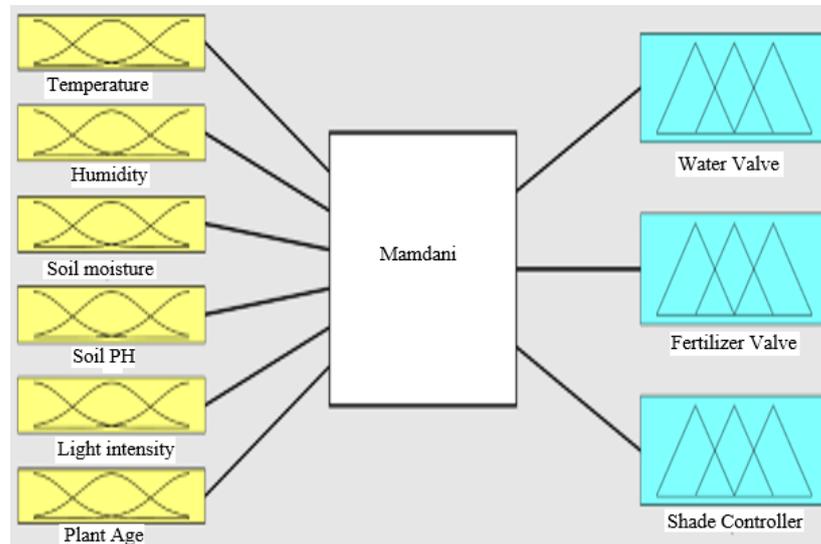


Figure 3. Mamdani fuzzy system.

MATLAB software was used to develop the Linear and non-linear FIS as shown in figure 3 before conversion was done to a standalone C program for the Arduino microcontrollers as shown in figure 4.

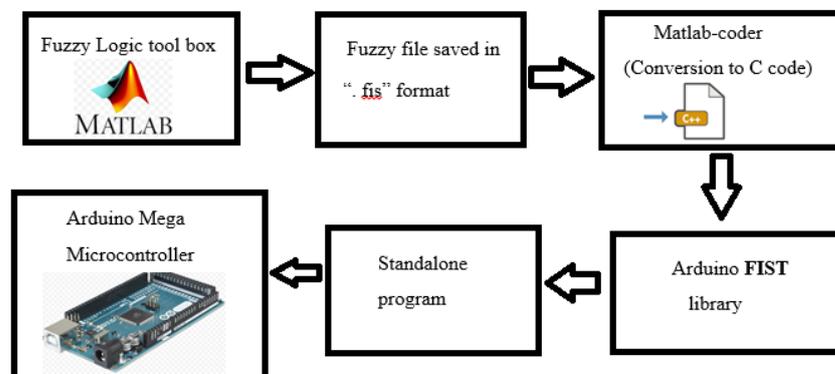


Figure 4. MATLAB Fuzzy Logic conversion to standalone Arduino.

The core of the Fuzzy Inference System (FIS) developed for precision farming is the rule system that is designed to mimic reasoning derived from human expert systems. During rule generation, rule testing was done whereby each rule was modified to get the expected output as shown in figure 3. The rule base developed for the decision-making system consists of 149 “IF” antecedent and “THEN” consequent rules that were devised based on information obtained from agricultural expert knowledge databases. In the Mamdani technique, as opposed to the Sugeno FIS, output Membership Functions can be defined and characterized by a rule base that is intuitive and interpretable, [4], [5] and [6].

2.2 Hardware Implementation

The embedded hardware system implemented for the precision farming system consists of a cartesian robotic system mounted with the aid of linear guides and stepper motors for movement actuation along the x, y and z axes as shown in figure 5. The operation of the robotics system developed is based on a 3D printer and is controlled with the aid of a web application based on commands derived from the Fuzzy based DSS.

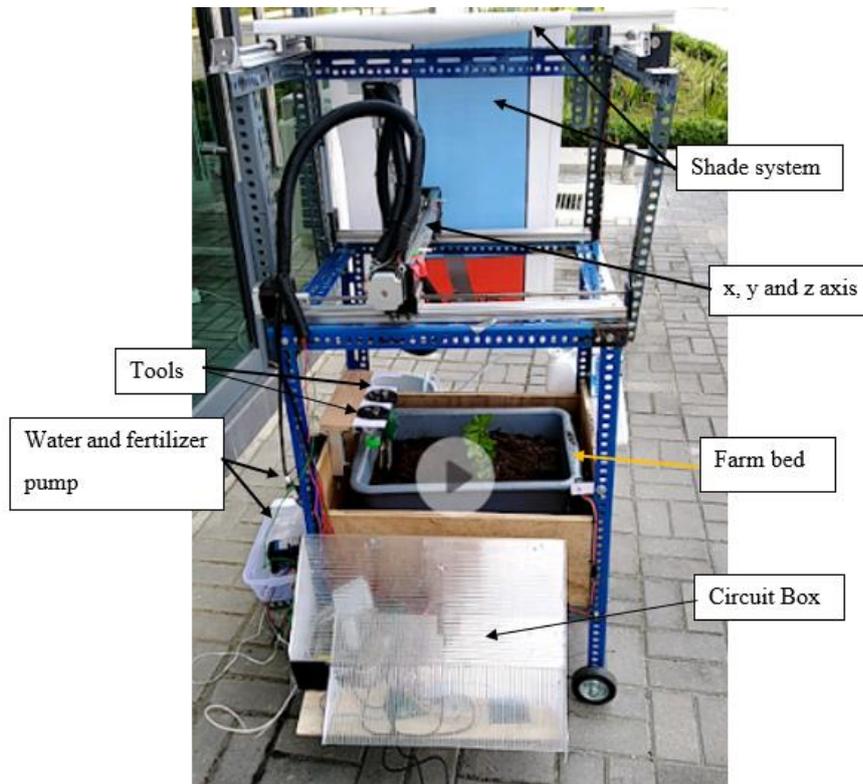


Figure 5. Embedded robotic system.

2.3 Testing and Results

Several tests were conducted on the developed system and the results obtained were compared with those achieved from other researchers. A simulation test was conducted in MATLAB to compare the accuracy of both linear and non-linear Fuzzy systems in terms of resource allocation based on random inputs used to model sensor Data. Results obtained from the rule viewer and surface viewer show that the system is able to de-fuzzify the soil and environment inputs to obtain desired outputs as highlighted in data bases from expert knowledge systems and previous experimental studies. Th spinach plants A and B harvested from the linear and non-linear FIS are as shown in figure 6 and 7 respectively.

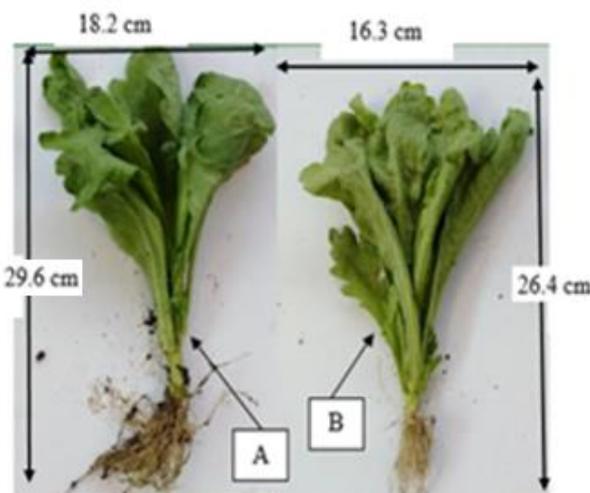


Figure 6. Spinach plant realized from both FIS DSS.



Figure 7. Spinach leaf dimensions.

Real time application of both Linear and non-linear FIS algorithms using the robotic system in the growth of two spinach vegetable plants of similar species show improved yield quality as shown in table 1.

Table 1. Result comparison with literature reviewed.

Literature reviewed	Length of leaf (cm)	Width of leaf (cm)	Thickness of leaf (cm)	Color of leaf	Overall height (cm)
Linear MF	19.4	6.8	0.12	Light green	29.6
Non-linear MF	17.2	5.7	0.12	Light green	26.4
[7]	14.88	6.95	-	Light green	27.34
[9]	14.79	5.86	0.28	-	26.87

Results obtained from the final plants show that the linear FIS is able to achieve better quality yield in comparison to the non-linear FIS as shown in figure 6 and 7. A comparison of the overall dimensions of the spinach plants from both systems and those reviewed from various researchers is as shown in table 3. In terms of resource allocation, the system is able to accurately supply the right quantity of water, fertilizer and sunlight allocated by the FIS, whereby the amount of water and fertilizer in the soil is kept above the threshold value of 0ml as shown in figure 8 for soil moisture.

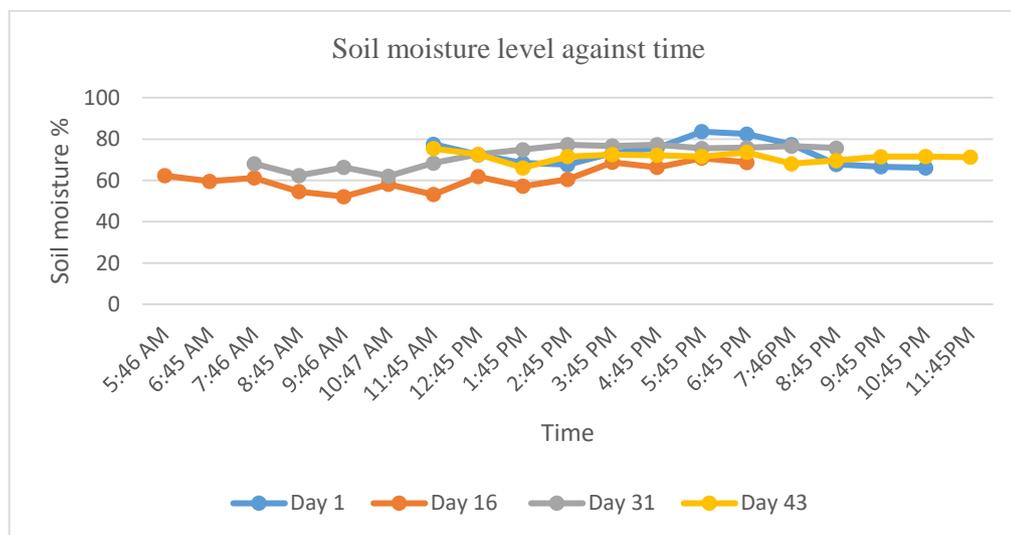


Figure 8. Graph of soil moisture against time for Non-linear MF FIS.

In terms of resource utilisation, the DSS is able to save up to 2031ml and 524 ml of water and fertilizer respectively over the 42-day gestation period for the spinach plants as shown in table 2.

Table 2. Resource utilization comparison.

System	Spinach gestation period	Water consumption (mL)	Fertilizer consumption (mL)
Implemented linear FIS	42 days	4726.5	1056.8

Implemented non-linear FIS	42 days	4697.6	1099.1
[10]	35 days	6090.0	1554.0
[9]	44 days	4871.4	None

The results from this research indicate that the developed Decision Support System can be implemented in real time with the aid of a robotics system to ensure optimum, sustainable and timely application of resources for improved crop yields. The system can be implemented in green house crop growth and management, whereby precise monitoring and resource allocation is a necessity for increased food production.

3. Conclusion

In this research study, the development and implementation of a precision farming Decision Support System (DSS) has been presented which is based on a Mamdani Fuzzy Inference System. The Decision Support System developed allows hourly monitoring of environment and soil parameters required for plant growth using a network of sensors, whereby real time sensor data collected and a rule base system are used for decision making through autonomous and sustainable application of water, fertilizer and sunlight. In addition, two Fuzzy Inference Systems consisting of 149 rules with linear and Non-linear input-output Membership Functions were developed and tested on two spinach plants grown on a raised farm bed under the same growing conditions to establish the efficiency of each Decision Support System. The experimental trials conducted over a period of 42 days showed that the FIS with linear input-output Membership Functions is able to produce reliable results in comparison to the FIS with non-linear input-output Membership Functions. In addition, the ability of the DSS to deliver sustainable amounts of water and fertilizer to the spinach plants was also investigated whereby the system was able to achieve 82.4 % and 86.8 % water and fertilizer savings respectively in comparison to other related systems in literature reviewed. The robotics system implemented in this research is fully autonomous and therefore eases the burden of manual monitoring and application of resources to the plants.

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