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Abstract. Soybean production has expanded intensively in South America over the last decades. As the second leading worldwide soybean producer, Brazil has in prospect to increase market share through production growth in soybean areas. Therefore, soybean fields ought to encompass a sizeable region among different types of soil and climate conditions, and so advanced irrigation methods should be advantageous. This present work aims to optimize soybean production through an irrigation system control based on environmental and plant requirements. It was developed an embedded fuzzy controller that is able to process soil moisture, air moisture, temperature, soil type and soybean growth stages and it returns the ideal amount of water. Also, to accomplish the data acquisition, a multiparameter sensor device establishes remote connection and provides continuous in-field measurement. The efficiency of the fuzzy controller and the monitoring unit was verified through simulations, and so, results reached the expected model.

Keywords: Soybean, fuzzy, multiparameter sensor

1 Introduction

Brazilian soybean fields have gradually increased production over the last three decades. Consequently, Brazil has firmly established as the second leading worldwide soybean producer. Although agriculture technology has increased average yield per acre significantly, soybean frontier's expansion in Brazilian agriculture has been especially held out as the main responsible for high production levels [1] [2].

Eventually, expanding soybean fields over a huge country such as Brazil ought to bring unprecedented challenges to the producers. In addition, the diversity of climates and soil types characteristics have led farmers to search for new technologies [3] [4].

Therefore, potential scenario begins to emerge as soybean farmers increase investments, and modern irrigation techniques appear to be suitable in soybean fields, but, in generally, irrigation systems are quite inefficient, spend water resources and electricity poorly and do not goal production results. Although Brazil has a privileged stand before many countries containing large part of available fresh water in the world, global trends defend the conscious consumption of resources, promoting sustainability in agriculture [5].

This paper presents the development of a control system that applies to irrigation devices in soybean fields. It was developed an embedded fuzzy controller, a supervisory control software and continuous monitoring sensor units. The control decision was settled according to soybean characteristics such as growth stages and water demand and also soil type, temperature and relative air moisture. The main objective of the system is to automate soybean irrigation mechanisms in order that production could increase based on fuzzy control and agricultural knowledges.

2 Relationship to Smart Systems

Smart system describes embedded and cyber-physical solutions consisting of diverse sub-systems and smart embedded applications are expected to deliver miscellaneous functionalities and services [6]. Although the development of precision agriculture claims to achieve a high-quality management of cultivable land and environment resources, wireless sensor network and advanced control techniques have been studied apart on agricultural developments and so, combined solutions are hardly available among farm applications [7] [8].

The proposed irrigation system control could increase efficiency in soybean fields crossing precision wireless monitoring and specialist control techniques, which base on environment characteristics and soybean water requirements. As shown in Fig.1, the proposed system integrates in-field measurement and supervisory control software.

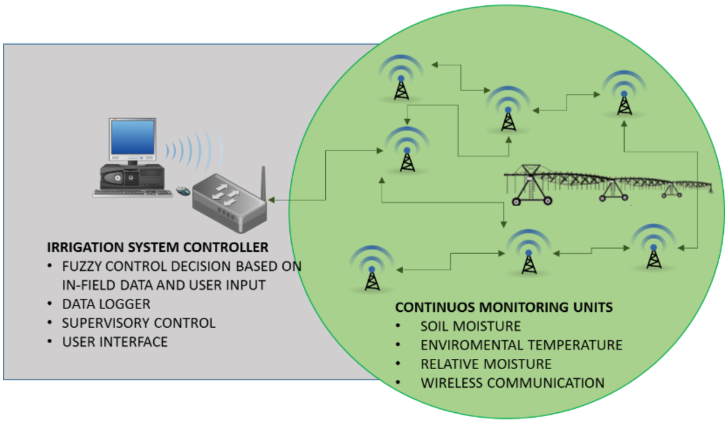

Fig. 1. Architecture of the Irrigation Control System. It represents Continues Monitoring Units (*right*) which operate in-field and transmit data over wireless network and the Irrigation System Controller (*left*) that processes received data and communicates to supervisory control software.

3 Design of Fuzzy Logic Controller

Fuzzy logic has been used in many segments such as industrial controllers, artificial intelligence applications, medical researches and robotics. Fuzzy logic approaches real world attributes/linguistics and computational capabilities. As a result, the amount of time spent by developers decreases as well as precision, optimization and efficiency increase slightly [9]. A fuzzy control model was appropriate for the present work due to the complexity of the input variables and long cycle operation required, which has many variations throughout each stage, besides fuzzy logic easily approaches the specialist knowledge and could be comprehend and accepted by farmers.

The control model bases on two fuzzy logics: main control algorithm and equalizer algorithm. The selection of input variables based on soybean water requirements, which relate to soil water status and soybean growth stage, and environmental conditions, such as temperature and relative moisture. The following topics present input variables.

Soybean Growth Stage. Soybean growth stages divide in vegetative stages and reproductive stages. A slight shortage of water during the vegetative stage do not affect production drastically. However, water deficits over reproductive stages could decrease soybean yield severely. In addition, the required amount of water depends on stage of growth due to the requirement of maintaining adequate water supply till the bottom of the root system [1] [4] [5].

Soil Type. The identification of soil type is important due to the distinct physical and chemical properties which take action on the movement and storage of water and nutrients. The soil texture is based on the relative amount of three main components: sand, silt and clay. According to the soil texture, each type of soil has a limited capacity of water storage known as Field Capacity. This typical feature is fundamental to the irrigation process and it should be a limit on water distribution. As a consequence of exceeding field capacity, there will be infiltration and nutrient loss eventually. Then soil type must be identified and based on each kind, the proposed system can adjust the amount of water required [10] [11].

Soil Moisture. Monitoring soil moisture over irrigation fields is fundamental on crop management practices applied to boost yields. Water availability is a control factor over soybean growth and development and water stress may reduce nutrient absorption because it increases the difficulty of nutrient uptake. However, the management of irrigation fields should be more reliable combining soil moisture data and climate monitoring information in irrigation fields.

Air Temperature and Relative Air Moisture. In order to attach environmental conditions to the control model, air temperature and relative air moisture balance the controller output. These input variables have strong action under harsh environmental conditions such as high temperature or poor air moisture levels.

The equalizer algorithm was planned according to the temperature and air moisture classification. The design of equalizer model rules bases on the statement that water demand slightly increases on a hot day and decreases on cold day. The same strategy embraces air moisture. The developed membership functions were shown in Fig.2.

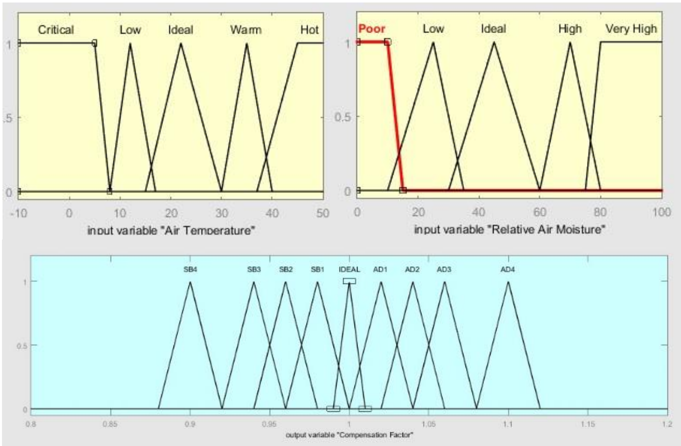

Fig. 2. This figure shows the membership functions of air temperature (*top and left*) and relative air moisture (*top and right*). The membership function of compensation factor (*bottom*) presents the response of equalizer algorithm.

The rule design in the main control algorithm considers the type of soil, soybean growth stages and soil moisture and the output was defined as the ideal amount of water to reach field capacity according to each soil, which increases production because then the fuzzy controller could assure that water supply have been provided to the entire soybean root system. Also, the main algorithm was developed to be in control of the whole plant cycle. The output variable was divided in many classes to achieve precision and a large number of rules were requested to approach the ideal amount of water over soybean stages. The fuzzy control output represents the amount of water which should be applied based on agricultural knowledge and ought to be compensated due to environmental conditions. The membership functions are presented in Fig.3.

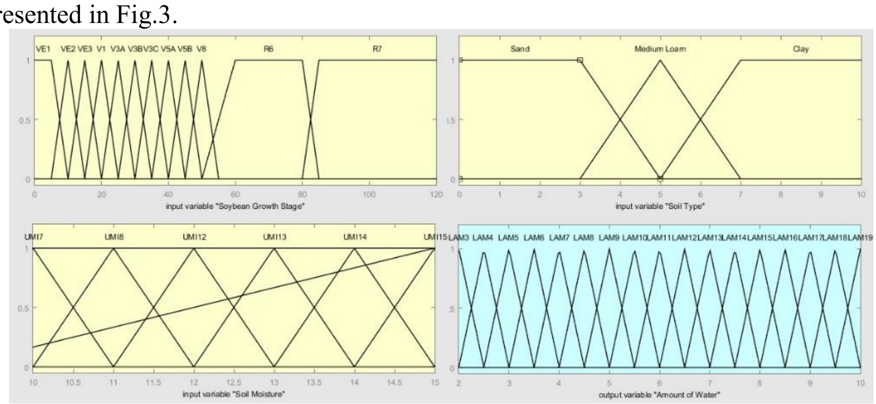

Fig. 3. As shown in figure, the membership functions are soybean growth stage (*top and left*), soil type (*top and left*), soil moisture (*bottom and left*) and amount of water (*bottom and right*). The last two membership functions are partial views because there is a large number of linguistic variables in soil moisture and amount of water.

According to Fig.4, the control model was developed on two fuzzy algorithms due to computational resource limitations. The divided solution reduces computational time and simplifies code compilation. The amount of water (*SHEET OF WATER*) can be obtained through the main algorithm (*CONTROLLER*) without compensation factor. The environmental compensation relays on temperature and air moisture combined through compensation algorithm (*EQUALIZER*). The large number of divisions in the output membership function simplifies defuzzification process because the linguistic terms from amount of water corresponds directly to the control variable. This application encompasses 268 rules in main control algorithm and 25 rules in equalizer algorithm.

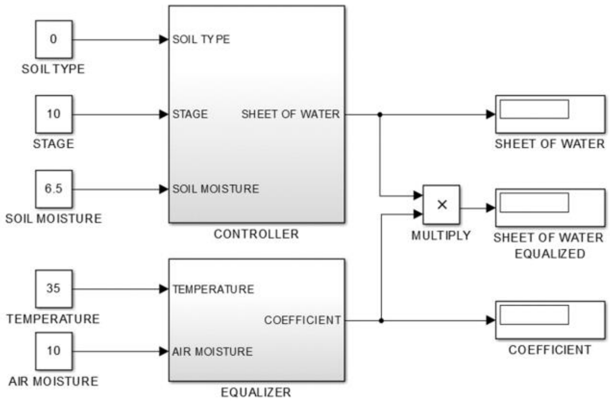

Fig. 4. The architecture of the developed fuzzy control model has based on two individual fuzzy algorithms.

4 Design of Continuous Monitoring Sensor Unit

The developed sensor bases on a capacitive element and the calibration method provides a soil moisture relationship. The sensor unit has an electronic circuit that is able to measure capacitance precisely. Also, the sensor unit integrates wireless connection, air temperature and relative air moisture elements.

4.1 Procedure of Calibration

The developed capacitive probe was calibrated in the Laboratory of Chemical Engineering at Faculdade de Engenharia de Sorocaba, where it was possible to detect a variation of the capacitance according to the mass quantity of water applied in each sample.

Two soil samples were used: clay soil and medium loam soil. These samples were dried and sifted to accomplish low moisture level. Each dried sample was weighed and had capacitance measured, and so, an acknowledged mass of water was applied on the soil sample and capacitance measured again.

Through collected data on capacitive probe calibration, it was highlighted the relationship between the percentage of moisture and measured capacitance, therefore it was possible to reach the exponential equation of calibration for clay soil and medium loam soil that works on developed sensor.

5 Design of Controller Unit and Supervisory Control Software

As shown in Fig.5, it presents the developed electronic controller device and the capacitive sensor element. The wireless communication network operates between sensor and controller. The supervisory control software was developed to Windows application as shown in Fig.6. The controller and the supervisory communicate through USB protocol. The controller unit has a digital output assigned to the fuzzy control. The output value can be adjusted by the supervisory control software based on irrigation mechanism to correspond a period of time. The supervisory control software displays collected data and storages each measurement.

Fig. 5. Irrigation System Controller (*left*) and supervisory control software (*right*). The operator can adjust parameters from the irrigation mechanism on software.

6 Results

A simulation was built in the software Matlab Simulink version 2015a. Adopted parameters have been used to better analyze the developed control logic. As shown in Fig. 6, it has demonstrated that the created system was able to process the input variables and the project met expectations for the proposed model. In addition, the surface view on the right of the picture presents the output response without equalizer action based on clay soil characteristics. Also, these surfaces present fixed soil type due to the number of available axes. The surface on the left shows the equalizer output, which adjusts system output based on air temperature (*TEMPERATURE*) and relative air moisture (*AIR-MOIS*TURE). The designed system has been able to operate on the complete soybean cycle and the control output has reached the ideal amount of water, according to the proposed objective.

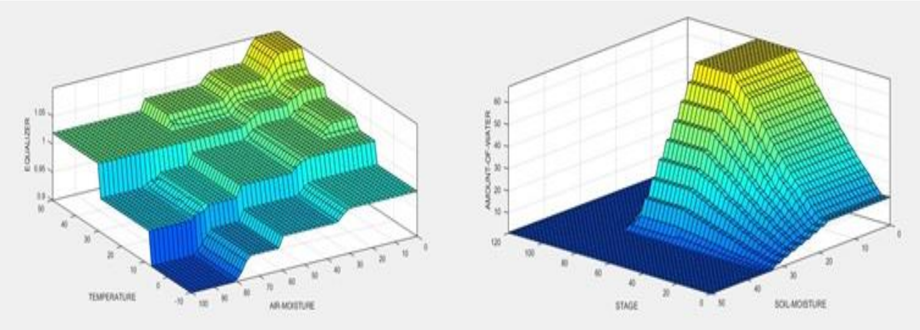

Fig. 6. Surface view model of the equalizer block (*left*) and Surface view model of the controller block for the soil type clay (*right*).

7 Conclusion

The proposed control system provides resources for continuous data acquisition of particular field variables and the developed control algorithm analyses these aspects successfully.

In order to evaluate the performance of the developed devices, it was monitored the system operation and it was realized that the control module and the sensor unit have been acting satisfactory, according to the design specifications.

The present solution can further be applied to others cultivable plants. In addition, the proposed system might integrate a meteorological station to accomplish prediction capability. Furthermore, the fuzzy architecture could be easily modified to aggregate other unexplored features, which could improve overall performance.

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