Fuzzy Control of Agricultural Irrigation System through Wireless Sensor / Actuator Networks

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***Abstract*—Crop growth is mainly influenced by, meteorological variables (temperature, humidity), the amount of water and fertilizers supplied by irrigation. Theoretically, the water and nutrients requirements of the different crop species are known and optimal crop yield (much production with better quality) is realized by controlling the environmental conditions. Minimum water usage is the primary objective of eco-friendly agricultural control systems. The integration of wireless sensor / actuator networks (WSANs) into irrigation management promises to overcome the excessive watering problem while providing additional functionality. In this study, we describe the design of fuzzy logic based irrigation control system by using WSAN. In our model, the flow rate and pressure of water are regulated by adjusting the position of solenoid valve with PWM method. The proportional electronic actuator accepts the control signal and actuates the valve to allow the valve to be partially open or close. The simulation results show that the proposed system can be effective to improve the water use efficiency.**

Keywords—precision agriculture; irrigation control; fuzzy logic; wireless communication

I. Introduction

In modern agriculture, it is needed to modern technologies that will enable to increase the efficiency of production and quality of crops while protecting the environment [1]. For this purpose, many parameters that vary with time and location, such as plant/soil characteristics and meteorological conditions, should be kept under control by monitoring them in real time and responding quickly to unexpected changes. To increase the effectiveness of control, the precision farming techniques are used instead of conventional methods [2]. Precision agriculture is a management strategy that uses information technologies to take decisions associated with crop production [3].

In precision agriculture, one of the popular research topics is the irrigation scheduling and water quantity control for increasing water use efficiency. Seasonal water demand and peak daily use vary considerably from crop to crop and from one field to the next. Deciding when to irrigate and how much water to apply are the two most difficult decisions to make in managing irrigation systems [4]. To measure the water content in the active root zone, the soil moisture sensor is connected to the controller. The key factor is not to add a drop of water more than required and not a drop less than needed for adequate plant growth [5].

In agricultural fields, the establishment of the cabling infrastructure for energy and data transmission is often not possible. Therefore, when a central control system is to be formed to build a network that enables data transfer between the sensors and the actuators, the wireless communication becomes inevitable. Recent researches show that the wireless sensor networks (WSNs) are the most suitable technology for monitoring and agricultural fields. A typical WSN is a passive data acquisition system which consists of a large number of sensor nodes (SNs) [6]. WSNs can help the farmers to monitor soil parameters [7-9].

The next step in the evolution of WSNs is wireless sensor/actuator networks (WSANs) [10,11]. WSANs are comprised of networked SNs and actuator nodes (ANs) to perform distributed sensing and control tasks. From a viewpoint of control theory, traditional WSNs are open-loop systems that only detect the physical world, whereas WSANs are closed loop systems that can further interact with it automatically [12]. The nodes are equipped with low-power radio frequency (RF) transceiver and low-cost microcontroller together with an energy source, usually a battery. In SNs, several sensors are connected to the node to provide necessary monitoring function. Besides, in ANs, actuators are attached to trigger control functions [13].

The computational capabilities of WSANs require intelligence to optimize the irrigation requirements according to the soil type, crop species and weather conditions [14]. Fuzzy logic enables the use of engineering knowledge and experimental results in designing an intelligent control system. Intelligent systems operate without human supervision and respond to changes in their external environment [15]. In this paper, we describe the fuzzy logic based control of agricultural irrigation system through WSANs. The main goal of proposed system is to monitor the soil properties and optimize the water consumption.

The remainder of the paper is organized as follows: Section II provides an overview of the system model and describes the proposed WSAN based irrigation system. The details of the hardware design are presented in Section III. Proposed fuzzy controller is explained in Section IV. Finally, the paper is concluded in Section V. The simulation results of the proposed method are also presented in this section through MATLAB Fuzzy Logic Toolbox.

II. System Model

The proposed WSAN based irrigation control system is composed of SNs, ANs and control node (CN). The SNs measure the physical parameters about ambient and soil conditions to optimize the irrigation scheduling. After that the collected information is send to the CN directly. In our semi-automated setup, the CN operates as field manager and makes decisions about the distribution of water. It is assumed that the CN is close to sensor/actuator pairs and then clearly one-hop communication can be applicable practically. The flowchart of information exchange between the components of the control system is shown by Fig.1. The direction of arrows indicates the direction of the data flow.

The SNs sense the physical variables of interest (temperature, soil moisture etc.) around their sensing range and report them to the CN. The CN evaluates collected data by comparing set points. If required, it sends control signals to the ANs that are regularly deployed over the field. The ANs drive the actuators (solenoid valves, pumps etc.) and applies the desired amount of water depend on the crop requirement. So, the water will reach the roots by going drop by drop.

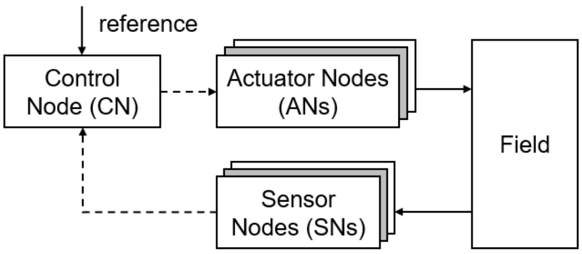

Figure 1. Structure of proposed control system

As shown in Fig.2, the proposed system can be used in both the drip and sprinkler irrigation systems. In drip irrigation case, the entire field is divided into laterals such that each lateral contains only one SN/AN pair. So, there are a lot of laterals which are irrigated independently. But in sprinkler irrigation, more than one ANs can be placed on the same lateral. So, a certain AN can be controlled according to the signal from more than one SNs. If the valve opening on main pipeline is less than predefined margin, the pump is turned off by the CN automatically.

The control system operates as follows: The SNs measure the actual values of soil moisture sensors and send a signal back along the feedback path to the CN. The CN calculates the difference between the reference value and the measured value that is known as the error signal. According to gathered information, the CN stimulates the related AN on the field. The ANs respond to control signal and vary the flow of the water by driving solenoid valves appropriately.

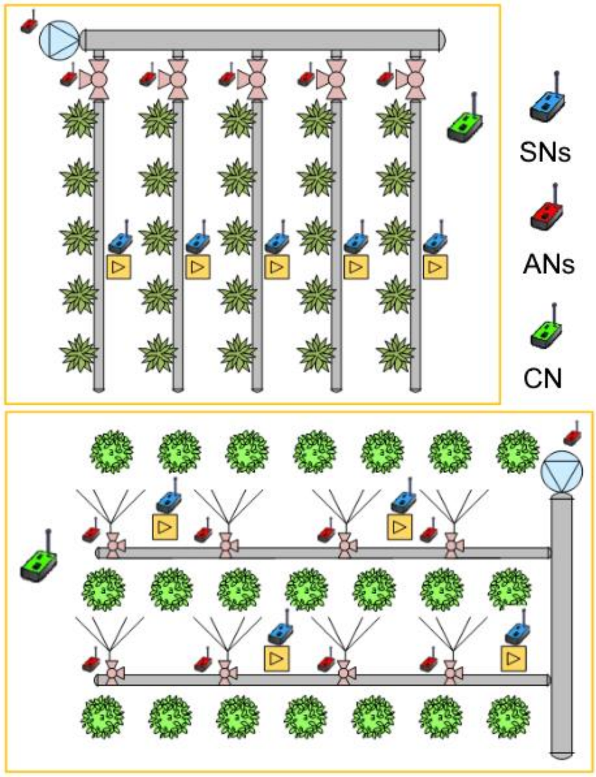

Figure 2. System layout for drip and sprinkler irrigation

III. Hardware Design

The proposed WSAN for irrigation control is built upon a variety of low cost, off-the-shelf hardware components that can be easily upgraded or replaced. The SN hardware is based on Arduino Nano platform as shown in Fig. 3. The SN has a nRF24l01+ low power transceiver module as shown in Fig. 3. The capacitive type soil moisture sensor also attached to the SN board.

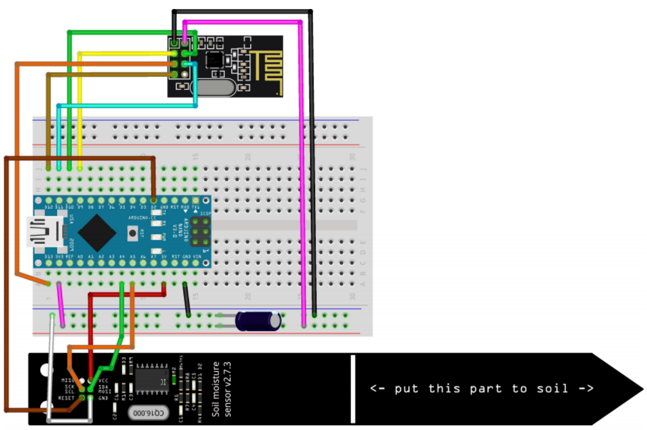

Figure 3. Hardware design of sensor node (SN)

The CN hardware consists of an Arduino Nano platform and nRF24l01+ transceiver module as shown in Fig. 4. The preset values of the physical parameters can be adjusted by user via TFT LCD on the CN.

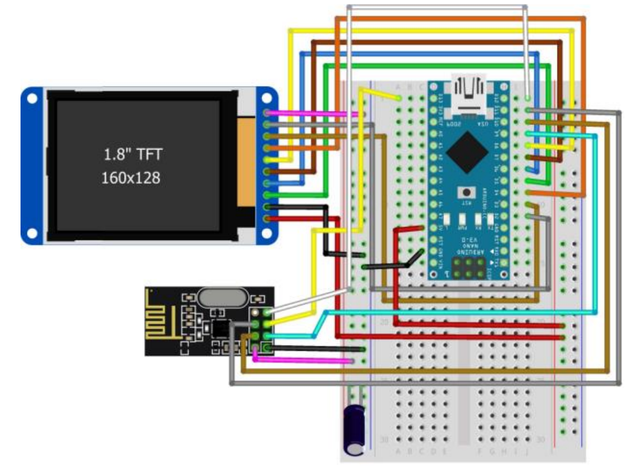

Figure 4. Hardware design of control node (CN)

The AN hardware consists of an Arduino Nano platform and nRF24l01+ transceiver module as shown in Fig. 5. The proportional solenoid valve attached to the AN board through driver circuit. The current driver can be constructed using power transistor as switching device. Both MOSFETs and insulated gate bipolar transistors (IGBTs) are capable of carrying high current levels. IGBT also provides an isolation function against reverse recovery charge. The proportional solenoid valve driving circuit with IGBT is shown by Fig. 6.

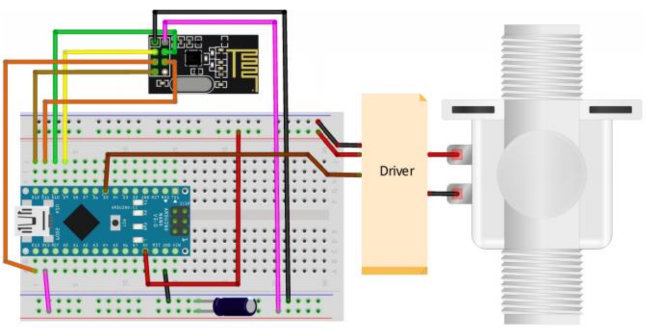

Figure 5. Hardware design of actuator node (AN)

Solenoid valve is an actuator that use a solenoid to control the valve position. In conventional approach, solenoid valves are controlled by relays to open and close the irrigation. Once the soil has reached desired moisture level, the sensors send a signal to the controller to turn off the relays, which control the solenoid valves. In this paper, we focus on the proportional control of solenoid valve. In this type control, the proportional solenoid valve positioned in intermediate positions in proportional to the difference between the set point and the measured real value. So, the actuator continually searches for the proper position from fully open to fully close. This allows the irrigation control system to apply the right amount of water at the right time.

Proportional solenoid valves are often used in precision agriculture applications that require precise control. To respond the control signals, proportional solenoid valve must be driven by high current. Driver converts the control signal into mechanical force and proportional solenoid changes the position of the valve. It receives control signals from microcontroller and delivers high power control current to the solenoid of the proportional valve. Pulse width modulation (PWM) signal can be used to drive the proportional solenoid valves.

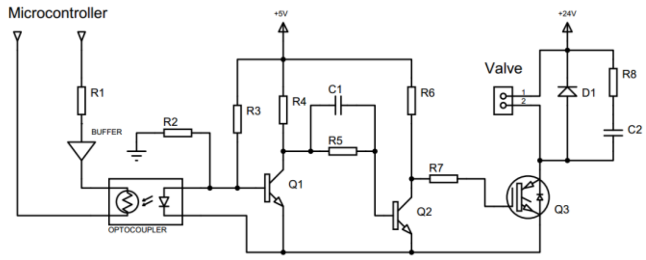

Figure 6. Driver circuit for proportional solenoid valve

IV. FUZZY CONTROLLER

The fuzzy logic based controllers have a rule base inference mechanism imitating the decision-making process of human brain for performing desired control processes on the controlled system. Fuzzy logic offers high control performance for time-varied nonlinear systems, which have unknown mathematical model. The fuzzy control function can be implemented by using the system error based on a set of predefined fuzzy rules. Fig. 7 shows the proposed fuzzy PD controller block diagram which is composed of fuzzification block, rule base, inference engine and defuzzification block.

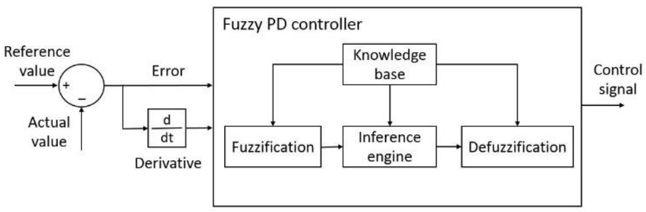

Figure 7. Block diagram of fuzzy PD controller

In order to control the water flow rate in the laterals, we use the set point error for soil moisture content (e) and its derivative (Δe) as inputs of fuzzy controller. The set point error is calculated by taking the difference between the reference value and sensor measurement at certain sampling times (n).

$$e[n] = \mathrm{r[n]} - s[n] \quad (1)$$

Error derivative input is determined by the ratio of the difference between the current and previous error values to the sampling period (Δ).

$$\Delta e[n] = (\mathrm{e[n]} - e[n-1])/\Delta \quad (2)$$

If sampling period is chosen as unity, the error derivative variable is simplified as change of error.

We assume that the error values typically in the range from 0 to 30 % by volume. Since the error value may change depending on the soil type, the controller performance can be increased by setting the sampling period accurately. Fuzzy sets of the linguistic variables error, error derivative and valve opening are {very small (VS), small (S), medium (M), large (L), very large (VL)}, {negative (N), zero (Z), positive (P)} and {closed (C), half closed (HC), medium (M), half open (HO), open (O)}, respectively. Due to the computation simplicity, we have used triangular membership functions for both input and output fuzzy variables as defined in Fig. 7, Fig. 8 and Fig. 9, respectively.

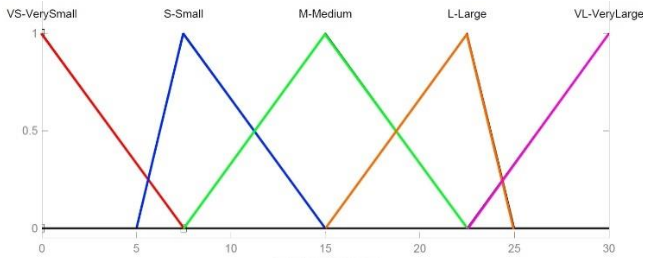

Figure 7. Membership functions of the error

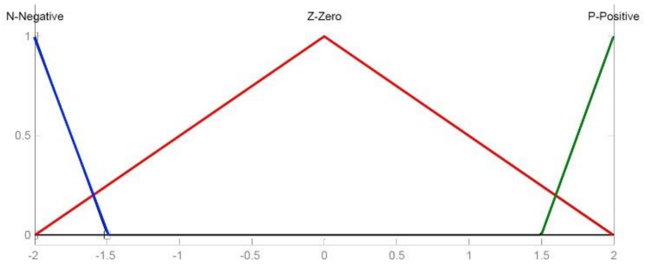

Figure 8. Membership functions of the error derivative

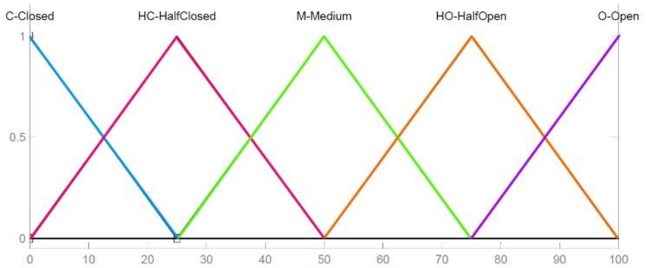

Figure 9. Membership functions of the valve opening

Fuzzy inference engine is responsible for decision making according to if-then rules database. The designed fuzzy rule base is given in Table 1. The Mamdani method is used for decision making and the defuzzification is done using weighted average method. By evaluating the measurements from sensors, the fuzzy controller calculates the system output to adjust the position of every solenoid valve separately.

TABLE I. THE RULE BASE OF DESIGNED FUZZY PD CONTROLLER

Valve Opening			Error				
			VerySmall	Small	Medium	Large	VeryLarge
			VS	S	M	L	VL
Derivative	Negative	N	Close	Close	HalfClose	HalfOpen	Open
	Zero	Z	Close	HalfClose	Medium	HalfOpen	Open
	Positive	P	Close	HalfClose	HalfOpen	Open	Open

The control surface of designed fuzzy PD controller is represented in Figure 10. This plot gives the percent of valve opening versus error and error derivative on soil moisture content.

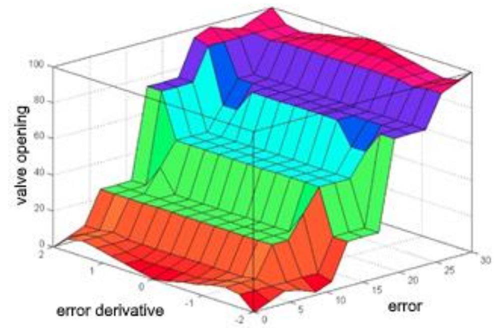

Figure 10. Control surface of fuzzy PD controller

V. SIMULATION RESULTS AND CONCLUSION

The control performance of proposed fuzzy PD controller is tested with the help of the fuzzy logic toolbox in MATLAB. In our experiment, we monitor the valve opening by choosing reference level as 28 % by volume. Fig 11. shows both the changes in soil moisture content and valve opening over sampling interval.

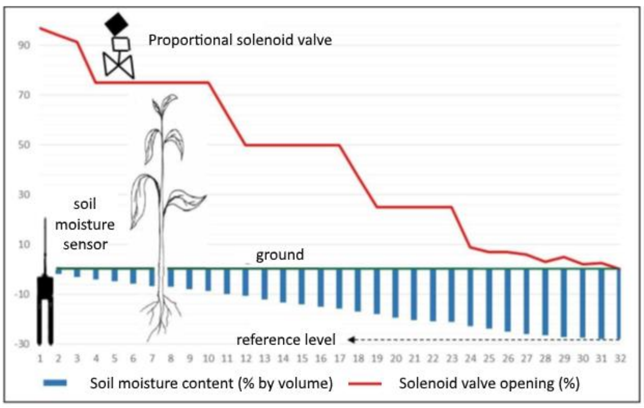

Figure 11. Fuzzy control of solenoid valve opening

Simulation result confirms that the proposed WSAN based control system can be a model to modernize the agricultural irrigation. It enables farmers to provide irrigation to larger areas of crops with less water consumption and lower pressure. The advantages of using WSAN are having the reduced wiring and piping costs, easier installation and maintenance. The system is easily applicable for large fields, which have different type of crops. Proposed system can also control the water consumption by changing speed of pump motor with a small extension.

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