Short Research Article

Research on Fuzzy Control System of Intelligent Irrigation Based on Soil Moisture

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ABSTRACT

Intelligent irrigation has been a critical initiative to achieve sustainable development of agricultural water. In this paper, a fuzzy control system is designed to realize intelligent and precise irrigation by combining fuzzy control with traditional feedback control based on the features that soil moisture has significant influence and ease of detection and adjustment in practical irrigation. The opening time of solenoid valve is decided by the control system in real time, and the deviation and deviation rate of change for soil moisture are regarded as input variables. The model of intelligent irrigation fuzzy control system is built and compared with the model of PID control by Simulink for simulation. The results show that the fuzzy control system operates stably and achieves real-time precise irrigation with faster response and stronger robustness. The issue of reduced accuracy in irrigation due to the coupling between human and environmental factors is effectively solved by this design.

Keywords: intelligent irrigation; fuzzy control; soil moisture; Simulink

1. INTRODUCTION

Systems for intelligent irrigation have gradually expanded into one of the directions for agriculture compared to traditional irrigation [1]. Crop growth in irrigation systems is related to soil moisture, light intensity, temperature, wind speed and other factors, of which soil moisture is essential and more easily detected and regulated. Soil moisture and other factors are coupled mutually, showing non-linear variations with large inertia and hysteresis [2,3]. The conventional control method tends to cause the system to have a large amount of overshoot, which is detrimental to water conservation [3,4]. The growth of the crop is hampered once the overshoot exceeds a certain value.

The algorithms of traditional control systems are based on known accurate mathematical models. However, for agricultural irrigation control system with nonlinearity and severe lag, it is tough to establish an accurate mathematical model, which is more cumbersome or simply impossible to handle, and cannot achieve efficient irrigation [5]. Sun [6] designed an intelligent irrigation system based on LSTM neural network by using Raspberry Pi as the lower computer controller and Ali cloud server as the upper computer. And Yuan [7] monitored and analyzed the light intensity, ambient temperature and soil moisture in real time by illuminance meter, thermometer and FDR type soil moisture sensor, and adjusted and controlled the sprinkler irrigation water volume in time according to the analysis results, then proposed a design scheme of intelligent irrigation system for urban parks based on GPRS+ZigBee wireless networking technology. Another intelligent irrigation system based on PowerBus bus technology using the Internet of Things, containing key hardware such as the master gateway, solenoid decoder, sensor decoder and terminal app control software by Zhang [8]. More intelligent control contributes more to the irrigation system [9-12].

Compared to the complexity of other control systems, fuzzy control is widely applied in agricultural irrigation systems due to its simplicity of implementation, compatibility with traditional control methods, ability to incorporate the experience into decision making, and better system robustness [13,14]. The current required irrigation quantity is analyzed by fuzzy inference from the detected information in fuzzy control, so that the actuator is adjusted in time to truly achieve the required quantity of water with deliver efficient, high quality and water saving results. The structure of intelligent irrigation system is shown in figure 1. The Mamdani type of fuzzy logic system is adopted for the advantages suited to the utilization of existing information and theoretical intuition, and the structure is shown in figure 2.

In this paper, an intelligent control system is established to significantly reduce the problems of large overshoot and slow system stability of traditional feedback control. The fuzzy controller model is built in Simulink with the growing irrigation of fields as the research object. The fuzzy controller in this system is analyzed by the deviation, the deviation rate of change for soil moisture and the opening solenoid time of valve. Simulation and comparison results with traditional PID control yield the relations between optimal soil moisture and irrigation time, ultimately maximizing the purpose of precise irrigation.

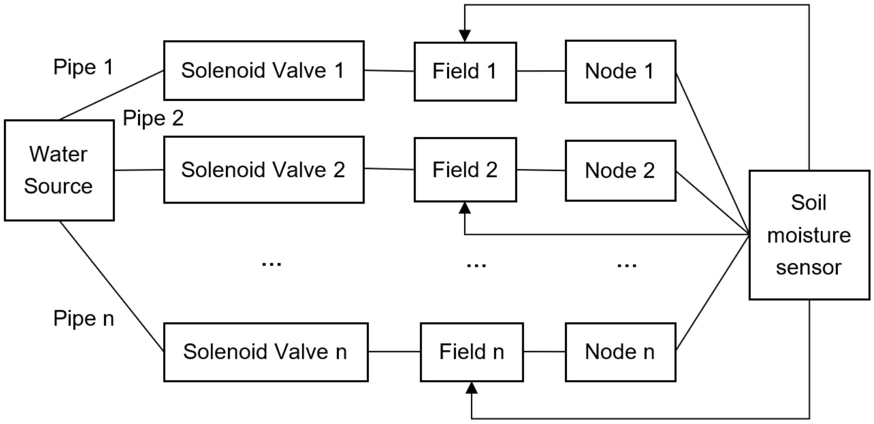


Fig. 1. The structure of intelligent irrigation system

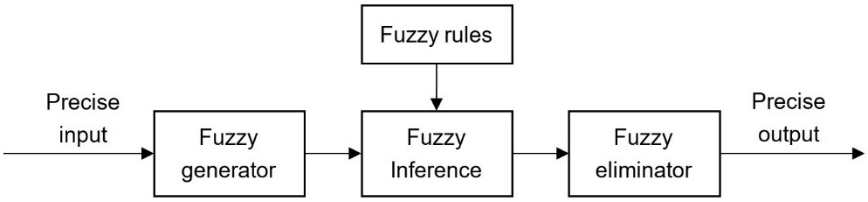


Fig. 2. Block diagram of Mamdani-type fuzzy logic system

2. DESIGN OF FUZZY CONTROLLER

2.1 Theoretical domain of input and output variables

The nonlinear equations of the irrigation system are uninvolved in this design, and the fuzzy controller structure is shown in figure 3. The system is consisted of two input parameters, one output parameter, and a fuzzy controller. The deviation of soil moisture *E* is expressed as

$$E(t) = S(t) - S_{best} \quad (1)$$

where *S(t)* denotes the collected soil moisture and S_{best} is the optimum soil moisture. The rate of change for soil moisture deviation *EC* yields

$$EC(t) = \frac{E(t)}{E(t-1)} \quad (2)$$

Genetic analysis [10] showed that the membership and structure of microbial communities differed significantly under different irrigation time, highlighting changes in the soil microbiota, which may deteriorate the biochemical cycling of the soil. Thus, the irrigation time is represented by *TIME* as the output.

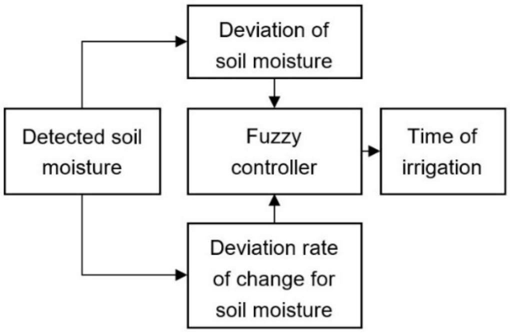


Fig. 3. The structure of intelligent irrigation system

The higher number of defined linguistic variables, the finer the fuzzy domain can be divided, the more comprehensive the coverage, and the better the final control effect, but the more corresponding rules, the more complexity increases. The fewer numbers defined, the simpler the rules of control, and yet result in smaller coverage of the rules and unsatisfactory system control [15]. The number of input and output linguistic variables defined in this design are all set to 7, which leads to a better manifestation of the control system. In order to facilitate the assignment of fuzzy variables and the formulation of fuzzy rule responsive table, the linguistic variables, the actual domain and the fuzzy domain of variables in this design are shown in table 1. The linguistic variables of the input and output are explained separately.

(a) For *E*, ZO means that the current soil moisture is optimal. NB, NM and NS represent three levels of soil moisture less than the optimal soil moisture with decreasing intensity in order. PS, PM and PB represent three levels of soil moisture greater than the optimal soil moisture with increasing intensity in order.

(b) For *EC*, ZO indicates no change for soil moisture. NB, NM and NS show the decrease of soil moisture variation, in order of decreasing speed. PS, PM and PB show the increase of soil moisture variation, in order of increasing intensity.

(c) For *TIME*, ZO denotes that no irrigation is required. PS, PS+, PM, PM+, PB and PB+ present sequentially increasing time of solenoid valve opening.

Table 1. Theoretical and linguistic variables of input and output

Variables	Linguistic Variables	Actual domain	Fuzzy domain
E	NB、NM、NS、ZO、PS、PM、PB	-0.1~0.1	-6~6
EC	NB、NM、NS、ZO、PS、PM、PB	-0.03~0.03	-6~6
TIME	ZO、PS、PS+、PM、PM+、PB、PB+	0~40	0~6

The quantitative factor is defined as the coefficient of the transformation mapping from the actual domain to the fuzzy domain, and, the quantitative factors of *E* and *EC* are derived respectively as 0.6 and 1 according to table 1. The mapping of the ratio factor is reversed, and the ratio factor of the output variable *TIME* gets calculated as 400.

2.2 Formulation of rules and rule responsive tables for fuzzy control

The affiliation function quantitatively describes the mapping relationship from the exact values of the input variables to the fuzzy ensembles and serves as a prerequisite for fuzzy inference. The performance of the fuzzy control system is tuned by adjusting the coverage area and position of the affiliation function on the fuzzy domain. In this paper, the input variables (*E* and *EC*) and the output variable (*TIME*) are distributed uniformly over the entire theoretical domain by adopting the triangular subordination function.

The fuzzy rules are created on the basis of practical working experience and theoretical knowledge. The controlling principle of intelligent irrigation is to select the output in the direction of minimizing the deviation when the soil moisture deviation is large, and to keep the soil moisture as stable as possible when the deviation is small to avoid overshoot, which is similar to the KP rule in PID control. Currently, intelligent irrigation systems have no actuators to react for over-wetting situations [16]. The fuzzy logic rules are given in table 2. As an illustration, if *E* is NM and *EC* is NB, then *TIME* is PB.

The accurate input is fuzzified by the fuzzy controller into the domain of the variable and the result is derived from the query responsive table so as to control the actuator, which can significantly improve efficiency and save memory [11]. The quantitative domains of *E* and *EC* are assigned as {-6, -5, -4, -3, -2, -1, 0, l, 2, 3, 4, 5, 6} and the quantitative domains of *TIME* are {0, 0.5, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6}. The relationship matrix is computed in accordance with the fuzzy rules, and the output fuzzy vector is obtained under the action of inputs E and EC based on the similar principle as the single-input and single-output fuzzy control algorithm. Then the maximum central affiliation method is applied for defuzzification to obtain the precise amount of the output, and the response of fuzzy rules is shown in table 3 after several parallel computational processes.

Table 2. The fuzzy rules for input and output

TIME		***E***						
		NB	NM	NS	ZO	PS	PM	PB
EC	NB	PB+	PB	PM+	PM	ZO	ZO	ZO
	NM	PB	PM+	PM	PS+	ZO	ZO	ZO
	NS	PM+	PM	PS+	PS	ZO	ZO	ZO
	ZO	PM	PS+	PS	ZO	ZO	ZO	ZO
	PS	PS+	PS	ZO	ZO	ZO	ZO	ZO
	PM	PS	PS	ZO	ZO	ZO	ZO	ZO
	PB	PS	ZO	ZO	ZO	ZO	ZO	ZO

Table 3. The response of fuzzy rules

TIME		***E***												
		-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6
EC	-6	6	5.5	5	4.5	4	3	3	3	0	0	0	0	0

	-5	5.5	5.5	4.5	4.5	3.5	2.5	2.5	2.5	0	0	0	0	0
	-4	5	4.5	4	3.5	3	2	2	2	0	0	0	0	0
	-3	4.5	4.5	3.5	3.5	2.5	1.5	1.5	1.5	0	0	0	0	0
	-2	4	3.5	3	2.5	2	1	1	1	0	0	0	0	0
	-1	3.5	3.5	2.5	2.5	1.5	0.5	0.5	0.5	0	0	0	0	0
	0	3	3	2	2.5	1	0	0	0	0	0	0	0	0
	1	2.5	2.5	1.5	1.5	0.5	0	0	0	0	0	0	0	0
	2	2	1.5	0.5	1.5	0	0	0	0	0	0	0	0	0
	3	1.5	1.5	0.5	1.5	0	0	0	0	0	0	0	0	0
	4	1	0.5	0.5	1.5	0	0	0	0	0	0	0	0	0
	5	1	0.5	0.5	0.5	0	0	0	0	0	0	0	0	0
	6	1	0.5	0.5	0	0	0	0	0	0	0	0	0	0

3. SIMULATION AND COMPARISON OF FUZZY CONTROL

3.1 Design and simulation of fuzzy controller

In this paper, the Mamdani system is adopted based on the default model, with the input variable and output variable set in MATLAB. Then the number of fuzzy subsets of variables and the affiliation functions are added, and the distribution of the affiliation functions are shown in figure 4, 5, and 6. A Sugeno fuzzy logic system is created by generating and modifying the logic with the formulated rules in chapter 2.

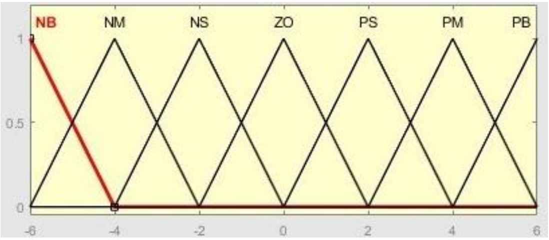


Fig. 4. Affiliation function of the soil moisture deviation

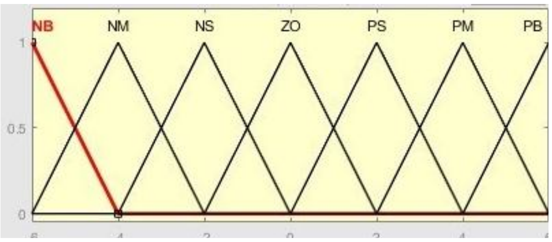


Fig. 5. Affiliation function of the rate of change for soil moisture deviation

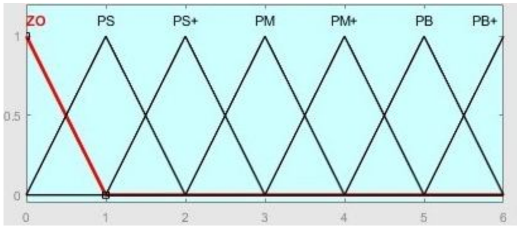
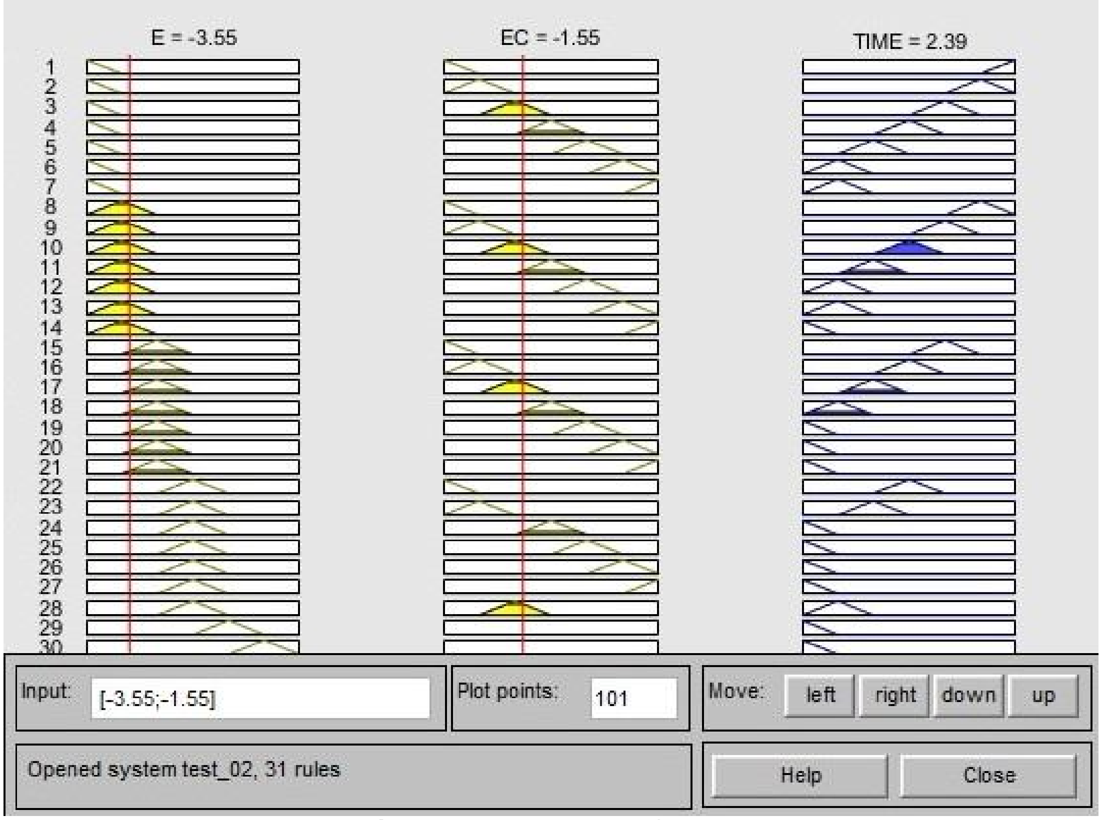


Fig. 6. Affiliation function of the irrigation time

The affiliation weighted average method is utilized by the Rules output of the fuzzy controller, with the output value by setting different input value to be viewed. Figure 7 illustrates that when the input deviation *E* is -3.55, which corresponds to falling between NM and NS, and the rate of change for deviation *EC* is -1.55, which corresponds to falling between NS and ZO in the affiliation functions respectively. This situation indicates that the soil is mildly to moderately water deficient, with the accompanying moisture is decreasing slightly. The output obtained by checking table 2 of fuzzy rules has PS+ and PM, corresponding to figure 6, the output is supposed to be between 2 and 3, which is consistent with the output of Rules. Therefore, the correctness of rule input is determined and the reasonableness of rules setting is judged. The output of Surface is given in figure 8. The 3D graph presented by Surface visualizes the trend of irrigation time versus soil moisture deviation and the rate of change for soil moisture deviation, and also provides a preliminary perspective to view the rationality of the rulemaking.



Input: [-3.55;-1.55]

Plot points: 101

Opened system test_02, 31 rules

Fig. 7. Output results of Rules

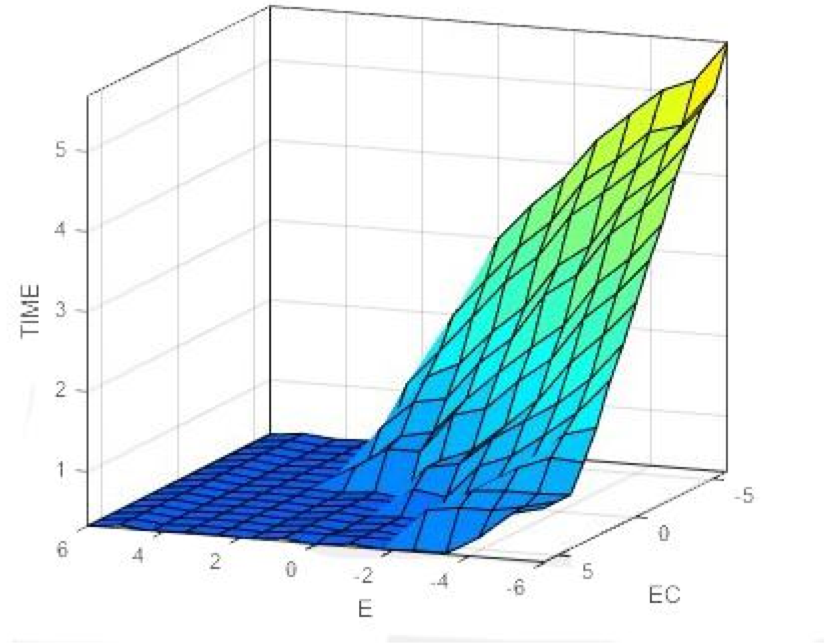


Fig. 8. Output results of Surface

3.2 Simulink simulation and comparison of model building

The fuzzy controller was put into the workspace after the design was finished. The simulation model designed in the Simulink environment consists of the input step signal, proportional module, limit module, fuzzy controller module, sine wave function module, delay module and indicator module, as shown in figure 9. The soil moisture deviation is transmitted to the fuzzy controller through quantization and limiting, then makes decisions based on the integration [17]. The output irrigation volume is amplified by a ratio factor to obtain the change in soil moisture based on the function of soil moisture and irrigation time, which is displayed and fed back to the input. Further, the closed-loop system is constituted with the decision period set to 0.1 s.

The scale module of the model is set according to the quantization factor and ratio factor, while the parameters of the limiting module are set according to the theoretical domain. The delay is employed to characterize the inertia and hysteresis of the system. The dependency function between the deviation of soil moisture and irrigation time is denoted as

$$\Delta = A\sin\left(\frac{2\pi t}{T}\right) \qquad (3)$$

where A is the controllable value of flow rate and T is depended on the drip irrigation rate in the actual system.

During the maximum irrigation time, the soil moisture varies from 9.56% to 28.07%. Therefore, T in this model can be calculated and modified to 1350, which leads to complete the setting of the sine wave function. Meanwhile, the PID control simulation model shown in figure 10 is established for comparison, with the same input step signal, output function, and delay time as the fuzzy control system.

When the step signal for a given input is 25, the results of the fuzzy controller simulation are obtained by using the display module as an oscilloscope, as shown in figure 11. There is a small and stable error range for the final value [18]. Nevertheless, for irrigation systems, which have a wider range of optimum soil moisture, the defined optimum soil moisture is in the middle with little impact of this scale. The obvious benefit of PID control is no large overshoot or fluctuations, and the results are given in figure 12.

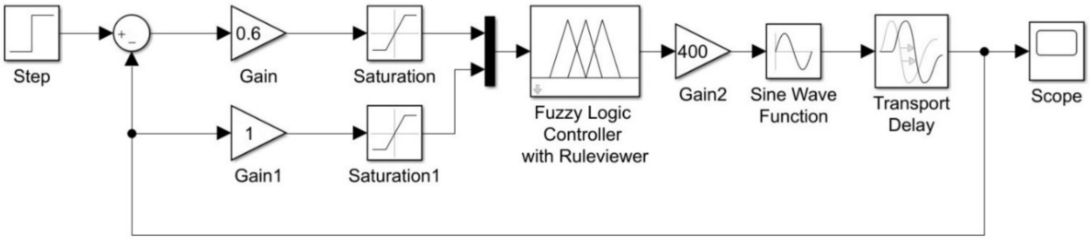


Fig. 9. The simulation model of fuzzy control

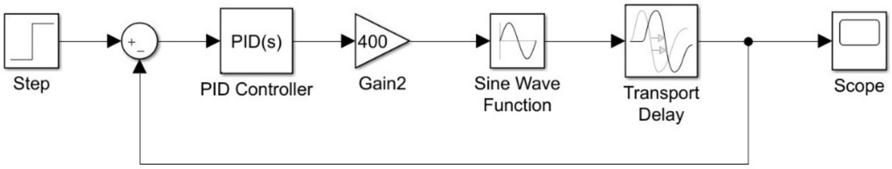


Fig. 10. The simulation model of PID control

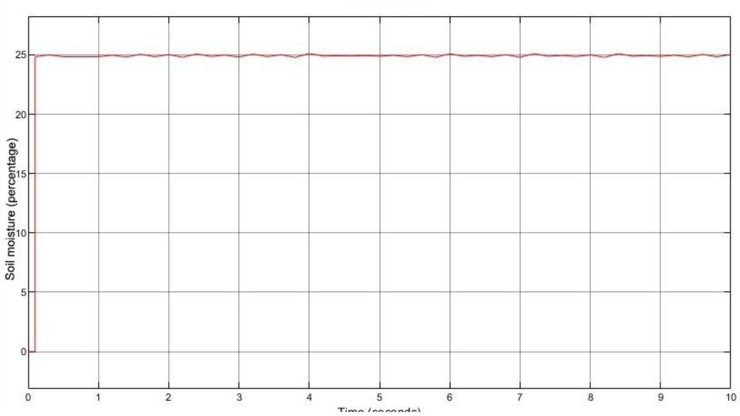


Fig. 11. The simulation results of fuzzy controller

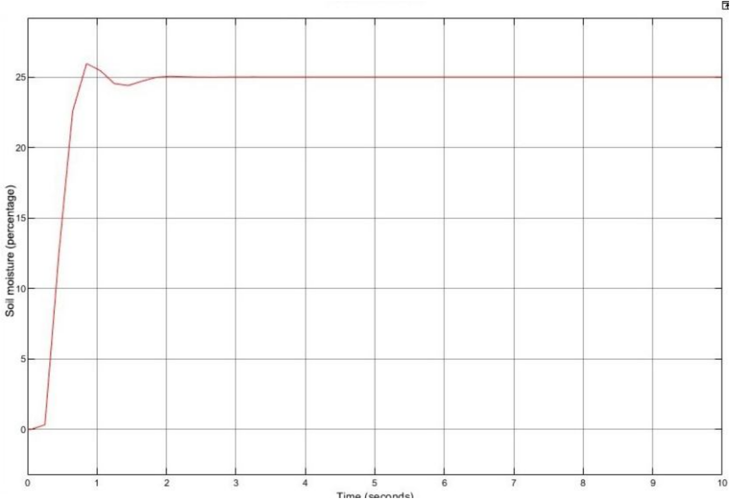


Fig. 12. The simulation result of PID controller

4. CONCLUSION

Aiming at the problem that conventional agricultural irrigation methods are limited to adjust the soil water demand promptly, a fuzzy control system is designed to perform intelligent and precise operation. The feasibility of the design solution was verified by the simulation and comparison experiments in Simulink. The results demonstrated that the system operates well and solves the problem of irrigating at the proper time, in the proper amount and automatically based on soil moisture, which contributes favorably to crop growth, cultivation and water conservation. Excellent energy conservation effects of the research idea also provide valuable reference for the development in modern agricultural greenhouses.

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