Design and implementation of expert decision system in Yellow River Irrigation

Wang Fuping\textsuperscript{1,*}, Lei Bingbing\textsuperscript{2}, Pan Jie\textsuperscript{1}

\textsuperscript{1}School of innovation and entrepreneurship, North Minzu University, Yinchuan, China
\textsuperscript{2}School of computer science and engineering, North Minzu University, Yinchuan, China

*Corresponding author e-mail: w_fuping@126.com

Abstract: How to make full use of water resources in the Yellow River irrigation is a problem needed to be solved urgently. On account of the different irrigation strategies in various growth stages of wheat, this paper proposes a novel irrigation expert decision system basing on fuzzy control technique. According to the control experience, expert knowledge and MATLAB simulation optimization, we obtain the irrigation fuzzy control table stored in the computer memory. The controlling irrigation is accomplished by reading the data from fuzzy control table. The experimental results show that the expert system can be used in the production of wheat to achieve timely and appropriate irrigation, and ensure that wheat growth cycle is always in the best growth environment.

1. Introduction

The Yellow River benefits to Ningxia. In Ningxia, the land was flat and expansive, and the irrigation from Yellow River has a long history in there. With the restriction of water withdrawals from Yellow River and the continuous increase of the demand for water resource, water resource has become the bottle neck in the social economic sustainable development of Ningxia. Therefore, spreading water-saving irrigation is of great importance to the irrigation from Yellow River in Ningxia. Based on automatic monitoring and measurement technology, the water-saving irrigation system could be used in Precision Irrigation by analyzing the characteristics of the crop water requirement and the properties of the farmland soil.

A novel expert decision system which is proposed for water-saving irrigation using the fuzzy control technology in this paper. The system has no necessary to establish the exact model of mathematical, meanwhile it is suitable for the nonlinear, impossible to model and dynamic farmland water-saving irrigation system. On account of the difference in wheat favorable growing conditions at different growth stages, we design this decision system to ensure the wheat growth environment at best stage according to the irrigation water demand in the different growth stages of wheat by calling

* About the authors: Fuping Wang was born in 1963. He is currently a master tutor and a professor with the Innovative-venturing Education Centre, North Minzu University, Yinchuan, China. His research interests focus on information detection and computer controlling technology. He has authored more than 30 papers published in national and international journals. He has implemented 1 project from National Natural Science Foundation, 5 projects at the provincial and ministerial level.
control tables. Experimental results show that the expert decision system reaches the requirement of Precision Irrigation.

2. Effect of climate change on wheat growing in Ningxia

There are 12 stages, such as seedling, three-leaf, tillering, overwintering, returning green, standing, jointing, booting, heading, flowering, filing and maturity in a growth period of wheat. The cycle of filling stage includes grain forming stage, milk ripe stage, wax ripeness stage and full-ripening stage. According to the effect of climate change on the different growth stage of wheat, the growth stage of wheat can be divided into 6 periods. The influence factors of each period of wheat growth are shown in Table 1.

| Period Factor          | Water      | Temperature                  | Water and thermal product |
|------------------------|------------|------------------------------|---------------------------|
| seedling-three leaf    | ----       | Optimum:20℃                 | ----                      |
|                        |            | Upper and lower bounds:39.2℃, 0.8℃ |                           |
| three leaf-jointing    | Optimum:151.1m m Upper and lower | Developing speed will increase with temperature | ----                      |
| jointing-booting      | ----       | ----                         | Optimum:2425.1m m ℃ Upper and lower |
| booting-flowering      | ----       | ----                         | Optimum:2670.9m m ℃ Upper and lower |
| flowering-milk ripe    | ----       | ----                         | Optimum:3696.3m m ℃       |
| milk ripe-maturity     | Developing speed will increase in straight line with | ----                      |                           |

Since the growing conditions of wheat are primarily influenced by temperature when wheat is in the period of seedling-three leaf, farmland temperature is selected as the critical point of irrigating. In the period of three leaf-jointing and milk ripe-maturity, the growth of wheat is mainly affected by water condition, so that we choose the water condition as the point. When wheat is in the period of jointing-booting, booting-heading and heading-flowering, we select the water and thermal product for the critical point of irrigating because the mostly influence fact of wheat growing is interaction between farmland temperature and water.

The water and thermal product (WTP) is defined as the product of \( \text{the thickness of water layer}(\text{TWL}) \) and temperature.

\[
\text{WTP} = (\text{TWL}) \times \text{Temperature} \tag{1}
\]

The data measured by water sensor is relative soil water content. Therefore, the thickness of water layer (TWL) can be got by calculating the product of \( \text{the thickness of soil}(\text{TS}) \), the relative water content of soil (RWS) and the field capacity (FC).

\[
\text{TWL(mm)} = \text{TS} \times \text{RWS} \times \text{FC} \tag{2}
\]

3. Design of expert decision system for water-saving irrigation

An expert decision system for water-saving irrigation was presented using the FC (Fuzzy Control) technology, and the essential of the design is a fuzzy controller. Considering the demand in the different growth stages of wheat, we design the fuzzy control rule tables correspond to the need of
various wheat growth stages. According to the time ranges of the different wheat growth stages, the timely and appropriate irrigation is realized by calling the tables of FC rule. In this part, the table of FC rule correspond to the period of jointing-booting is described in detail, and so on.

3.1. Design of Fuzzy Controller

In this section, a 2D fuzzy controller which has dual inputs and single output is given to achieve the goal of water-saving irrigation, and its schematic diagram is shown in Figure 3.1.

![Schematic diagram of fuzzy control system](image)

In Fig. 3.1, we can see that this system of fuzzy control has a closed loop control system similar to traditional control system, which is extension and complement of the traditional control system. In the fuzzy control system, the biggest ingredient difference is that the fuzzy controller is adopted instead of the traditional one. The fuzzy controller is proposed for the fuzziness of input signal, which can be used to design the control rules and make fuzzy reasoning through knowledge base and expert experience. The back fuzzy of the output was given, and finally the goal of water-saving irrigation is achieved by controlling open and close of the electromagnetic valve.

3.2. Input and Output of Fuzzy Controller

In the period of jointing-booting, we select the water and thermal product as the critical point of irrigating. The dual input parameters of the fuzzy controller have difference between initial and real measurement value of the water and thermal product $e$, or its change rate $ec$. The irrigating time $u$ is the single output parameter. The sampling period is 60 min. The basic domain of the parameter $e$ is [-1882.5, 1945.5]. The basic domain of the parameter $ec$ is [-63.8, 63.8]. The basic domain of the parameter $u$ is [0, 40].

The variables of fuzzy of the parameter $e$, $ec$ and $u$ are $E$, $Ec$ and $U$ respectively. The input fuzzy variables $e$ and $Ec$ both include 7 linguistic variables, for example NB, NM, NS, 0, PS, PM and PB. Their quantitative domains are [-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4]. The output fuzzy variables $U$ includes 4 linguistic variables, such as 0, PS, PM and PB. Their quantitative domains are [0, 1, 2, 3, 4]. Then the quantifying factor of the parameter $e$ can be written as

$$K_1 = \frac{2 \times 6}{1945.5 - (-1882.5)} = 3.13 \times 10^{-3}$$

The quantifying factor of the parameter $ec$ can be given

$$K_2 = \frac{2 \times 6}{63.8 - (-63.8)} = 0.094$$

The quantifying factor of the parameter $u$ can be defined as

$$K_u = \frac{40}{4} = 10$$

3.3. Linguistic Assignment Tables of Fuzzy Variables

There are various membership functions of the fuzzy number, and we choose the triangular membership function. The fuzzy parameter was given according to the membership function, so we gain the linguistic assignment table. As shown in Fig. 3.3.1 the parameter $E$ and $Ec$ are using the same membership function. The membership function of the parameter $U$ is shown in Fig. 3.3.2.
According to membership function shown in Fig. 3.3.1 and Fig. 3.3.2, we can get the linguistic assignment tables of the parameter $E$, $Ec$ and $U$ as showed in Table 2 and 3.

Table 2. Linguistic assignment table of Input variables $E$, $Ec$

| Language | Membership Function Grade | -6 | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|----------|--------------------------|----|----|----|----|----|----|---|---|---|---|---|---|---|
| FD       | 1.0 0.5                  | 0  Z | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| FZ       | 0.5 1.0                  | 0  Z | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| FX       | 0.5 1.0                  | 0  Z | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| ZO       | 0.5 1.0                  | 0  Z | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| ZX       | 0.5 1.0                  | 0  Z | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| ZZ       | 0.5 1.0                  | 0  Z | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| ZD       | 0.5 1.0                  | 0  Z | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |

Table 3. Linguistic assignment table of output variable $U$

| Language | Membership Function Grade | 0 | 1 | 2 | 3 | 4 |
|----------|--------------------------|---|---|---|---|---|
| ZO       | 1.0 0.2                  | 0 | 0 | 0 | 0 | 0 |
| ZX       | 0 0.7 0.5                | 0 | 0 | 0 | 0 | 0 |
| ZZ       | 0 0 0.5 0.7 0            | 0 | 0 | 0 | 0 | 0 |
| ZD       | 0 0 0 0.2 1.0            | 0 | 0 | 0 | 0 | 0 |

3.4. Determining of fuzzy control rule

The rules of fuzzy control come mainly from expert experience and knowledge base, which can be described as a set of description rules. This paper present a control system with two inputs and one output, which uses conditional statements (if $A=E$ and $B=EC$ then $C=U$). The condition encountered during irrigation and corresponding control policy is summarized and listed in the following Table4.
Based on Table 2, Table 3 and Table 4, the fuzzy relational \( R_i, (i = 0, 1, 2 \ldots 49) \) corresponding to the condition statements during the period of wheat jointing-booting can be calculated. Thus we get

\[
R_i = (E_n^T \cdot EC_n)^T \cdot U \cdot Z
\]

(6)

where the linguistic variables of the parameter E, Ec and U are m, n and z respectively. Hence we can get the fuzzy relationship in that time period

\[
R = R_1 \cup R_2 \cup R_3 \ldots \cup R_n
\]

(7)

The table of fuzzy control can be set up through calculation, and shown in Table 5.

### Table 4. Table of fuzzy control rule for water-saving irrigation system

| U  | E  | FD | FZ | FX | Z0 | ZX | ZZ | ZD |
|----|----|----|----|----|----|----|----|----|
| FD | ZO | ZO | ZO | ZO | ZO | ZO | ZO | ZO |
| FZ | ZO | ZO | ZO | ZO | ZO | ZO | ZO | ZO |
| FX | ZO | ZO | ZO | ZO | ZO | ZX | ZX | ZX |
| ZO | ZO | ZO | ZO | ZO | ZO | ZX | ZX | ZX |
| ZX | ZO | ZO | ZO | ZO | ZO | ZD | ZD | ZD |
| ZZ | ZO | ZO | ZO | ZO | ZO | ZD | ZD | ZD |
| ZD | ZO | ZO | ZO | ZO | ZO | ZD | ZD | ZD |

Table 5 is stored to computer memory. After quantifying two input variables, the quantification level of the output variable can be obtained by querying the table. The irrigating time can be gained through fuzzy(multiplying scale factor Ku), so we can accomplish the goal by controlling the opening time of the strobe.

### Table 5. Table of fuzzy control

| Ec | U | -6 | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|----|---|----|----|----|----|----|----|---|---|---|---|---|---|---|
| -6 | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| -5 | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| -4 | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| -3 | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| -2 | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| -1 | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 0  | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 1  | 2  | 3  | 3  | 3  | 3  | 3  |
| 1  | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 1  | 2  | 3  | 3  | 3  | 3  | 3  |
| 2  | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 1  | 2  | 3  | 3  | 3  | 4  | 4  |
| 3  | 0  | 0  | 0  | 1  | 1  | 2  | 3  | 3  | 3  | 4  | 4  | 4  | 4  | 4  |
| 4  | 0  | 0  | 0  | 0  | 1  | 1  | 2  | 3  | 3  | 3  | 4  | 4  | 4  | 4  |
| 5  | 0  | 0  | 0  | 2  | 2  | 3  | 3  | 3  | 4  | 4  | 4  | 4  | 4  | 4  |
| 6  | 0  | 0  | 0  | 2  | 2  | 3  | 3  | 4  | 4  | 4  | 4  | 4  | 4  | 4  |

3.5. Simulation Verification

As shown in Fig. 3.5.1, we get the surface chart output variable through MATLAB simulation experiment. In Fig. 3.5.1, each axis of the chart that represents a fuzzy variable, and axis range is the domain of fuzzy variable. The chart is the equivalent of fuzzy control table. Through comparing with Fig. 3.5.1, we can evaluate the correctness of Table 5.
4. Software design of system

A JAVA program is designed to realize this fuzzy control system by logging Table 5 into computer memory. It extracts storage sensors data from database at 60-minute intervals. The water and thermal product can be calculated from the storing sensors data. In control process, compare set point of system water and thermal product with corresponding value measured by sensor, we can obtain the water and thermal product of soil e(k1) and its error rate ec(k2) per 60-minute. Through fuzzifying the parameter e(k1) and ec(k2), we get fuzzy output value by querying Table 5. According to refining the value of fuzzy output, controlling irrigation time can be implemented.

![Figure 3.5.1 output surface chart](image)

![Figure 4.1 Fuzzy control flow chart](image)
5. Conclusions
This paper, based on the difference in wheat favorable growing conditions and the irrigation water demand in the different growth stages, gives the water-saving irrigation system to achieve the requirement of which irrigation water in the different growth stages of wheat. Based on fuzzy control technology, it applies peasant irrigation experiences to computers control system through using soil water condition, farmland temperature and water and thermal product as index. Experimental results demonstrate that the expert decision system can realize the timely and appropriate automatic irrigation in accordance with the change of soil environment.

Acknowledgments
Foundation project: University-level key science and technology service project, the key technology of water-saving irrigation with wireless network research for the precision agricultural. (Grant NO. 2015KJ01)

References
[1] Xie Shouyong, Li Xiwen, Yang Shuzi, He Binghui, “Design and implementation of fuzzy control for irrigating system with PLC”, Transactions of the CSAE, vol.23, No.6, PP-208-210, 2007.
[2] Wang Liwen, Bao Hairong, Li Chunyang, “Construction of Automatic Spray Irrigation System of football ground lawn”, China Water and Waste water, vol.22, No.24, PP-98-100, 2006.
[3] LIU Yong, PENG Zhenghong, “Design and simulation of fuzzy logic control system based on MATLAB”, Engineering Journal of Wuhan University, vol.41, No.2, PP-132-135. 2008.
[4] Kuang Yingchun, Shen Yue, Duan Jiannan, Yao Bangsong, “Application of fuzzy control to automatic water-saving irrigation of rice”, Transactions of the CSAE, vol.27, No.4, PP-18-21, 2011.
[5] HUANG Feng, SHIXin-min, ZHENG Peng-hui, FANG Ning-lian, YANG Bao-ling, “Regional Simulation of Spring Wheat Growth in Ningxia Under the Climatic Change Conditions”, Journal of Arid Land Resources and Environment, vol.21, No.9, PP-118-122, 2007.