On Fuzzy Logic based Model for Irrigation Controller using Penman-Monteith Equation

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ABSTRACT
In this paper design for fuzzy logic based irrigation controller using penman-Monteith equation is proposed. The irrigation requirement for any crop is the amount of water that must be applied to meet the crop's evapotranspiration (ET). The amount of (ET) includes water that is needed for both evaporation and transpiration. Penman Monteith equation is used to compute the actual evapotranspiration. Here difference between actual and desired evapotranspiration is one of the input parameter to fuzzy inference system. The longer the crop growth period the higher is the water requirement. Therefore month after sowing a crop is also an important parameter taken into consideration. As there is no mathematical model exists for both parameters, fuzzy logic technique is most suitable for modeling. This paper also discusses fuzzy inference system for fuzzy irrigation controller.

General Terms
Design, Modeling, simulation, controller

Keywords
Fuzzy inference System, Fuzzy Controller, Penman Monteith equation, irrigation controller

1. INTRODUCTION
In the field of agriculture crop irrigation management plays key role. Effective utilization of water resources as well as preventing water losses is equally important. For this estimation of water requirement of the crop is needed. The irrigation requirement for any crop is the amount of water that must be applied to meet the crop's evapotranspiration (ET) needs. The amount of (ET) includes water that is needed for both evaporation and transpiration. Evaporation occurs from all wet surfaces, including soil, water and plants. Transpiration is the evaporation from plant through the leaves stomata. Both evaporation and transpiration occur in response to climate demand.

A large number of more or less empirical methods have been developed over the last 50 years by numerous scientists and specialists worldwide to estimate evapotranspiration from different climatic variables. To accommodate users with different data availability, four methods were presented to calculate the reference crop evapotranspiration (ETo): the Blaney-Criddle, radiation, modified Penman and pan evaporation methods. The analysis of the performance of the various calculation methods reveals the need for formulating a standard method for the computation of ETo. The FAO Penman-Monteith method is recommended as the sole standard method [1]. It is a method with strong likelihood of correctly predicting ETo in a wide range of locations and climates and has provision for application in data-short situations.

Aim of this research work is to help in irrigation management by estimating water requirement of the crop using FAO Penman-Monteith equation and implementing a model of irrigation controller using advanced soft computing methods. Estimated Evapotranspiration is compared with the required Evapotranspiration of crop. Initially conventional on-off irrigation controller is modeled. Further advancement in controller design has been done with the help of fuzzy logic. Error value of evapotranspiration is acting as one input to fuzzy controller. The longer the crop growth period the higher will be the water requirement. Therefor month after sowing a crop is another input parameter for fuzzy controller. The result of both type of controller was observed. Complete modeling process is carried out in MATLAB environment.

2. LITERATURE REVIEW
System and the complexity of the system are directly related to the requirements of the system's application. Control systems are broadly classified as either closed loop or open loop. An open-loop control system is controlled directly, and only, by an input signal where as in close loop feedback from the output is also fed to input side. The major factor in the irrigation process is the time. Therefore, the open-loop controller uses a periodic irrigation policy [3].

Fuzzy Logic Controllers have been widely applied to both consumer products and industrial process controls. In particular, FLC's are very effective techniques for complicated and imprecise processes for which either no mathematical model exists or the mathematical model is severely nonlinear, because FLC's can easily approximate a human expert's control behaviors that work fine in such ill-defined environments [2].

Factors which determine the total water requirements of a crop are Evapotranspiration, Permeability of soil, Drainage, The length of the growing season, The levelness of the soil surface. Some of these parameters are fixed for the session and are of an agricultural and some of them vary and should be measured during the irrigation process. These parameters are of a physical nature (such as temperature, air humidity, radiation in the ground, soil humidity, etc.). So when these conditions change, the amount of water being used for the irrigation should change also [4].

This system is designed for two parameters evapotranspiration and the length of the growing season. The length of growing season is going to vary with the type of crop. Here the fuzzy controller is specifically designed for rice. Growing season for rice is 6 months.

3. MATHEMATICAL MODELING
Water is used by crop through evaporation from the soil or water surface and by transpiration through the leaves. In the early stages of crop growth, most water is used through evaporation. However,

when the crop develops a full canopy cover, transpiration accounts for most of the water used. The combined use, which is called evapotranspiration (ET)

The total evapotranspiration varies from crop to crop. This quantity depends on seasonal conditions such as temperature, humidity, wind and sunlight hours as well as the length of the growing period. The Food and Agriculture Organization (FAO) of the United Nations has been proposed the famous and well known Penman-Monteith equation, Allen et al. [1], as the most adequate method of calculating the reference evapotranspiration (ET_O). The crop water requirements which is equal to the evapotranspiration (ET) for any crop can be calculated from the equation (ET = kC x ET_O), where the value of the crop coefficient (kC) is known for different crops at different growing stages. The most frequently used method employed to evaluate any crop ET uses the Penman- Monteith equation for calculating the value of (ET_O). Associated correlations for predicting solar radiation, evaporation from bare soil associated with crop transpiration are based on a water balance of the soil surface layer. The reference evapotranspiration (ET_0) is given in (mm/day) from the Penman-Monteith equation as,

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \qquad (1)$$

Where, Rn is the net solar radiation at the crop surface (MJ/m2 day), G soil heat flux density (MJ/m^2 day), T mean daily air temperature at 2 m height (°C), U_2 wind speed at 2 m height (m/s), e_s saturated air vapor pressure (kPa), e_a vapor pressure of the actual air (kPa), Δ slope of saturated air vapor pressure curve (kPa/°C), and γ is the psychrometric constant (kPa/°C).

In this system the net radiation Rn, Mean daily air temperature T, Wind speed U2 and relative humidity RH which is required to calculate vapor pressure of the actual air e_a are artificially generated as sine wave. Remaining all the parameters are reduced in terms of temperature

The psychrometric constant, γ is given by,

$$\gamma = \frac{C_p P}{\varepsilon \lambda} \qquad (2)$$

Where, P is the atmospheric pressure = 101.3 (kPa)

Cp specific heat at constant pressure = 1.005 (KJ/kg °C),

ε ratio between molecular weight of water vapor/dry air = 0.622,

and λ is the latent heat of vaporization (MJ/kg)

The latent heat of vaporization (λ) is given as a function of air temperature by Harrison [3] as,

$$\lambda = 2.51 - 2.361 \times 10^{-3} T \qquad (3)$$

Substituting equations(3) in (2), the psychrometric constant can be written respectively as,

$$\lambda = 1 / (15.33517 - 0.014425\, T) \qquad (4)$$

The slope of saturation vapor pressure curve (Δ, kPa/°C) can also be obtained in terms of air temperature (T, °C) as given by Murray [7] in the following formula,

$$\Delta = \frac{4098\left[0.6108 \exp\left(\frac{17.27T}{T+273}\right)\right]}{(237.3+T)^2} \qquad (5)$$

The following best fit equation given by [8] is used for computation of Δ.

$$\Delta = 0.00021501\, T^2 - 0.00025132\, T + 0.061309 \qquad (6)$$

Saturated air vapor pressure e_s (kPa), can be obtained from the equation

$$e_s = 0.6108 \exp\left(\frac{17.27\,T}{T+237.3}\right) \qquad (7)$$

The equation is reduced and can be expressed as given by [8]. It is used here for estimating saturated air vapor pressure e_s.

$$e_s = 7.167 \times 10^{-5} T^3 + 7.167 \times 10^{-4} T^2 + 0.061309T + 0.57075 \qquad (8)$$

Vapor pressure of the actual air e_a (kPa) depends on saturated air vapor pressure e_s and relative humidity RH which is defined as the ratio of actual vapor pressure in the air (e_a) to that of saturated air (e_s) at the same temperature. Relationship between these three parameters is given by

$$e_a = e_s \left(\frac{RH}{100}\right) \qquad (9)$$

The last parameter required to compute ETo is G soil heat flux density (MJ/m^2 day). G is directly depends on net radiation, hourly value can be approximated as 0.1 times of net radiation.

3.1 Proposed Methodology

The block schematic for the proposed system model is shown in Fig.1. It includes four input parameter blocks. Temperature, humidity, net radiation and wind speed are required to compute actual ET_0. All these parameters are fed to ET_0 estimator block which computes actual value of evapotranspiration. This value is compared with the desired value of ET_0 block and error value is used as the one input of the fuzzy controller. Another input to fuzzy controller is length of sowing period of crop. Output of controller decides the valve position required to fulfill the requirement of evapotranspiration of soil.

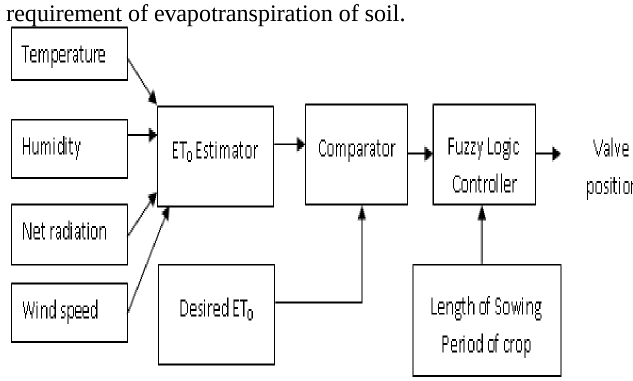

Fig 1: Proposed model for irrigation controller

Experimental frame work used for the implementation of this model is MATLAB 7.8.0.347. Complete model is structured in simulink. Mathematical model of ET_0 Estimator block is implemented with the help of embedded MATLAB function. Further the fuzzy inference system for fuzzy logic controller is designed using GUI tool of fuzzy logic toolbox.

3.2 Implementation

The design of conventional irrigation controller is implemented first. Input parameters temperature, humidity, net radiation and wind speed are simulated as sinusoidal signal and frequency is set according to 24 hrs (one day). In conventional controller output of controller can be controlled based on the difference between desired and actual ET0 estimated by estimator block. It is difficult in conventional controller to incorporate another parameter that is length of sowing period of crop, which shows the need of intelligent controller which can incorporate both the parameters simultaneously. This can be done with the fuzzy logic controller for which intelligent fuzzy inference system has designed. This system is designed for two parameters evapotranspiration and the length of the growing season. The length of growing season is going to vary with the type of crop. Here the fuzzy controller is specifically designed for rice. Growing season for rice is considered 6 months.

3.3 Fuzzy Inference System Design

The linguistic fuzzy variables 'large negative(LN)', 'small negative(SN)', ' equal(EQ)', ' small positive(SP)', ' large positive(LP)', 1,2,3,4,5,6, comprise the two fuzzy sets; evapotranspiration difference and month after sowing. First input has five fuzzy variables whereas second input has six fuzzy variables, as shown in Figure 3, and used to develop Linguistic Rules in Table 1. The products of these rules are then aligned to determine the valve position of the actuator.

The Table1 shows how input linguistic variables derives the output fuzzy sets, which are '(FC) full close', '(QO) quarter open', '(HO) half open', '(FO) Full open' .

Table1. Fuzzy input variables and corresponding output

Month after Sowing → / ET0 diff. ↓	1	2	3	4	5	6
LN	HO	HO	FO	FO	FO	HO
SN	QO	QO	HO	HO	HO	QO
EQ	FC	QO	HO	HO	HO	FC
SP	FC	FC	QO	QO	HO	FC
LP	FC	FC	FC	FC	FC	FC

The inputs have been fuzzified to obtain valve position, and the inference method has generated a rule matrix. The next process in the FL algorithm is defuzzification. MATLAB's default procedure is the Centroid Method, which uses the center of gravity (COG) equation shown in Eq. 10, with the solutions from each of the rules listed in Table 1.

$$\mu^{crisp} = \frac{\sum_i b_i \int \mu_{(i)}}{\sum_i \int \mu_{(i)}} \tag{10}$$

The equation used to derive the COG calculates the area in a particular output MF at height equal to that confidence level derived by that rule. Where µcrisp is the crisp output value. bi is the center of each output MF and is also called the weight factor, and providing that the MFs are symmetrical it can be shown that the area µ(i) beneath the confidence level can be derived by multiplying the MF's width by a factor of its height. The equation is listed below, as Equation 11.

$$\int \mu_{(i)} = w_i (h_i - \frac{h_i^2}{2}) \tag{11}$$

The Fuzzy Logic controller is composed of two inputs and one output. The two inputs are defined as the 'Difference' signal between the actual and desired evapotranspiration and the 'month after sowing' Using MATLAB the first objective is to define the FIS, further the fuzzy sets are defined with their range values. For each input as well as output variable range of interest is decided. Further the matrix is generated using the input variables and their MF names to derive the consequent to each premise. This is accomplished through a series of "IF premise THEN consequent" statements, which are inserted through the Rule-Editor using the fuzzy 'AND' method. After defining the rules the built-in Rule Viewer is used to verify any concept issues that may arise in the future.

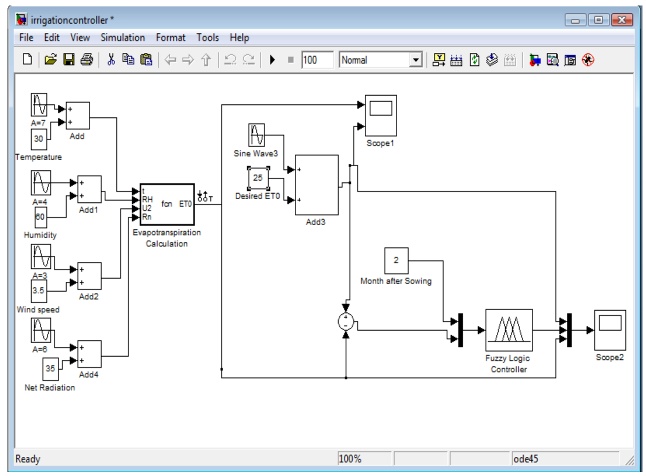

Fig 2 : The simulink model of irrigation controller with fuzzy logic block

4. RESULT AND DISCUSSION

Output waveform for conventional on-off irrigation controller is displayed in fig.3. It clearly shows the fluctuation in the output of controller, As the threshold error value is crossed controller switched on or off. Also there is no other way to add the intelligence of adding second parameter of crop sowing period. Fig. 4 shows the output for irrigation controller with fuzzy logic block. There is clear differentiation between the outputs of both type of controller. Pink colored waveform indicates output of fuzzy logic block, yellow waveform indicates desired ET0 and blue waveform indicates actual ET0. It shows that fuzzy controller output is varying according to the error value of actual and desired ET0. The change in output of controller is not abrupt as it was in conventional controller.

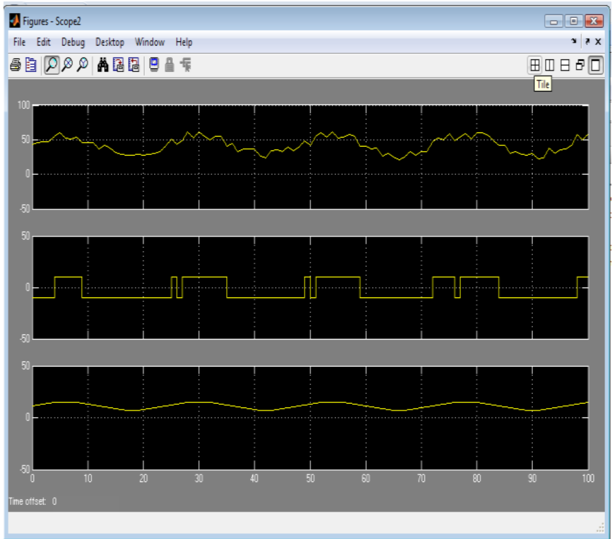

Fig 3: Output waveforms of conventional on-off irrigation controller

5. CONCLUSIONS

The design works very well and the outputs are very smooth. The new irrigation controller with fuzzy logic block is far superior to the conventional method. The conventional controller provides abrupt changes in the valve position either on or off. The irrigation controller with fuzzy logic block gives smooth output corresponding to error value of evapotranspiration and the month after sowing. This system can improve the performance of automatic irrigation management systems, increase the crop yield, reduces the human efforts and it can also save lot of water.

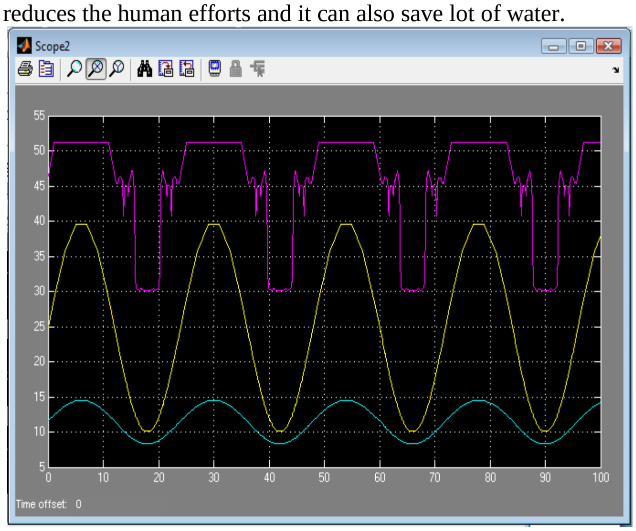

Fig 4: output of irrigation controller with fuzzy logic block

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