Simulation of Automated Irrigation ON-OFF Controller Based on Evapotranspiration Analysis

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Abstract— **Climate change tends to be extreme that have a negative impact on the productivity of agriculture business. An automated system is one attempt to solve the problem. This paper presents the development of ON-OFF controller on automated irrigation system based on evapotranspiration analysis. The input data included: temperature, heat radiation, wind speed and air pressure were used to calculate evapotranspiration using revised Penman Mointeith equation. Furthermore the output of such equation was used for input data of ON-OFF controller end then it was compared with a reference of soil moisture data. The use of ON-OFF controler, a reference of soil moisture is approximated by triangular signal, in which the deviation error can be decreased by reducing discretization sampling time. Sampling time of 0.5 second and 0.005 second yielded the deviation error of 30.5% and 11,1%, respectively.**

Keywords— evapotranspiration; ON-OFF controller; climate change; automated irrigation

I. INTRODUCTION

Climate change is the important issue that directly impact to the availability of food resources as well as the human living. In the agriculture business, climate change affect on the productivity and the product quality. The water availability in dry season is difficulty obtained, but it opposites in the wet season. To restore the productivity of agricultural products, application of automated agriculture system is importantly considered. Irrigation system can be automated by installing water control valve based on the time function. However the use of this controller, optimal growing condition of plant is difficulty achieved. The next technology uses a soil humidity control system. The use of this control system, pests can be minimized, although application of this controller was only success on water full land condition. The high cost in investment and the difficulty of maintenance of such sensors become considerations of the reasons why these sensors were not widely applied.

In the last decade, application of soil humidity sensors spreads widely and it was correlated to the reasoning of low cost in investment and maintenance. Currently, the goal of research activities in this area are aimed particularly to reduce water consumption based on smart controller system [1], [2]. Dukes (2012) developed smart controller based on water conservation on irrigation area. Based on water resources management system which used rain water as a supplement in irrigation system, long term retrenchment can reach around of 67% [3]. Application of automated irrigation system must consider the location of topographic and water resources. Development of smart irrigation system which is applicable on sand agriculture was performed by Michael et al [6]. The developed controller system based on evapotranspiration condition and level of water consumption was limited by the availability of water resources. The important key of this method was the scheduling of irrigation process based on the calculation of crop water balance [6]. Theoretically, water consumption in agriculture area is proportional to the content of water loss caused by land evaporation and transpiration of plants in this area, this called as evapotranspiration [5]. Reference of *ET* (*ETo*) is defined as the ET from a 3-6" tall cool season grass that completely covers the ground, and is supplied with adequate water. In the application, ETo is not routinely measured but instead computed from a mathematical formula such as the Penman or Penman-Monteith Equation. The empirical formulation can be performed by inputting several data include temperature, air pressure, radiation and wind speed. According to Allen et al [6], Penman-Monteith equation is expressed in Eq.1 as follow:

$$ET_{P-M} = \left[0.404\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)\right]/[\Delta + \gamma(1 + 0.34u_2)] \quad (1)$$

where : ET_0 = reference evapotranspiration [mm/day], R_n = net radiation at the crop surface [MJ m-2/day], G = soil heat flux density [MJ m-2 day-1], T = mean daily air temperature at 2 m height [°C], u_2= wind speed at 2 m height [m s 1], e_s = saturation vapor pressure[kPa], e_a = actual vapor pressure [kPa], $e_s - e_a$= e_0(T)= saturation vapor pressure deficit [kPa], D = slope vapor pressure curve [kPa °C-1], g = psychometric constant [kPa °C 1], P = atmospheric pressure [kPa], z = elevation above sea level [m], $e°(T)$ = saturation vapor pressure at the air temperature T [kPa], λ = latent heat of vaporization, 2.45 [MJ kg-1], Cp = specific heat at constant pressure, 1.013 10-3 [MJ kg-1 °C-1], ε = ratio molecular weight of water vapor/dry air =0.622

This work proposes the development of automated irrigation control system based on evapotranspiration analysis. By this control system, the irrigation water is controlled by balance analysis so that the soil moisture is kept constantly refers to the reference of soil moisture. Revised Penman-Monteith equation is used to calculated the actual evapotranspiration [7], and the result is employed as a reference input of the developed ON-OFF controller.

II. METHODOLOGY

This research simulates the automated irrigation system using ON-OFF control system. Input signals of the ON-OFF control were derived from analysis of the Equation of Revised Penman-Monteith evapotranspiration and the reference of soil moisture. The system is described as the following section.

Inputs of the modeling irrigation system included air temperature, air pressure, radiation and wind speed. Furthermore, the input data was used to calculate evapotranspiration condition that refers to the revised Penman -Montein equation. The error between the reference soil moisture conditions (which represents the optimal soil moisture conditions for crop cultivation) and evapotranspiration data is then used as the input data of ON-OFF control. Fig. 1 depicts block diagram of the proposed ON-OFF controller. Here, the irrigation water flow is assumed constant. The supplied water volume represents the needed soil moisture which is controlled by on-off periods of the solenoid valve.

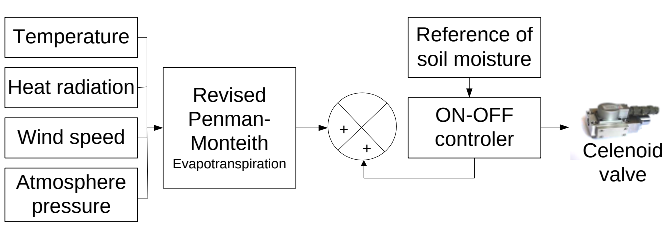


Fig. 1. Block diagram of ON-OFF controler of automated irrigation system.

A. Input Parameters

Calculation of evapotranspiration conditions was performed in cycle base of 24 hours using the weather data input. These data include: air temperature, radiation, wind speed and air pressure which were assumed as sinusiodal signal. Referring to the data, simulating data input is described as follows:

- Heat radiation is a major factor determines the rate of evapotranspiration. Heat radiation is a component on plants energy balance with respect to the net radiation. In fact, infrared radiation is also a component in the net radiation. However, the balance is always negative or zero so that it can be neglected. In this simulation, radiation was assumed as a sinusiodal signal with amplitude of 2 MJ/m^2 in range of 112 MJ/m^2. The frequency is 2π/24 or 0.2168 rad/hour derived from 24 hours cycle.
- Temperature and humidity are parameters that affect on the drought and the atmosphere drying capability. While, vapor pressure deficit (VPD) is a meteorological variables were used to measure the atmosphere drying capability. VPD shows the vapor pressure difference (concentration of water vapor) between plants and air-dried moisture. On the modeling, the air pressure is assumed as sinusiodal signal with amplitude of 5 kPa and the constant of 95 kPa. Frequency is 2π/24 or 0.2168 rad / hour.
- Temperature affects on alteration of the ET correlation VPD and also advection. When all other factors are equal, ET on warm conditions tend to be larger than the plant temperature. ET will increase for warm vegetation because less energy is required to evaporate the water. Temperature also impacts the relative effectiveness of the radiant energy and wind affects on evaporating water. Radiant energy is more effectively utilized for ET when temperatures are high. In contrast, wind has more impact on ET when temperatures are low. In this simulation, temperature is a sinusoidal signal with amplitude 5^oC in 24 hours cycle, so the frequency is 2π/24 or 0.2168 rad / hour. The temperature range (offset) is arround of 30^oC.
- The wind has two major roles; firstly, it transports heat that builds up on adjacent surfaces such as dry desert or asphalt to vegetation which accelerates evaporation (a process referred to as advection). Secondly, wind serves to accelerate evaporation by enhancing turbulent transfer of water vapor from moist vegetation to the dry atmosphere. In this case, the wind constantly replaces the moist air located within and just above the plant canopy with dry air from above. Wind speed was assumed as a sinusoidal curve with an amplitude of 1 km/h in range of 3.5 km/h.

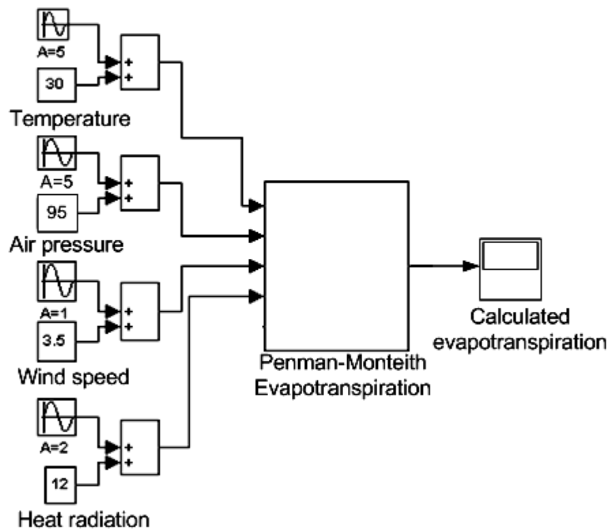
B. Reference Soil Moisture

Output parameter of the evapotranspiration calculation represents actual soil moisture influenced by weather parameters. Soil moisture conditions should be arranged to appropriated to the specific soil moisture which is determined by the cultivation plant type by adjusting water irrigation.

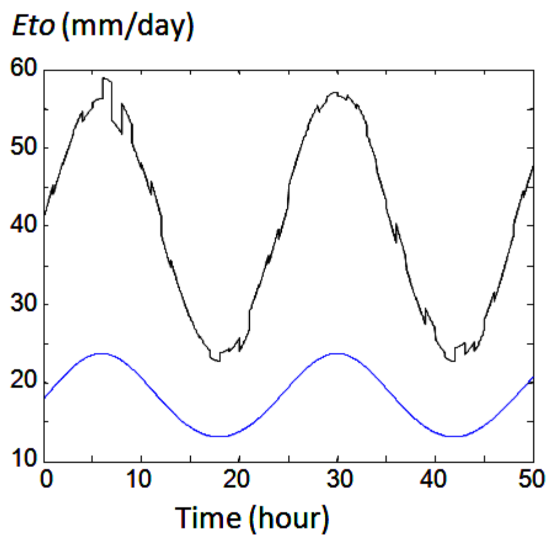
In real conditions, besides the type of plant, soil moisture is also influenced by age of plant and soil type. In this modeling, the reference soil moisture was assumed as an Gaussian sinusoidal signal. Reference soil moisture is assumed in a range of 35% with an amplitude of 15%, while the frequency is 2π/24 following the 24-hour cycle.

III. Result and Discussion

The model of input parameters of the revised Penman-Monteith evapotranspiration was simulated by using Matlab-Simulink software as presented in Fig. 2a. The result of simulated evapotranspiration process is a sinusoidal signal where its frequency is same as the frequency of the reference soil moisture, but the amplitude is lower than the reference signal as shown in Fig. 2b. It implies that the designed ON-OFF controller must have the amplification function.



(a)



(b)

Fig. 2. a. Inputs configuration in revised Penman-Monteith evapotranspiration model, b. Comparison between the reference of soil moisture (black) and the output parameters of the calculated evapotranspiration (blue).

In the application, Output signal is a form of ON-OFF configuration with variation of pulse width [7,8]. ON-OFF controller used discretization circuit and memory integration as a feedback signal as shown in Fig. 3. The result of ON-OFF controller simulation shows that the reference soil moisture is approximated by triangular signal, wherein the frequency determines the error level as shown in Fig 4a.

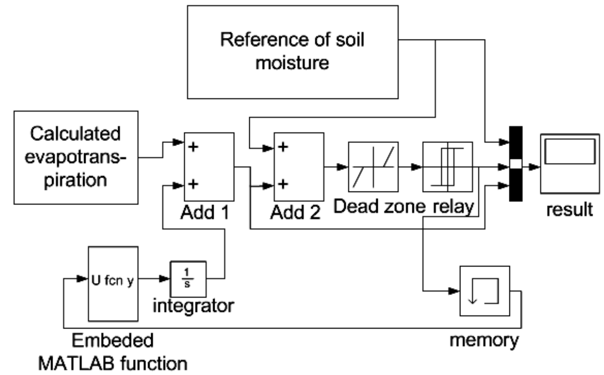
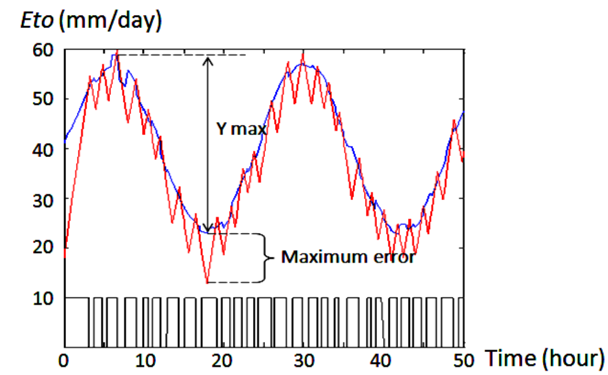
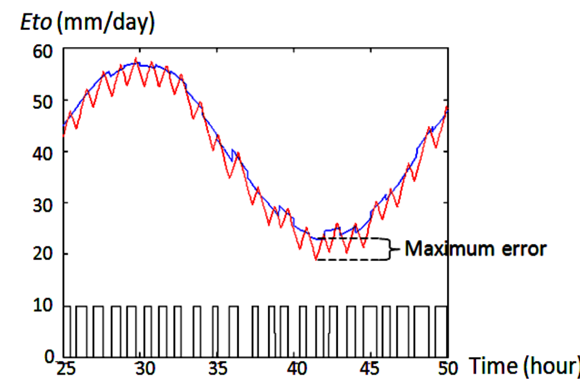


Fig. 3. a. Discretization circuit and memory integration of ON-OFF controller.

Maximum error of the controlled signal using sampling time of 0.5 second achieves 30.55% (ratio between max error and Y max, Fig 4a). By reducing the sampling time of discretization, deviation error can be reduced to 11,1% as shown in Fig. 4b.



(a)



(b)

Fig. 4. a. ON-OFF controller performance (red), reference of soil moisture (blue), approximated pulse width modulation signal (black, sampling time of discretization of 0.5 second), b. Discretization sampling time of 0.005 second decreases the deviation.

IV. Conclussions

The research presents the use of ON-OFF controller applied to automated irrigation system. The proposed controller system employed input data included temperature, heat radiation, wind speed and air pressure. These data was then used to calculate evapotranspiration using revised Penman-Mointeith equation. The output of such equation was used for input data of ON-OFF controller and then it was compared with reference of soil moisture data. The reference of soil moisture was approximated by triangular signal, in which the deviation error can be decreased by reducing sampling time. Sampling time of 0.5 second and 0.005 second yielded the deviation error of 30.5% and 11,1%, respectively.

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