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ANALYSIS OF SMART AUTOMATION PROCESSES OF IRRIGATION SYSTEMS

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Abstract. This research paper investigates the automation process of irrigation as an efficient tool for irrigation scheduling. Classification and analysis of different techniques will be investigated: automation based on soil moisture sensors, irrigation automation based on evapotranspiration, and automation based on a predetermined volume/time interval will be covered.

Keywords: microirrigation, irrigation automation, soil moisture sensors, evapotranspiration.

Introduction. Irrigation is defined as the replenishment of water in the plant root zone during periods when natural rainfall is not sufficient for good plant growth. Traditional irrigation based on low frequency (i.e. irrigation every two weeks), large volume irrigation usually results in over-irrigation. With this type of irrigation, a large portion of the applied water percolates quickly to the shallow groundwater, potentially carrying with it nutrients and other agrichemicals applied to the soil. In addition, excess water in the root zone from excess irrigation can reduce crop yields [1, 2, 3].

As an alternative to traditional irrigation systems, a low volume of water can be applied frequently to maintain a desired moisture range in the root zone that is optimal for plant growth. The term microirrigation is defined as the frequent application of small quantities of water under low pressure to plant root zone, on or below the soil surface as drops, tiny streams, or miniature spray through emitters or applicators placed along a water delivery line. Microirrigation encompasses a number of methods or concepts such as, drip irrigation, subsurface drip irrigation and sprays [4, 5, 6].

Microirrigation systems apply water directly to the root zone of plants which means that the spaces in between plants remain dry. Small portion of wetted land by emitters will greatly minimizes the loss of water in evaporation and percolation processes and inhibits weed seed germination. Inhibited weed growth will minimize the use of herbicides and weed control tillage, and elimination of nutrient and water loss will reduce operating costs and energy [7, 8, 9].

Irrigation Scheduling is defined as the determination of the correct amount and frequency of irrigation and is used to maximize irrigation efficiencies by applying the exact amount of water at the exact time needed by the plant. With variability and irregularity in rainfall and high required frequency in microirrigation; a fully automated system is almost a necessity to make irrigation scheduling efficient [4].

Research objective. This research aims at analysis of different types of smart control of irrigation systems, that are developed to save water, labor and energy costs. A comparison between preset programmed traditional controllers and controllers based on sensors feedback will be investigated.

Materials and methods.

There are a number of distinct reasons that promote the implementation of automation in irrigation systems in any region around the world, some of these reasons are:

- Better control of the amount of the irrigation water added.
- Low requirements of human labour and human interference.
- In addition to programmed irrigation; additional operations, such as fertigation, filters cleaning, etc. can be automated.

- Inconvenient situations such as network failures, pump malfunctions and pipe clogging can be detected and controlled.

An irrigation controller is defined as a device that is used to automatically operate the irrigation system. Traditional controllers operate on a preset programmed schedule and timers and have a means of setting the frequency of irrigation, the start time, and the duration of irrigation. In contrast, smart irrigation controllers monitor weather, soil conditions, evaporation and plant water use to automatically adjust the watering schedule to actual conditions of the site [10, 11].

According to the Irrigation Association smart irrigation controllers are defined as: controllers that reduce irrigation water use by monitoring and using information about site conditions; such as soil moisture, rain, wind speed, soil, plant type… etc. and apply the right amount of water based on those factors. These irrigation controllers receive feedback from the irrigated system and schedule or adjust irrigation duration or frequency accordingly. There are generally two types of smart controllers:

1. Soil moisture-based controllers and,
2. Evapotranspiration-based controllers [9].

Results and discussions.

Soil moisture-based irrigation controllers:

Automation of irrigation systems based on soil moisture sensors may improve water use efficiency by maintaining a desired soil moisture range in the root zone that is optimal for plant growth, than a cycle of very wet to very dry during the irrigation interval under manual irrigation events. The target soil moisture may be expressed in terms of soil suction or matric potential (kPa or cbar), which describes the amount of energy that has to be exerted by a plant to absorb water that is held by the soil. The target soil moisture may also be expressed in terms of volumetric moisture, which is defined as the percentage of water volume in a volume of soil [4, 12].

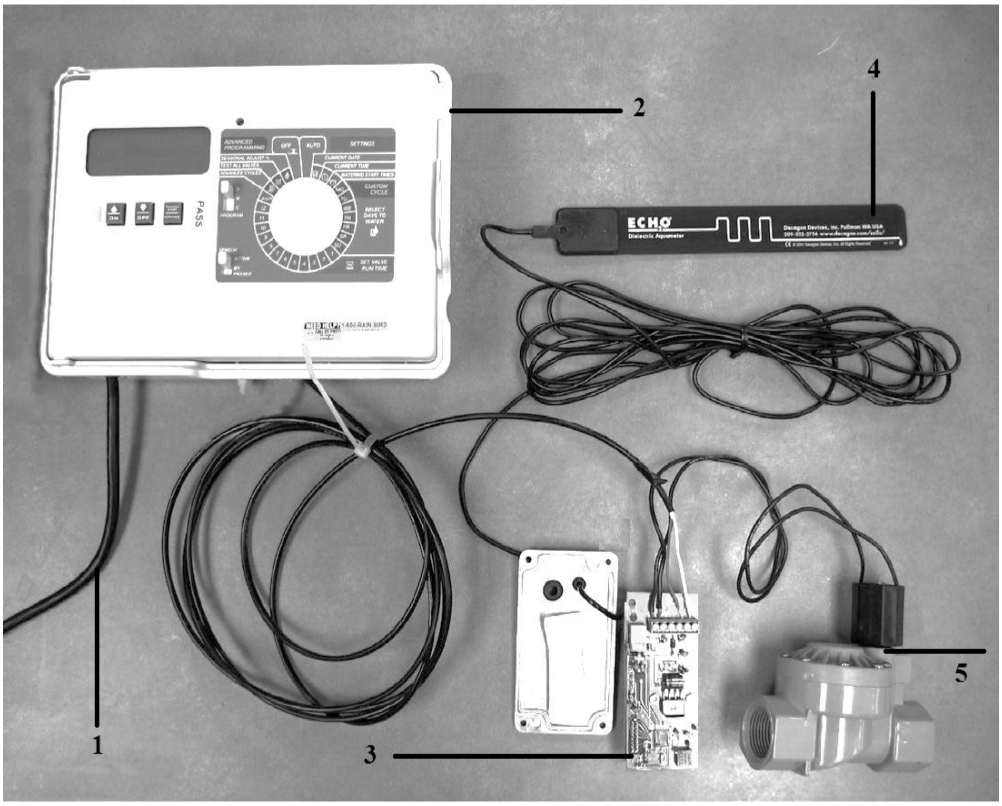

Figure 1 – Soil moisture sensor based irrigation controller [11]

Soil moisture sensors can be permanently installed at representative points in an agricultural field to provide repeated moisture readings over time that can be used for irrigation management. Many soil moisture sensing methods are available for monitoring soil water content. An in-depth review of available techniques, their measuring range, appropriate soils and advantages and disadvantages is given in [4].

A description of the soil moisture based smart irrigation controller is shown in figure 1. The system was developed in the department of agricultural and biological engineering, university of Florida, USA. The system consist of: power source 1, user interface 2, programmable microcontroller 3, soil moisture sensor of capacitance type and produced by Decagon Devices Company 4, and solenoid valve 5 [10, 11].

Evapotranspiration-based controllers:

Evapotranspiration-based controllers operates according to the principle that the water requirement of plants can be determined from a balance of water inputs and outputs to the plant root zone and is called a soil water balance. Rainfall and irrigation enter the root zone as inputs. Water exits the soil and plant system from runoff, deep percolation, evapotranspiration. Evapotranspiration is the quantity of moisture which is both transpired by the plant and evaporated from the soil and plant surfaces. Irrigation is scheduled so that, there are negligible losses. Deep percolation is minimized by irrigation events that do not exceed the soil water holding capacity while surface runoff is minimized by applying the irrigation water in a rate less soil infiltration. Therefore the equation that is used to balance the change in soil water storage in the root zone of a plant can be written as:

$$\Delta S = R - ET_c + I - D - RO, \quad (1)$$

$$I = ET_c - R, \quad (2)$$

where ΔS – change in soil moisture, (mm); R – the amount of rain per day, (mm); ET_c – crop evapotranspiration per day, (mm); I – net irrigation depth per day that penetrates the soil, (mm); D – loss of water from the root zone by deep percolation per day, (mm); RO – Run off from the soil surface per day, (mm) [13].

The ASCE and United Nations Food and Agriculture Organization (FAO) proposed the FAO-56 Penman–Monteith standardized reference evapotranspiration (ET_o) for irrigation scheduling, as seen in Equation 3. This equation is used for daily ET_o calculations and is based on wind speed, temperature, relative humidity, and solar radiation.

$$ET_o = \frac{0{,}408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)}, \quad (3)$$

$$ET_c = ET_o \times K_{c,} \quad (4)$$

where ET_o – reference evapotranspiration, [mm day^{-1}]; R_n – Net radiation at the crop surface, [MJ m^{-2} day^{-1}]; G – Soil heat flux density, [MJ m^{-2} day^{-1}]; T – average daily air temperature at a height of 2 m, [°C]; U_2 – wind speed at a height of 2 m, [m s^{-1}]; e_s – saturation vapor pressure, [kPa]; e_a – actual vapor pressure, [kPa]; (e_s - e_a) – Vapor pressure deficit [kPa]; Δ – Slope of saturated vapor pressure curve, [kPa°C^{-1}]; γ – psychrometric constant, [kPa °C^{-1}]; K_c – crop coefficient [2].

From equations 3 and 4 evapotranspiration (*ETc*), is a function of weather conditions and plant type. In evapotranspiration based controllers (*ET*) the controller or timer adjusts the schedule automatically as weather changes or crop produces. These controllers utilize sensors installed on-site to measure weather conditions and then calculate real-time ET_O based on the data collected. The sensors collect readings at intervals from every second to every fifteen minutes and then a daily *ET* is calculated from those values. On-site sensors could include: temperature, solar radiation, or even a full weather station [14, 15].

To avoid complexity; some controllers use Simplified ET estimation methods for example Blaney-Criddle equation instead of the FAO-ASCE standardized ET_o equation. Blaney-Criddle equation is temperature dependent allowing the sensor to measure only temperature.

$$ET_o = (0.46\, T_{mean} + 8) \times P, \tag{5}$$

$$T_{mean} = \frac{T_{max+}T_{min}}{2}, \tag{6}$$

where T_{mean} – average daily temperature, [°C]; P – mean daily percentage of annual daytime hours.

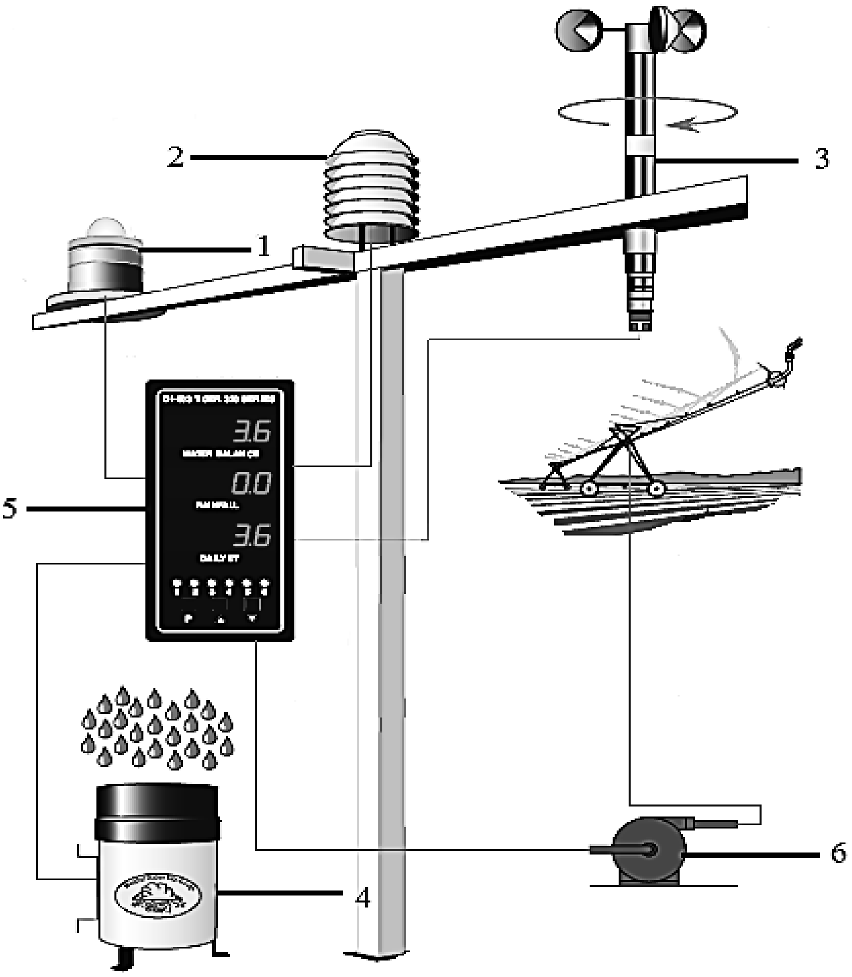

Figure 2 – Evapotranspiration-based smart irrigation system controllers

The components of ET-based irrigation controllers are shown in figure 2, and as following: solar radiation sensor 1, air temperature sensor 2, wind speed sensor 3, rain gauge 4, controller 5, and the irrigation pump or actuator 6.

Conclusion. An automated irrigation system saves water, energy and labor costs as compared with the manual system, with no negative impact on crop yields. In soil moisture based system; irrigation starts at the predetermined low level of moisture content and stops irrigation as the desired soil moisture content or field capacity is attained. In weather or evapotranspiration based irrigation controllers; the system supplies the amount of water that has been lost in evapotranspiration process. Both systems take into account the effective rainfall and the change of the crop water consumption during its growth stage. Research should be undertaken to assess the sensor performance under various soil types and different climatic conditions. A research is undergoing in Kazan State Agrarian University to evaluate the efficiency of soil sensors to increase the irrigation efficiency in the case of uneven pressure distribution within the irrigation system network.

АНАЛИЗ ПРОЦЕССОВ АВТОМАТИЗАЦИИ ПОЛИВА НА ОСНОВЕ ИНТЕЛЛЕКТУАЛЬНЫХ СИСТЕМ

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Аннотация. Приведены исследования процессов автоматизации полива, их использовании в качестве инструмента управления орошением сельскохозяйственных угодий. Дано описание таких методов, как автоматизация на основе датчиков влажности почвы, автоматизация орошения на основе эвапотранспирации и автоматизация на основе заданного объема или временного интервала.

Ключевые слова: микроорошение, автоматизация орошения, датчики влажности почвы, эвапотранспирация.

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