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A Design of Fully Automated Irrigation System IoT-Based Approach for Greenhouses

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Abstract

Turkey is a country with a high potential for agriculture purposes. Irrigation is a need to receive agricultural output. Crop yield increases with optimal irrigation. Therefore, this work has designed a fully automated irrigation system with an IoT-based approach for greenhouses. Using 10HS soil moisture and pt1000 temperature sensors, the system has successfully generated irrigation-based decisions and saved 25 tons/da water compared to Et (Evapotranspiration) controller-based irrigation while plants received optimal irrigation. The system works online and has two operation modes: fully automated and manual. Fully automated system decreased water-wastages and labouring costs. Switching between modes can be operated using a mobile application and parameters of the system communicates via cloud services.

Keywords: Internet of things, Smart irrigation, Soil moisture sensors

Seralar için Tam Otomatik IoT Tabanlı Sulama Sistemi Tasarımı

Öz

Türkiye, topraklarında tarım yapma potansiyeli yüksek bir ülkedir. Tarımsal çıktı almak için sulama bir ihtiyaçtır. Optimal sulama ile ürün verimi artırılır. Bu çalışmada, seralar için Nesnelerin İnterneti tabanlı bir yaklaşımla tam otomatik bir sulama sistemi tasarlandı. 10HS toprak nemi ve pt1000 sıcaklık sensörlerini kullanan sistem yardımıyla, sulamaya dayalı karar sistemi oluşturularak, bitkilerin optimum

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sulama alması sağlandı. Evapotranspirasyon denetleyici tabanlı sulamaya kıyasla 25 ton/dönüm su tasarrufu elde edildi. Sistem çevrimiçi çalışır ve iki çalışma moduna sahip olarak tasarlandı: tam otomatik ve manuel. Tam otomatik sistem, su israfını ve işçilik maliyetlerini azaltarak tasarruf elde edildi. Modlar arasında geçiş, bir mobil uygulama tasarlanarak gerçekleştirildi ve sistemin parametreleri bulut hizmetleri aracılığıyla iletişim kurdu.

Anahtar Kelimeler: Nesnelerin interneti, Akıllı sulama, Toprak nem sensörleri

1. INTRODUCTION

The use of the Internet of Things (IoT) based smart systems is increasing day by day. The ability to communicate between devices brings new solutions to the problems that exist in a wide range of application areas in both industry and society. These solutions are used in the field of logistics, assisted driving, mobile ticketing, environment monitoring, augmented maps, tracking, authentication, sensing, smart environments, social networking, theft detection, robot taxi, city information modelling, and agricultural automation [1-2]. In such systems sensors enable the devices to observe, detect, identify i.e., understand the environment. Communication between devices allows users to monitor and control the process. Since devices can react faster than human beings to the parameters, this reduces wastage and saves time.

One of the major consumptions on earth is freshwater consumption. About %70 of the freshwater is used for irrigation, %22 is used in industrial applications and cooling, and %8 is used for domestic purposes [3]. The high demand for irrigation indicates how important water management is. IoT-based embedded systems allow users to measure the soil moisture and temperature at real-time speed and complete the irrigation with the least freshwater possible. Also, the communication between different platforms (Web, UART, Mobile applications) makes it possible to monitor and remote control the system when needed. Such systems are also called Wireless Sensor Networks (WSN).

Wireless Sensor Networks (WSN) consist of a group of spatially dispersed sensors that are used for monitoring and recording parameters for the conditions of an environment [4]. For the irrigation systems, these conditions are commonly humidity, temperature, sound, and pollution. WSN takes advantage of wireless connectivity and spontaneous formation of networks and can transport the data wirelessly. In such network systems, each sensor has a radio transceiver that is connected by an internal antenna, or the system is supported with an external antenna in order to enable the control of the sensor activity. SensorScope is an example of a WSN-based system [5]. This system is a low-cost data transmit and receive system using up to seven sensors in each of its stations with flexible commissioning options. SensorScape viability tests were performed both indoors and outdoors in Génépi, Switzerland, to collect rain, wind, and temperature data in order to classify the region's microclimate and forecast the frozen soil evolution. Other contributions to smart monitoring systems are Smart Water Pollution Monitoring systems (SWPMs) and Smart Air Quality Monitoring systems (SAQMs) [6-8]. SWPMs check the harmful contaminants in water, reservoir water quality and monitor the environment for a natural water body. SAQMs have a purpose to contribute to smart urban solutions for air quality. One of the contributions to SAQMs is ERA-PLANET Project which used both sensors and satellite products in Kyiv Smart City Project [9]. In 2020 and 2021, research on reliable LoRa Networks, WSN, and autonomous irrigation in Indonesia and Thailand gained momentum with global water shortages with a focus of application based optimization [10-12].

This paper presents the design of a fully automated irrigation system, using embedded systems and mobile application and aims to reduce water wastage for the greenhouses. The general diagram in Figure 1 shows the hardware system for the implementation of the process.

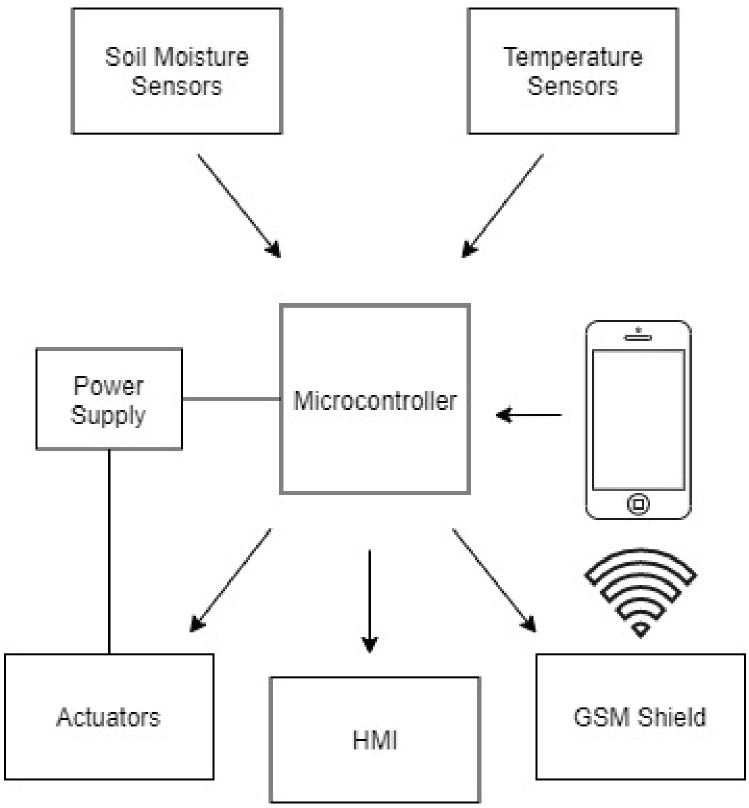

Figure 1. A general diagram for the proposed system

2. EMBEDDED SYSTEMS

The proposed architecture consists of a microcontroller, soil moisture sensor, temperature sensor, GSM (Global System for Mobile Communication) shield module, Liquid Crystal Display (LCD) screen, power supply, and actuators. In such applications, small volume soil moisture sensors may not provide a good measurement since the soil itself is a naturally heterogeneous system. Therefore, 10-cm long Decagon 10HS soil moisture sensors were used to determine the volumetric water content (VWC) via measuring the dielectric constant of the growing media. To observe the soil temperature, pt1000 digital temperature sensors with a measuring range of -40 °C to +85°C were used. The sensor measurement data were sent to an ATMEL microcontroller to implement the algorithm.

3. IRRIGATION MANAGEMENT

Although irrigation is perhaps the most important factor in ensuring greenhouse farmers can meet their agricultural production demands, most farmers base their irrigation practices on their expertise and experience, or the weather conditions. However, since the demands of the plants cannot be completely met when irrigation is performed in this manner, diseases, yield losses, lack of quality, and nutrient washing in plants result [13]. In many agricultural regions, insufficient irrigation scheduling and inefficient use of water resources are common factors that limit output [14]. Furthermore, it is unknown how plants will respond to issues like climate change. As a result, the need to determine the best amounts of variables in crop production with the least error pushes the trend toward technology-based systems. Crop monitoring, optimization, and precise control are all possible with technology-based systems, enabling farmers to achieve maximum crop output of the highest quality [15-16]. It is vital for producers to keep track of stress fluctuations in order to prevent plant stress levels from reaching dangerously high levels as a result of unproper irrigation programs. Furthermore, developing methods to mitigate the harm caused by water stress, in particular, is critical for the future of agriculture. In this context, the research aimed to automatically track the moisture level in the soil of the greenhouse located in the Agricultural Structures and Irrigation Department of Çukurova University to provide the plants with the optimum amount of irrigation water at the appropriate time. The drip irrigation system was used in the experiment, and irrigation was applied automatically through soil moisture sensors as shown in Figure 2. Lateral pipes were black, flexible polyethene pipes with a 20.00 mm diameter. Up to the beginning of the parcel, irrigation water was delivered through a Ø 50 PVC main pipeline. Drippers with a flow rate of 2 lt/h were spaced 30cm apart to provide a dripper for each plant. Moreover, to determine the effectiveness of the designed system, a manual irrigation control issue was also included. The images taken from the irrigation test site is shown in Figure 3 and Figure 4.

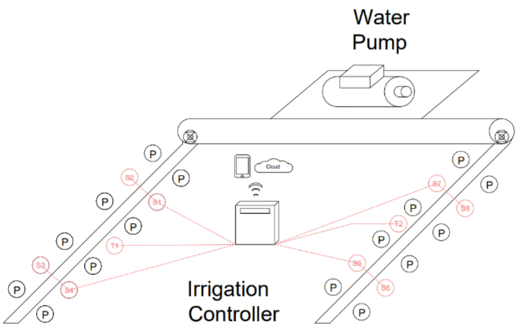

Figure 2. Placement of the Sensors (S1, S2, S3, S4, S5, S6, S7, S8, T1, T2), Plants (P), and irrigation system greenhouse located in the Agricultural Structures and Irrigation Department of Çukurova University

Figure 3. Irrigation test site before the implementation of the irrigation system

Figure 4. Fully functional irrigation system implemented in the test site

3.1. Soil Moisture Based Systems

These systems are designed to automatically monitor irrigation by receiving feedback from soil moisture values through sensors placed in the crop's effective root region. The majority of these systems are enabled by a single fixed level of volumetric soil water content (lower limit or upper limit). However, This study was designed to obtain a cycle between two different levels by determining the field capacity and the allowable amount of usable water. In this study, the usable water capacity (UWC) of the greenhouse soil was determined by a series of processes, the automatic irrigation water process was designed to start when

35% of the UWC was consumed and continue until it reaches the field capacity. 10HS soil moisture sensor is used to measure the UWC consumed. The main reason to use 10HS sensor is, its ability to measure soil moisture with a higher accuracy in meaning of volumetric capacitive magnetic field. A water meter was used to calculate the volume of irrigation water used in this process at the end of the experiment.

3.2. Et Controller-Based Systems

Weather data is used to calculate reference evapotranspiration (ETo) to estimate plant water needs. The amount of irrigation water for manually irrigated subjects was calculated (I = ETo x Kc) by multiplying the reference plant water consumption (ETo) values obtained from an automatic climate station that set up in the greenhouse by the plant coefficient (Kc) values which chosen according to the development time. Besides, the calculated amount of irrigation was applied to the plants manually weekly.

3.3. Comparison of Soil Moisture-based System with Et Controller-based System

In comparison to conventional approaches, both systems are beneficial. Several studies have been carried out to assess both soil moisture sensor-based and Et controller-based systems. For instance, according to [17], irrigation reductions were 7–30% for rain sensor-based treatments and 0–74% for soil moisture-based systems as compared to a no-sensor treatment. Furthermore, when compared to historical Et results, [18-20] recorded water savings of 59 to 82%, 11 to 28%, and 51% with using soil moisture-based system, respectively. However, it is unclear at what levels the soil moisture sensors began or stopped irrigation in any of these experiments, or which approach was used to incorporate this device into the irrigation program. In the current study, the field capacity of the trial soils was determined as 35% and the wilting point as 23%. Besides, it is planned to irrigate up to the soil field capacity when 35% of the UWC is consumed. For this reason, irrigation was initiated whenever the soil moisture level fell to 27.2% and ended with the soil moisture levels reaching 35%.

4. DESIGN OF THE IRRIGATION SYSTEM

The irrigation system was designed to make irrigation fully automated using high-resolution sensors to reduce the amount of irrigation water and manpower. Also, users were able to change the operation mode between automatic and manual irrigation using a mobile app and monitor all the parameters of the irrigation. The interaction between mobile application and microcontroller was supported by Google Firebase online cloud services.

Soil moisture sensors $S_1, S_{2,}S_3, S_4, S_5, S_{6,}S_7, S_8$ and temperature sensors t_1, t_2 were place in four different locations in the greenhouse. The Volumetric Water Content (VWC) value was calculated using Raw measurement m and the Equation 1 to determine the soil moisture below as shown below:

$$\text{VWC Value}=\left(1{,}17 \times 10^{-9}\right)(m^3)-\left(3{,}95\times10^{-6}\right)(m^2)+\left(4{,}90\times10^{-3}\right)(m)-1{,}92 \quad (1)$$

Algorithm 1 provides an overview of our fully automated irrigation system which completes irrigation cycles within weekdays between 07:00 – 17:00 using optimal soil moisture thresholds 27.00 – 35.00 ppm to reduce the water wastage. The time and date values TD were obtained using a Real-Time Clock module (RTC). The mode switching was operated using irrigation bit X from the cloud. The mobile app also allowed the user to determine manual irrigation thresholds M_1, M_2. As output, our system triggered solenoid valves V and alert A the user if the greenhouse temperature falls below 12° C. If the system is in manual mode, the parameters were selected from the mobile application according to the user choice. The results of the irrigation system test are shown below in Figure 5. Over 50.000 sample with sampling time of 1000 ms, our system successfully irrigated the system precisely according to the given parameters.

It was determined that 255.7 tons/da of irrigation water applied with the system proposed, while 281 tons/da of irrigation applied with the Et-based system (Table 1). In other words, as compared to the Et-based system, the system based on the soil moisture sensor has been found to save 9% water.

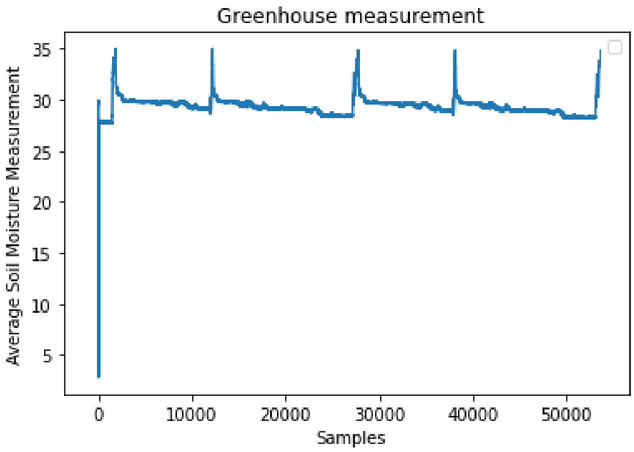

Figure 5. The results of the irrigation system test over 50.000 samples

Table 1. The cumulative amount of irrigation water applied at the end of the trial (ton/da)

Water-cost	Proposed system	Et controller-based system
Irrigation water	255.7	281

Algorithm 1: Irrigation Algorithm

Input: Soil moisture measurements : S
Temperature measurements : t
Date and time stored using RTC : TD
Irrigation hours (07:00-17:00) : T_+
Allowed Irrigation Dates : D
Mobile app Irrigation Mode Bit : X
Mobile App Manual Thresholds : M_1, M_2
AWC Down-threshold : $AWCD$
AWC Upper-threshold : $AWCU$

Output: Solenoid Valve Trigger Signals : V
Alert Signal : A

Initialize S, T_1, T_2 TD and update cloud database for mobile application
for all $TD \in : T_+$ **and** D **do**
Start online sampling to cloud database, pull online variable X
  if $X = 1$ **do**
    if $Average(S) < AWCD$ **do**
      Activate V:1
      Until $Average(S)= AWCU$
    else
      Deactivate V:0
      end if
    if $Average(S) < AWCD$ ppm **do**
      Activate V: 1
    else
      Deactivate V:0
      end if
  update cloud variables
  if X:0 **do**
    if $Average(S) < M_1$ **do**
      Activate V:1
      Until $Average(S)= M_2$
    else
      Deactivate V:0
      end if
end for
for all $TD \in : T_+$ **or** $\notin D$ **do**
  if $Average(t) < 12°$ **do**
    Activate A: 1
  else Deactivate A: 0
  update cloud variables
end for
repeat

5. CONCLUSION

Turkey is a country with a high potential for agriculture on its land. Irrigation is a need to receive agricultural output. Crop yield increases with optimal irrigation. Therefore, this work has designed a fully automated irrigation system with an IoT-based approach for greenhouses. Using soil moisture and temperature sensors, the system has successfully generated irrigation-based decisions and saved 25 tons/da water while plants received optimal irrigation. The system works online and has two operation modes: fully automated and manual. Switching between modes can be operated using a mobile application and parameters of the system communicates via cloud services.

6. ACKNOWLEDGEMENT

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