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Control of soil moisture with radio frequency in a photovoltaic-powered drip irrigation system

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Abstract: Solar-powered irrigation systems are becoming increasingly widespread. However, the initial setup costs of these systems are very high. To reduce these costs, both the energy usage and the prevention of losses from irrigation systems are very important. In this study, a drip irrigation control system of 1000 dwarf cherry trees was controlled using soil moisture sensors in order to prevent excessive water consumption and energy losses in a solar-powered irrigation system. The control system comprises units that are energized with solar panels, and the flow of information is implemented via radio frequency. Thus, by removing the cables that create difficulties in the cultivation of gardens, both the easy cultivation of the soil is enabled and cable costs are eliminated. The portability of the units is enabled by using solar energy; thus, units might be mounted wherever the user wishes. It has been indicated that the moisture of the application area varies depending on the data obtained regarding volumetric water content and the defined area in need of irrigation. In this way, there are reductions in the dependence on instantaneous water demand, the amount of water to be pumped, and the energy requirements needed for irrigation. In addition, pump power and the power of the motor that drives the pump are also reduced. According to the obtained measurement values, it was calculated that hourly water demand decreased by 36%. Thus, the numbers of solar panels, electrical machines, batteries, and units of power control that supply all the energy of the system and constitute a large part of the initial setup costs are reduced at the same rate by means of the applied technique. Thanks to the developed site-specific irrigation system, unnecessary energy consumption was avoided. Along with the elimination of excessive and unnecessary irrigation, problems with trees were also eliminated.

Key words: Soil moisture sensor, wireless sensor networks, drip irrigation, control of soil moisture

1. Introduction

The consumption and need for water and energy are 2 of the most important issues of the world in which we live. Human nutrition, meeting basic needs, and watering plants cannot be considered without water; water cannot be considered without energy. Classical flood irrigation systems are known as wild irrigation; they use an excessive amount of water and cause the growth of weeds. These drawbacks can be removed by the use of drip irrigation systems applicable solely to the areas where the plants and roots are located.

Solar-powered drip irrigation systems are becoming very common. However, the initial installation costs of these systems are very high [1]. In order to reduce these costs, both energy usage and preventing losses in the irrigation system are very important.

An equal amount of water is applied to all trees in classic drip irrigation systems. However, soil moisture

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values vary. Furthermore, the irrigation of trees is dependent on the producer's skill and knowledge. Water needs may vary according to the age and characteristics of the trees and the type, variation, and structure of the soil [2]. Giving an excessive amount of water to trees means greater energy consumption. This not only increases the cost of the solar-powered systems unnecessarily but also causes salinization and increases the consumption of both water and energy. Moreover, it also reduces crop yields by leading to the decay of tree roots. Not giving enough water may cause a reduction in the product efficiency obtained from the trees and may cause the trees to wither. Irrigation according to the properties of the soil and the trees eliminates these disadvantages. Site-specific irrigation not only reduces operating costs (i.e. energy, water) but also increases product efficiency. Nowadays, the sensor-based site-specific irrigation system is the most emphasized [3–6].

For the last 20 years, with the development of wireless technologies, many researchers have focused their studies on sensor-based automatic irrigation to reduce water usage [7,8]. Soil moisture content measurements are carried out using soil moisture sensors in the majority of sensor-based site-specific irrigation. Depending on the soil moisture content, the areas to be irrigated are determined and water flow is controlled accordingly. This is done by switching electric valves (electrovalves) into open/closed positions based on the information received from these sensors. The communication between the sensors and the valves can be wired or wireless. Wired communication results in both an increase in cost and the loss of information over long distances. Using wireless sensor networks offers many advantages, such as eliminating cable and cable installation costs, providing easy and portable assembly (especially in large areas), and the fact that they do not require maintenance [9–11]. After wireless technology began to be used in the agricultural field, various types of controllers and protocols were tested. Studies have been conducted for controlling precision irrigation systems using technologies such as microprocessors, field-programmable gate array, GSM/GPRS, and Bluetooth in this field [10,12–15]. The biggest drawback of high frequency (2.4 GHz and above), which has provided faster and more reliable flow of information in recent studies, is the high installation cost [16–18].

Li et al., who used wired communication between a central unit and sensor units, evaluated the quality of wired communications and the differences between values obtained by burying sensors measuring soil moisture and temperature at the same time at different depths [19]. Cardenas-Lailhacar et al. compared the performance of different types of sensors in different terrains and determined that soil moisture sensors reduce water usage [20,21]. In studies comparing sensors using various measurement techniques in a lab environment, it was determined that sensors measuring volumetric water content give more reliable results [22,23]. In the past few years, the energy consumption and energy usage of various sensor types, communication protocols, equipment, and techniques have been investigated. Reducing the total energy consumption of the system reduces the installation costs of the systems, which are quite high for users. For this purpose, in wireless sensor-based site-specific irrigation work where energy demands are often met by solar energy, studies have been conducted on developing protocols that reduce energy consumption and select products with low energy consumption in order to reduce costs [18,24].

In this study of a solar-powered irrigation system where energy demands are met by solar energy, the difference from previous studies is that a site-specific drip irrigation system depending on soil moisture was designed; instant information about soil moisture was taken by radio frequency (RF) and used in the irrigation of cherry trees. Thus, both energy and water consumption were reduced by controlling soil moisture. Moreover, since a less powerful pump would be enough to provide irrigation, the solar panels and motor power required for the initial setup were reduced. Software was developed for this control, and control of the valves was achieved by comparing instant soil moisture values and user-specified threshold humidity values. Volumetric soil water content (VWC) information was detected by a sensor unit and sent to the central unit. Moisture information obtained by the central unit was transferred to a computer with a serial port. Depending on the user-defined VWC threshold value in the developed software, open/closed positions of the valves were determined and this information was sent to the related valve unit. The flow of the water coming from the main irrigation pipe was provided via electrovalves mounted on each lateral. Communication among the units in the system was performed using low-cost RF modules working at 434 MHz; thus, cost reduction was achieved.

2. Design of the soil moisture measurement system with radio frequency

The study was carried out on dwarf cherry trees across 0.8 ha located in the Zile district of Tokat Province in Turkey at 40°10′48.12” N, 35°51′59.21” E. An overview of the applied area-installed system of this study is shown in Figure 1. The water taken from the dam lake by Pump 1 was sent to a 100-t tank located approximately 200 m away. Stored water was added to the main drip pipe via Pump 2 by passing it through the filters protecting the drip irrigation system. Twenty-four panels, each with a power of 80 W making 1.92 kW in total, were installed to provide the energy that was needed for each pump. Additionally, a 6240-W battery bank was added to Pump 2 to provide energy for the motor in the event of low solar irradiation.

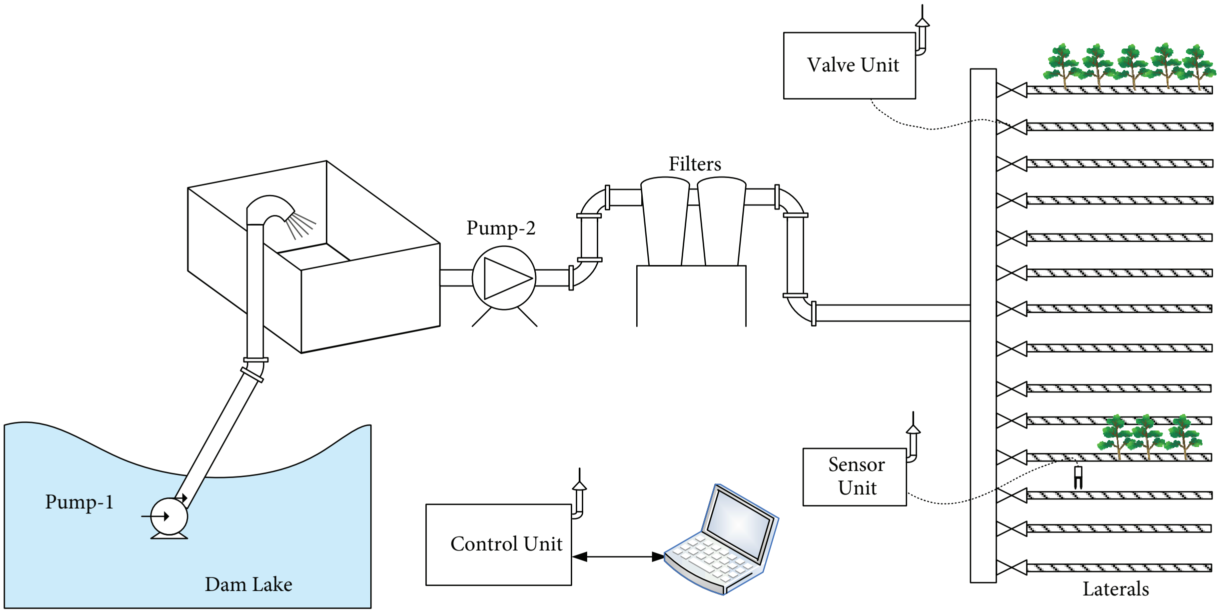


Figure 1. Overview of the applied area installed system.

Drippers were connected to the main pipe and mounted to 14 lateral pipes of 50.8 cm each in parallel positions. The moisture values created by the water obtained from the drippers were detected via the analog channel of a microcontroller using soil moisture sensors. Soil moisture information determined in the sensor unit was sent to the central unit together with encoded information containing sensor information. The values obtained from the central unit were transferred to the computer; by evaluating them depending on the threshold determined by the developed software, the data for open/closed positions of the valves were transferred to the relevant valve units. When the transferred information reached the valve unit, the valve position was changed. In addition, moisture information transferred to the computer via the central unit was saved to a file with date, time, and sensor number. Thus, the moisture information of the garden was made available for the user at any time. By meeting the energy requirements of the units via the solar panels of each unit, portability of the units was achieved; cable costs were eliminated by using RF in the information flow among units. In addition to the solar panel, a battery was added to the valve unit. An overview of the solar panels is shown in Figure 2.

2.1. RF module

In this study, a UDEA brand UFM-M11 model RF module (RFM) was used. To this low-power module using the frequency of 434 MHz, a UGPA-434 model antenna, which is capable of multicasting and capable of communicating up to 400–500 m in an open area, was added. For modulation, the module uses the frequency shift keying method. Power consumption of the module, with a maximum output power of 10 dBm, was 10 mW at 434 MHz. During transmission and receiving, 30 mA current and 17 mA current were drawn, respectively.

2.2. Soil moisture sensor

The Decagon brand 10HS model moisture sensor used in this study measures the VWC using the dielectric properties of the water by the capacitance technique. The sensor drawing 12–15 mA current during measurement works at a 3–15 V supply voltage. Analog information obtained at the output varies between 300 and 1250 mV regardless of the supply voltage. The sensor is given in Figure 3.

Figure 2. Overview of solar panels.

Figure 3. Decagon brand 10HS model soil moisture sensor.

2.3. Electrovalve

The Tork brand electrovalve (1.905 cm), which was normally closed when used in this study, has a 10 W coil working at 12 V voltage. A valve is mounted at the entrance of each lateral.

2.4. Circuits design of control units

2.4.1. Power supply circuit

The UFM-M11 RFM used in this study works at a 3 V voltage level. In Figure 4, the power supply circuit for the RFM that was used in each unit is shown. The 9 V input voltage of the power supply circuit was obtained from a 3 W solar panel.

2.4.2. Circuit of sensor unit

The design of the sensor unit's circuit is given in Figure 5. Volumetric water content information taken from the sensor was detected by the analog input (RA0) of a microcontroller. The obtained analog information was converted to digital and sent to the central unit via the RFM.

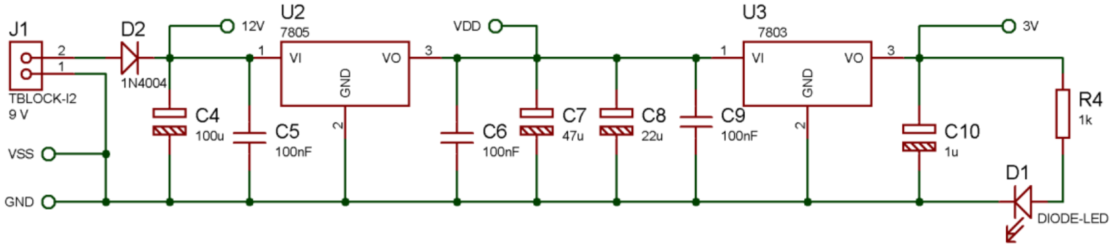


Figure 4. Power supply circuit of RFM.

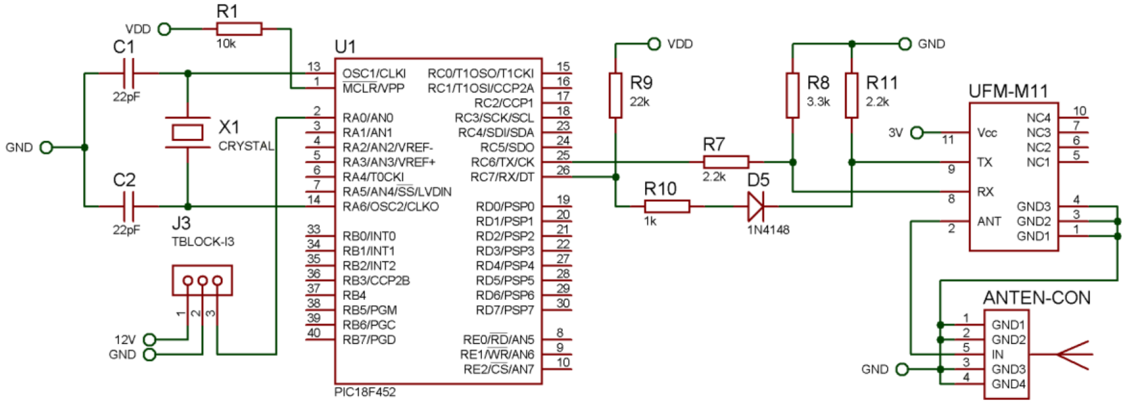


Figure 5. Circuit of sensor unit.

In order to establish communication between the microcontroller with an output of TTL level and RFM with an input of 3 V, a level converter circuit was designed and applied successfully.

The location of the sensor placed underground and a view of the mounted sensor unit in the application area are given in Figures 6 and 7, respectively.

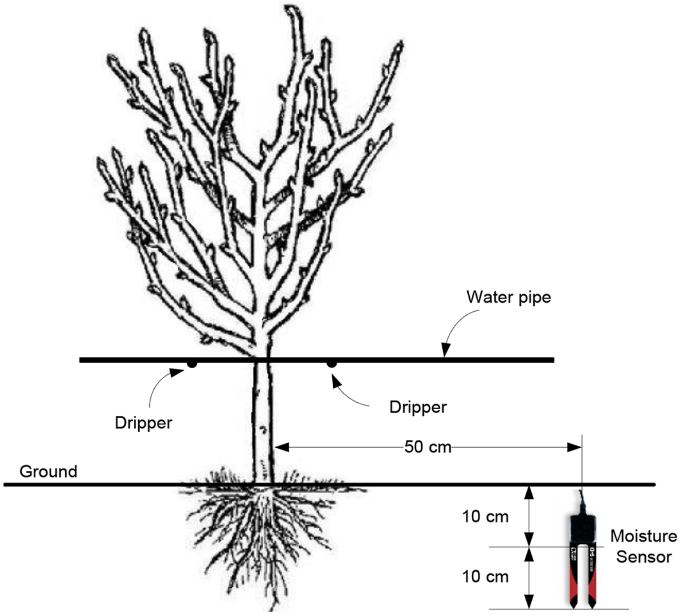


Figure 6. Installation location of soil moisture sensor underground.

Figure 7. View of mounted sensor unit.

2.4.3. Circuit of central unit

The design of the central unit's circuit is given in Figure 8. By designing the RS232 (serial port) circuit in order to communicate between the RFM and computer, the moisture information obtained from the sensor unit was transferred to the computer. The position information of the valves, depending on the threshold values determined by the user in the developed software, was sent to the valves through the central unit. The connection between the computer and RFM was made by a MAX232 serial port buffer chip.

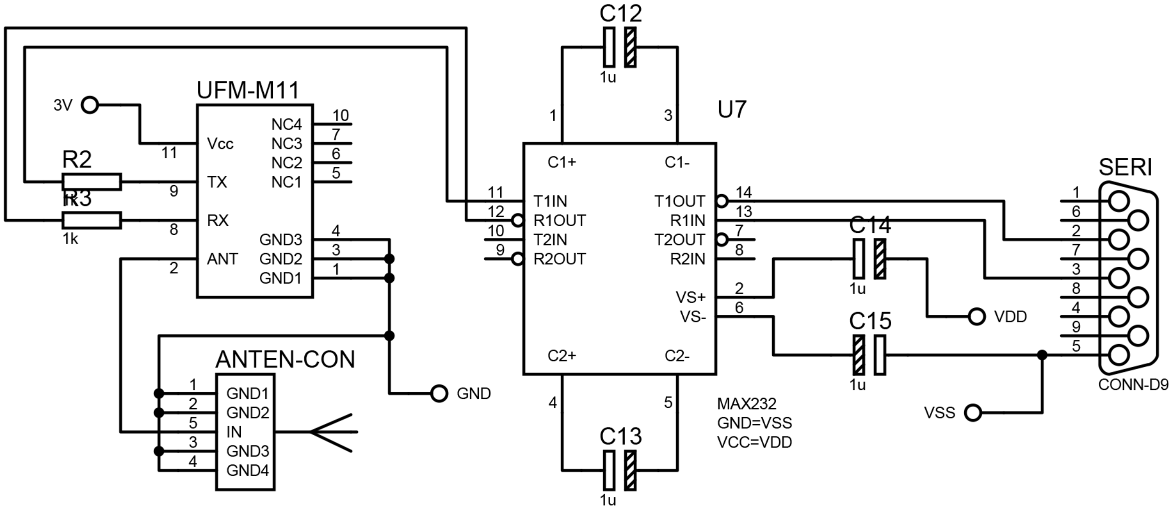


Figure 8. Circuit of central unit.

2.4.4. Circuit of electrovalve unit

The coil of the valve in the electrovalve unit was driven by an MJE3055 transistor, and the bias signal of the transistor was produced from RD6 digital output of the microcontroller (Figure 9). A view of the electrovalve unit mounted on the drip irrigation pipe at a lateral is shown in Figure 10.

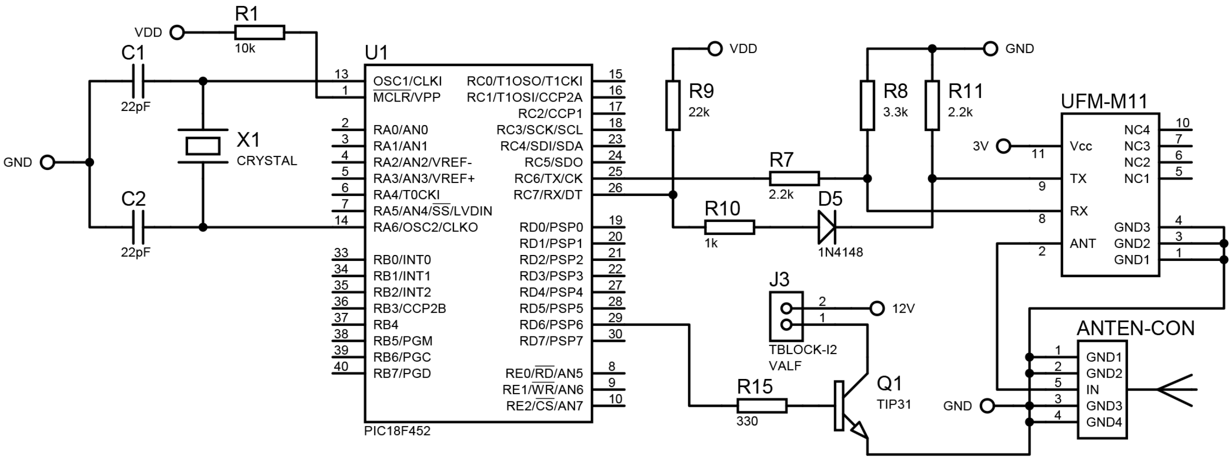


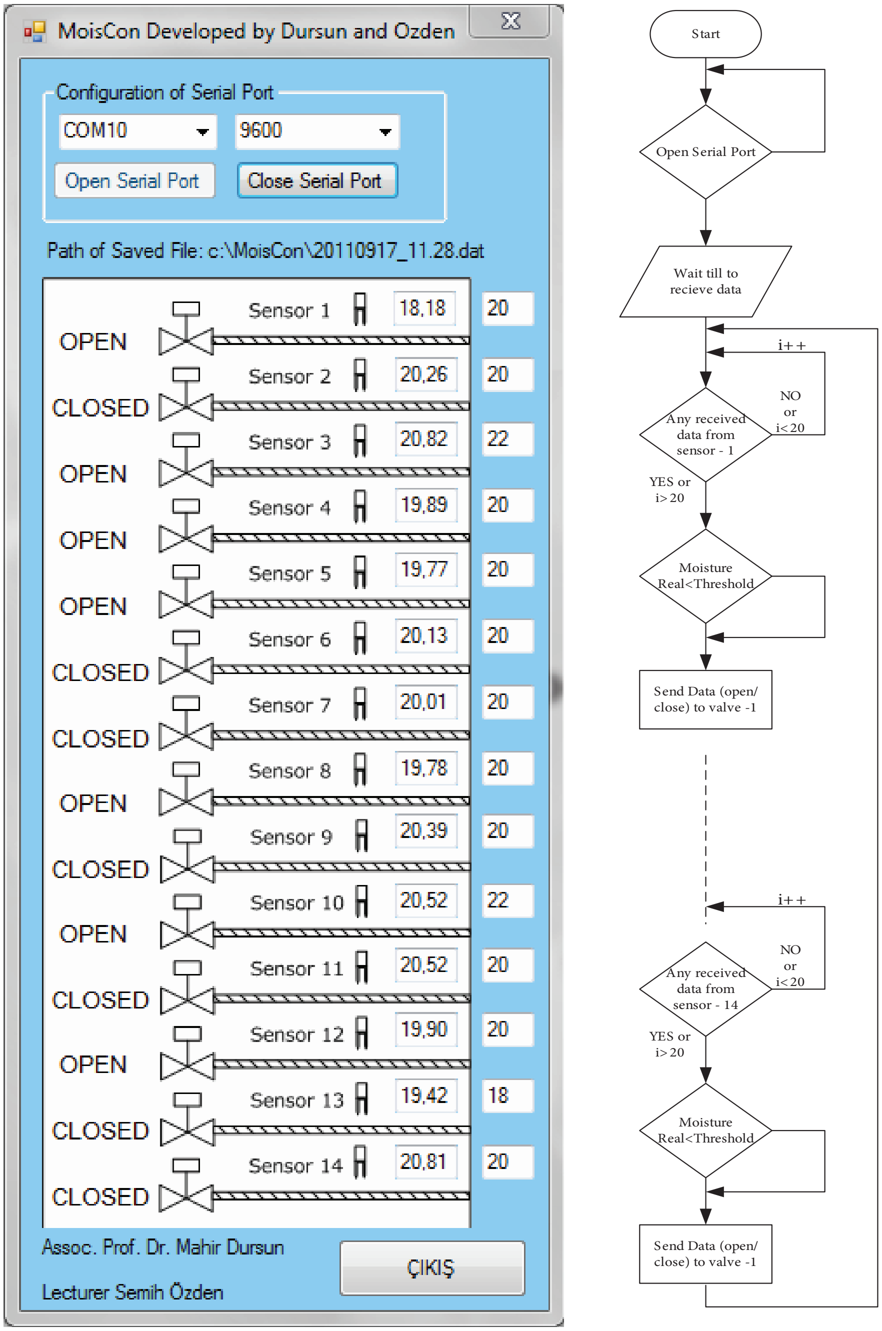
Figure 9. Circuit of electrovalve unit.

3. User interface

A view of the user interface software and the algorithm developed using the Visual C#.net 2008 programming language in this study are given in Figure 11. The name and the speed of the serial port where the information is taken must be chosen from the "serial port settings" section. After the necessary settings are applied, the "open the serial port" button is pushed, and installations required for the communication are completed. In the event of any error in opening the serial port, the user is warned to check the settings. After the serial port is opened, the name and the location of the file where the sensor values are to be recorded are specified. When receiving information from the sensors, the humidity values are written in the related sensor box.

Figure 10. View of installed electrovalve unit.

When information is received from the sensor, by comparing the received instant moisture value and the user-defined threshold value, open/close information of the valve is sent via the central unit through the serial port and the "OPEN" or "CLOSED" information next to the valve is updated. When the second set of information is received from the same sensor, the previous position of the valve is checked. If there is no change in the position, transmission of the information is not performed. This software allows users to instantly see moisture values in the garden so that they can determine the required watering areas. In view of the software in Figure 11, the threshold values of Sensor-3 and Sensor-10 were set to 22, and the threshold value of Sensor-13 was set to 18. It can be seen that the user can irrigate different areas of the fields with different amounts of water.



MoisCon Developed by Dursun and Ozden

Configuration of Serial Port: COM10, 9600

Path of Saved File: c:\MoisCon\20110917_11.28.dat

OPEN	Sensor 1	18,18	20
CLOSED	Sensor 2	20,26	20
OPEN	Sensor 3	20,82	22
OPEN	Sensor 4	19,89	20
OPEN	Sensor 5	19,77	20
CLOSED	Sensor 6	20,13	20
CLOSED	Sensor 7	20,01	20
OPEN	Sensor 8	19,78	20
CLOSED	Sensor 9	20,39	20
OPEN	Sensor 10	20,52	22
CLOSED	Sensor 11	20,52	20
OPEN	Sensor 12	19,90	20
CLOSED	Sensor 13	19,42	18
CLOSED	Sensor 14	20,81	20

Assoc. Prof. Dr. Mahir Dursun

Lecturer Semih Özden

Figure 11. View of the user interface software and the algorithm.

4. Experimental results

In this study, recording of the soil moisture values with the developed software was started at 0930 hours; the irrigation pump started to run at 1130 hours. The irrigation process was carried out by ensuring that the pump remained open for approximately 2 h. The recording process continued up to 1800 hours. By recording moisture values every 5 s over a total of 510 min, 6200 pieces of data in total were obtained.

In the application, 3 drippers with 2 L/h capacity were installed on each tree. The hourly water demand of 1000 trees is 6000 L. Based on the experimental results, it was calculated that 360 trees were excessively irrigated during an hour. Therefore, in total, 2160 L of water gain per hour was achieved with the developed system. Thus, by recording the application results of the developed system and classical systems and comparing them, it was observed that water consumption was reduced by 36% using the new system.

Analog data obtained from soil moisture sensors were converted into digital information via microcontrollers. Digital moisture information was converted into volumetric water content with a formula given by the manufacturer. The conversion formula is given in Eq. (1). ADC in the formula represents the analog value in the mV type in the output of the sensor.

$$VWC = 1.17 * 10^{-9} * ADC^3 - 3.95 * 10^{-6} * ADC^2 + 4.90 * 10^{-3} * ADC - 1.92. \tag{1}$$

Volumetric water content was determined by calculating the analog values obtained for each lateral with the formula, and daily changes were obtained graphically. In the graphs, the horizontal axis refers to the time, and the vertical axis refers to the volumetric water content in the soil as a percentage. The lower and upper limits on the vertical axis of all graphs were chosen to be the same (17.5–21.5) in order to show the difference among the laterals clearly. Instead of giving the changes in VWC values of all 14 laterals, only the results from the 1st, 7th, and 14th laterals are given.

The volumetric water content of the soil obtained from Lateral 1 shows variation starting from 18.18 to 18.38 during irrigation (Figure 12). After irrigation started, the value increased slowly at first and rose more quickly after that. The maximum value after irrigation ended was 19.66. After reaching this value, the VWC value at the end of the recording showed variation between 19.42 and 19.54. At the end of 2 h of irrigation, VWC was observed to have changed at a rate of 1.48%.

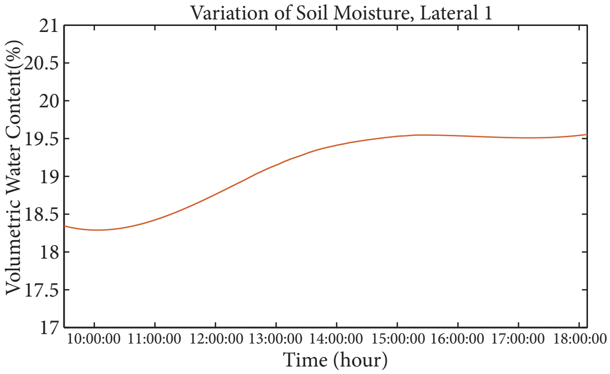


Figure 12. Variation of the volumetric water content on Lateral 1.

The volumetric water content of the soil obtained from Lateral 7 shows variation starting from 19.03 to 19.17 during irrigation (Figure 13). After irrigation started, the value increased slowly at first and rose more quickly after that. The maximum value after irrigation ended was 20.01. After reaching this value, the VWC value at the end of the recording showed variation between 19.90 and 20.01. At the end of 2 h of irrigation, VWC was observed to have changed at a rate of 0.98%.

The volumetric water content of the soil obtained from Lateral 14 shows variation starting from 19.42 to 19.54 during irrigation (Figure 14). After irrigation started, the value increased slowly at first and rose more quickly after that. The maximum value after irrigation ended was 20.98. After reaching this value, the VWC value at the end of the recording showed variation between 20.52 and 20.66. At the end of 2 h of irrigation, VWC was observed to have changed at a rate of 1.44%.

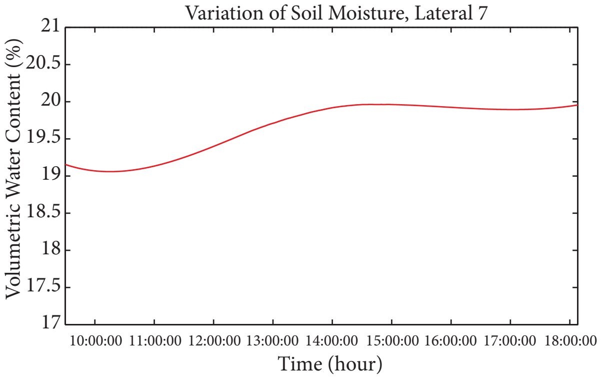


Figure 13. Variation of the volumetric water content on Lateral 7.

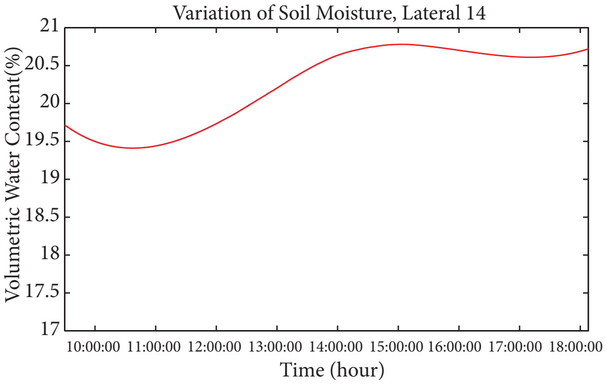


Figure 14. Variation of the volumetric water content on Lateral 14.

The experimental results show that all of the laterals responded differently in terms of VWC variation under the same irrigation conditions. This results from the properties of the soil, the age and type of tree, and the terrain. The land has a slope, and the Lateral 14 side of the land is closer to the water source (a dam lake). However, growers irrigate regardless of these parameters and in weather conditions like those in this experiment. This causes heterogeneous moisture distribution and therefore excessive water and energy consumption. This system was developed to understand soil moisture distribution. When irrigation is controlled by the developed system, the soil moisture distribution of the area will be kept constant.

5. Conclusion

In this study, a site-specific drip irrigation system depending on the soil moisture value with the required energy need provided completely by solar power was developed and applied in the control of the irrigation of cherry trees. By supplying the energy of the units that are the components of the control system using solar energy, portability of the units was achieved, and it was made possible for the users to mount them in desirable locations. Cable costs were eliminated by using an RFM in the communications between the units. With the realization of irrigation depending on the moisture content of the soil, instant water demand and thus the power of the pump providing the water for the drip irrigation system was reduced. Driving the watering pump caused a reduction in the power of the electric motor driving the pump. In this way, the number of solar panels that power the system and form a large part of the initial setup costs was reduced.

With the developed software, the user is able to determine the moisture value needed for the irrigation area. Moreover, the software enables the user to reach those VWC values in the future by saving the related VWC values with their date and time information in the computer. Moisture values among the laterals varied depending on the soil moisture values obtained from the experiment. With the developed control system, unnecessary water and energy usage were avoided. Hourly water demand was reduced by 36% with the developed system; thus, it was observed that installation of solar panels, power levels of the motor and pump, and values of the motor's power control equipment could be reduced in the same proportion. As a result of using solar energy to meet the energy demand, the applicability of the developed system is increased, and the usage of local sources is also enabled.

Acknowledgments

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