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Full Length Research Paper

A wireless application of drip irrigation automation supported by soil moisture sensors

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Irrigation by help of freshwater resources in agricultural areas has a crucial importance. Because of highly increasing demand for freshwater, optimal usage of water resources has been provided with greater extent by automation technology and its apparatus such as solar power, drip irrigation, sensors and remote control. Traditional instrumentation based on discrete and wired solutions, presents many difficulties on measuring and control systems especially over the large geographical areas. This paper describes an application of a wireless sensor network for low-cost wireless controlled irrigation solution and real time monitoring of water content of soil. Data acquisition is performed by using solar powered wireless acquisition stations for the purpose of control of valves for irrigation. The designed system has 3 units namely: base station unit (BSU), valve unit (VU) and sensor unit (SU). The obtained irrigation system not only prevents the moisture stress of trees and salification, but also provides an efficient use of fresh water resource. In addition, the developed irrigation method removes the need for workmanship for flooding irrigation. The designed system was applied to an area of 8 decares in a venue located in central Anatolia for controlling drip irrigation of dwarf cherry trees.

Key words: Wireless soil moisture sensor**,** irrigation, real time monitoring, drip irrigation, automation.

INTRODUCTION

Agricultural irrigation is highly important in crop production everywhere in the world. In Turkey, 75% of the current fresh water is consumed in the agricultural irrigation (Dursun and Ozden, 2010). Therefore, efficient water management plays an important role in the irrigated agricultural cropping systems (Kim and Evans, 2009; Sezen et al., 2010).

The demand for new water saving techniques in irrigation is increasing rapidly right now. In order to produce "more crop per drop", growers in (semi) arid regions currently explore irrigation techniques in the range from using less fresh water (Balendonck et al., 2008; Ngaira, 2007). One of them is making agriculture in a manner of sense, which uses different type of sensors (Lopez, et al., 2009). A site-specific wireless sensor-based irrigation control system is a potential solution to optimize yields and maximize water use efficiency for fields with variation in water availability due to different soil characteristics or crop water needs and site-specifically controlling irriga-tion valves (Miranda et al., 2005; Coates and Delwiche, 2006; Dursun and Ozden, 2011). Decision making process with the controls is a viable option for determining when and where to irrigate, and how much water to use. Temporal monitoring of soil moisture at different growth stages of crop could prevent water stress and improve the crop yield (Doraiswamy et al., 2004; Coates et al., 2005; King et al., 2002).

Sensor–based irrigation systems have been studied in many applications (Stone et al., 1985; Jacobson et al., 1989; Zazueta and Smajstrla, 1992; Meron et al., 1995; Wyland et al., 1996; Testezlaf et al., 1997; Abreu and Pereira, 2002; Kim et al., 2008, 2009). In last two decades, with development of wireless technologies, several researches focused on autonomous irrigation with sensors in agricultural systems (Oksanen et al., 2004; Zhang, 2004). Amongst these works, a micro sprinkler system has a different place, and it was designed for latching the controlled solenoid valves in a citrus orchard with wireless sensors (Torre-Neto et al., 2000).

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Afterwards, soil moisture sensors and sprinkler valve controllers are begun to use for site-specific irrigation automation. (Kim and Evans, 2009; Miranda et al., 2003; Wall and King, 2004; Perry et al, 2004; Damas et al., 2001). The advantages of using wireless sensors are having the reduced wiring and piping costs, and easier installation and maintenance in large areas (Panchard, 2006; Wang et al., 2006; Kim et al., 2006; Baggio, 2005).

After the usage of wireless technology began in agricultural irrigation, a trial was made to involve different types of equipments in such instrumentations. In terms of controllers, Miranda et al., 2003; Coates et al., 2006a; Coates et al., 2006b were designed microcontroller site-specific irrigation, wireless monitoring system was implemented with a field programmable gate array (FPGA) by Mendoza-Jasso et al. (2005). In terms of protocols, infrared, GSM/GPRS WPANs (Wireless Personal Area Networks), Bluetooth, WLANs (Wireless Local Area Networks) have been put to different utilities to implement wireless sensors in precision agriculture (Wang et al., 2006; Camilli et al., 2007; Vellidis et al., 2008; Siuli and Bandyopadhyays, 2008; Pierce and Elliot, 2008). Many studies have successfully demonstrated the usage of active and passive microwave remote sensing too (Engman and Chauhan, 1995; Ulaby et al., 1996; Jackson et al., 1999; Du et al., 2006).

It has been seen that many irrigation scheduling methods by wireless sensors have been developed for the last several decades. Many of the commercially available sensors, valves and modules assembled for irrigation system networks are too complex and/or costly to be feasible for site-specific management of fixed irrigation systems. Adoption of them by producers has been limited due to cost, installation time, maintenance, and complexity of systems (Thelen et al., 2005; Miranda et al., 2005).

The main aim of the research is to develop and to test an autonomous, having low cost equipped and feedback type controller for site-specific management of irrigation systems with solar powered wireless acquisition stations. Such a system can be cost effective monitoring control systems for growers. Moreover, this irrigation method can remove work man power that is needed for flooding irrigation. It can also prevent moisture stress of trees and salification which comes from the main water reservoir.

The proposed system has been realized in form of 3 portable units. These are named as base station unit (BSU), valve unit (VU) and sensor unit (SU). All of the units are involved in UDEA brand 434 *MHz* RF module, 7 V, 1.8 W solar panel (s) and low power Microchip PIC18F452 micro controller chip. Decagon brand soil moisture is seen in SU which sends data of soil moisture to base station unit. BSU evaluates the data received from SU and decides which part of area must be irrigated and which types of signals must be sent as open or close information to valve unit. Also all data and position of valves were monitored by the software in a computer with BSU. The VU involves a 12 V, 10 W normally-closed solenoid valve and a 12 V, 26 *Ah* battery.

MATERIALS AND METHODS

The designed system was applied for controlling drip irrigation of 1000 dwarf cherry tree. This drip irrigation was performed by solar powered pumps. One of them (pump-1) carries water from Dam Lake to water tank, another one (pump-2) is used for achieving the required pressure for irrigation of orchards. Application area is located in a geographical area of 40°10'48.12” North and 35°51'59.21" in central Anatolia; this is within the boundaries of east coordinate of Zile District of Tokat Province of Turkey. In this area 14 laterals which are irrigated independently with control of valves have been setup. The configuration of this application (not as a whole, as only 2 units) can be shown in Figure 1.

Hardware

There are three different units which were designed and applied in this schema: Base station unit (BSU), valve unit (VU) and sensor unit (SU). All of these units contain a RF module, an antenna, a 7 V and 1.8 W solar panel(s) and a low power micro controller chip (MCU). All the electronic devices, sensors, and solenoid valves were selected to meet the low power and low cost requirement for the system. The units used in the application were designed as a portable device. It decides which parts must be measured and controlled.

The MCU has a 20 *MHz* oscillator frequency, 768 bytes of internal RAM, 32 KB program memories, 256 bytes EEPROM memory, 8 ADC channel and 40-pin DIP package with 34 programmable I/O pins (TTL-level), one additional pin dedicated to asynchronous communications. This MCU was selected in terms of the parameters according to cost, processor speed, low power requirements, rapid software development, and ease of system integration with custom circuits.

Wireless module

This is a model named as UFM-M11 and produced / marketed by Udea Technology Inc. RF module has been chosen for soil moisture sensor. A 434 *MHz* low power wireless modules and UGPA-434 Omni-direction antenna were connected. Outdoor radio transmission range of the module is 400 to 500 m. RF modules use Frequency-Shift Keying (FSK) modulation and maximum output of power is 10 *dBm*. Its power consumption is 10 *mW* at 434 *MHz* and current consumption is 17 *mA* for receiving mode and 30 *mA* transmitting mode. RF wireless modules were used to have communication 9.6 *Kbps* with MCU and its view is given in Figure 2. UFM-M11 has a special data format to communicate with the other modules.

Every module has got transmitting/ receiving function. Some properties have to be fulfilled to establish connection. These are appropriate general data in RS232-TTL level, 8 data bits and one stop bit. General data format is shown in Figure 3. A 60 bytes maximum length data package can be sent to the transmitter module by MCU which is administrated by the Radio Frequency (RF) synchronizing protocol. Also the module allows optimal working frequency (433.05 to 434 *MHz* with 200 *Hz* steps).

Power supply

The designed system needs to have two different voltage levels. The microcontroller used in the system (PIC) runs by a 5 V, the RF

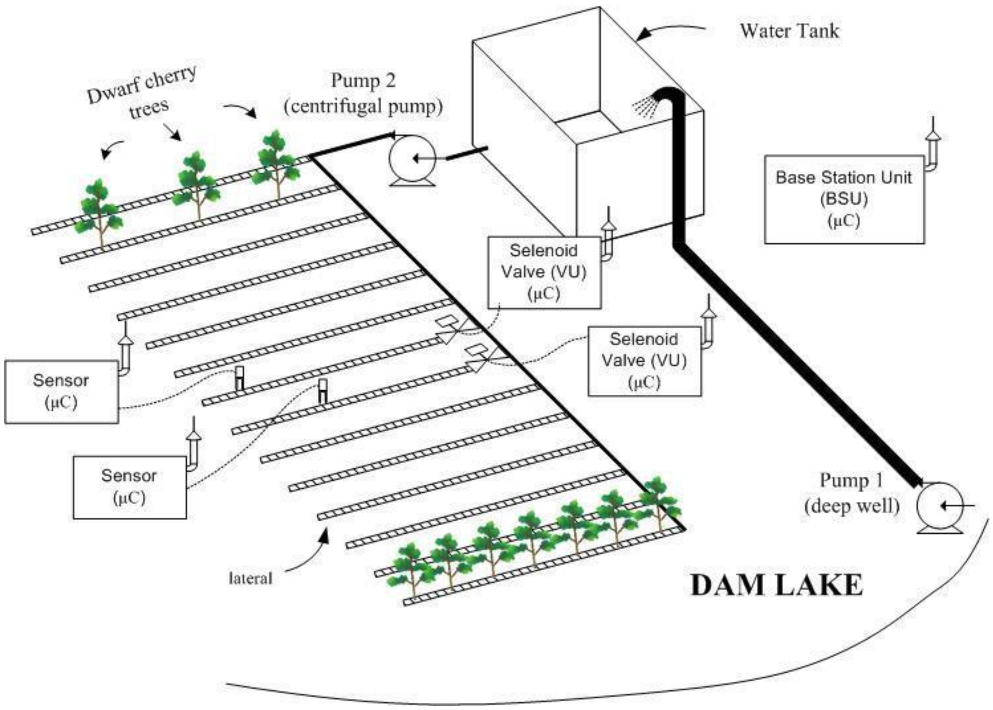
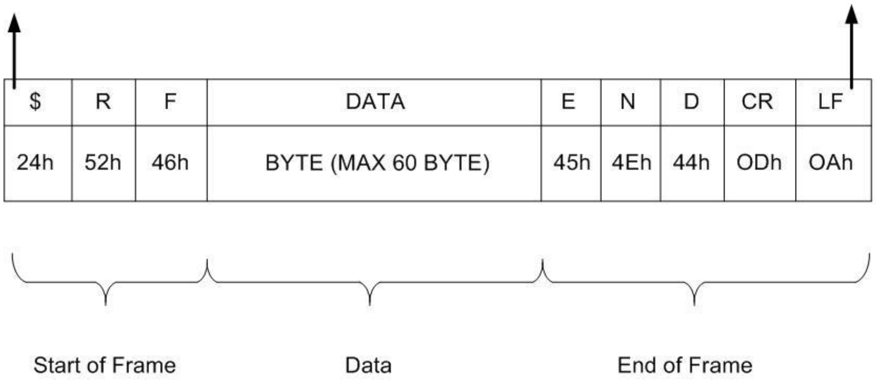


Figure 1. Overview of the system installed in the area.

Figure 2. UDEA UFM-M11 RF Module.



$	R	F	DATA	E	N	D	CR	LF
24h	52h	46h	BYTE (MAX 60 BYTE)	45h	4Eh	44h	ODh	OAh

Figure 3. RF Module general data format.

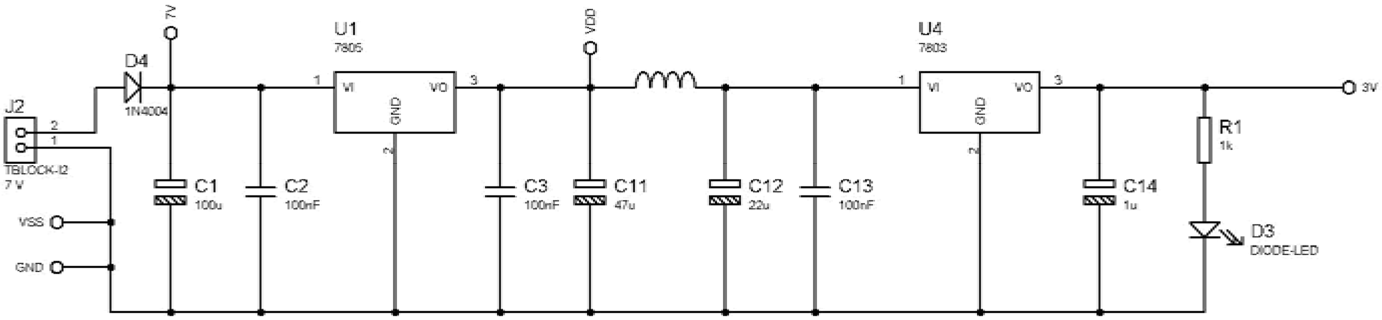


Figure 4. Schematic diagram of the power supply of the modules

Figure 5. Soil moisture sensor brand by Decagon.

module runs by a 2.7 to 3.3 V DC. Power supply unit must be stable for a stable connection with the RF modules. A solar panel (1.8 W, 7 V) was used to supply the units. The input voltage is passed through 1N4004 diodes for protecting system against the short circuit currents. The voltages level was kept as 5 V with 7805 for PIC and 3.0 V with LP2950 for RF module. In the circuit it is seen that a few capacitors and inductors were used to filter ripples of the voltages. The power supply of the system discussed earlier is shown in Figure 4.

Soil moisture sensor and unit

In the developed system, 10 HS coded pre-calibrated Soil Moisture Sensor of Decagon has been used to measure water content of soil (Figure 5). The 10 HS has a low power requirement and very high resolution. This gives you the ability to make as many measurements as you want (that is, hourly) over a long period of time with minimal battery usage. 10 HS needs 12 to 15 *mA* and runs with 3 to 15 V DC. Output voltage of sensor is 300 to 1250 *mV* (independent from the excitation voltage).

The 10 HS measures the dielectric constant of the soil in order to find its volumetric water content (VWC) using a capacitance technique. Since the dielectric constant of water is much higher than that of air or soil minerals, the dielectric constant of the soil is a sensitive measure of volumetric water content.

The SU acquires data given by the ADC, and the data sent to BSU. Value of ADC input which comes from the sensor is stored in a 10-bit register. Different type of sensors can be added easily for future developments. Output voltage level of PIC (5 V) is higher than RF module (3 V). Cause of that 5 to 3 V level conversion was used for communication microcontroller with RF module. In this design, a 20 *MHz* oscillator was selected to use. The output value which was produced by the sensor value is as an analog data and it is converted to digital data by the PIC and sent to PC via serial ports. In this system two LEDs were added for notifications. These hardwires of SU are given in Figure 6. Application of SU is given in Figure 7. This figure also presents solar panel, PCB of SU, sensor, RF antenna and dwarf cherry tree.

Valve unit

Valve unit has the same connection with wireless module and the same properties with SU. It has an output for controlling the valve. This valve was operated digital outputs (RD6) on the microcontroller by transistor (MJE3055). PVD Brand, ½", normally-closed solenoid valves with a 12 V, 10 W coil was selected. This application of the VU is shown in Figure 8.

Base station unit (BSU)

The BSU is a master device that is programmed to read and to evaluate sensors data, to control valves and to communicate with other units. Installing BSU in the system is given in Figure 9 as a photographic view. The mounted PCB was interfaced to the outsides by a RS-232 serial port.

Software

The flow chart of this software is shown in Figure 10. After power-up, the BSU sends address data with sensor numbers to the SU for getting the data. The SU sends moisture data with sensor number. If the BSU matches the SU data, it can evaluate the moisture data. If it requires, the position of valve can be changed. Afterwards, the BSU sends address data for getting new sensor value. The SU measures soil moisture after receiving it from the BSU and then it

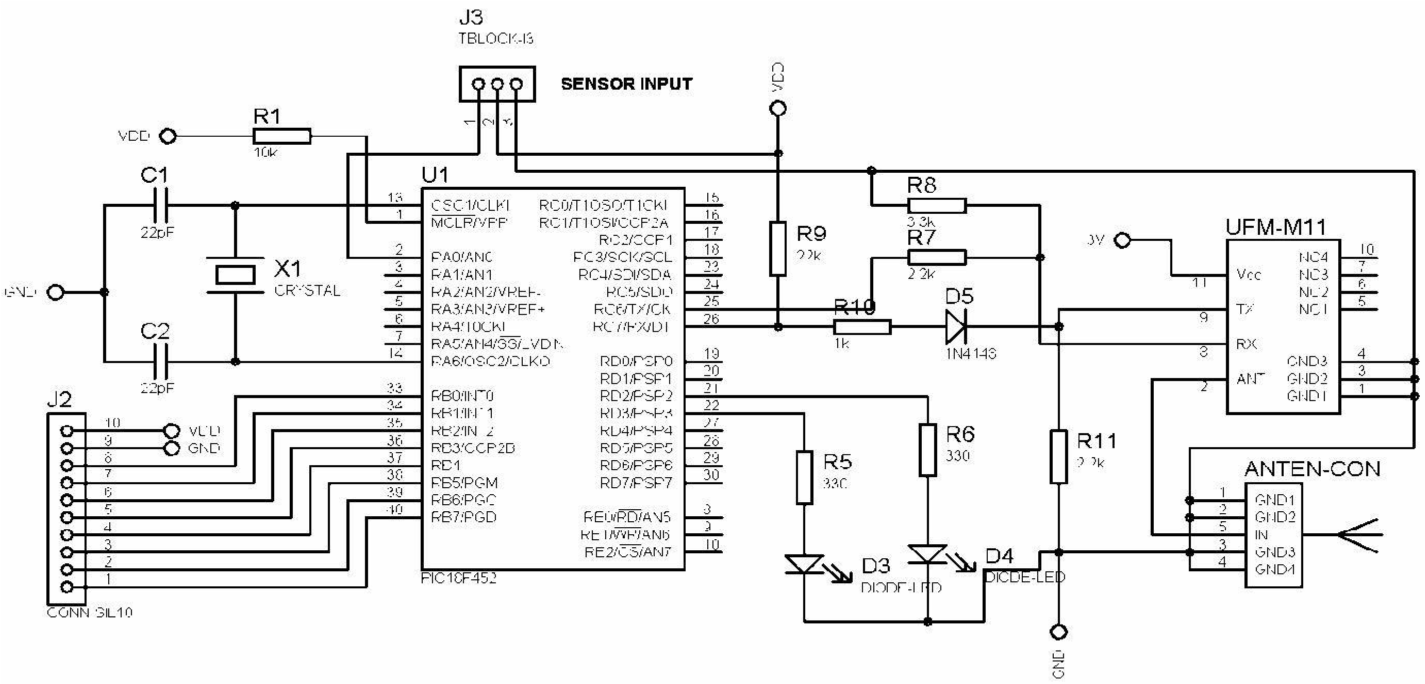


Figure 6. Hardware schematic diagram supported by sensor unit.

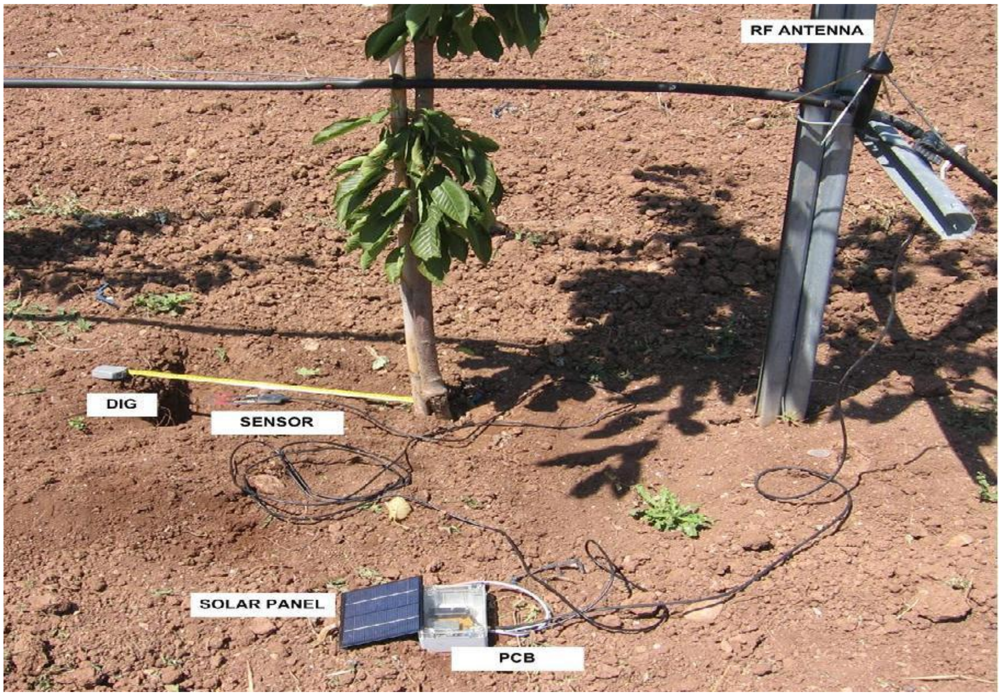


Figure 7. System's application around dwarf cherry tree with sensor unit.

sends data. The VU changes the position (on or off) after receiving the data from BSU.

Figure 11 represents an instantaneous case during irrigating a dwarf cherry tree and its soil moisture. The position of the soil moisture sensor is given in Figure 12.

EXPERIMENTAL STUDY

The soil moisture sensor which is used in this application has been located 20 cm of depth from ground and 50 cm

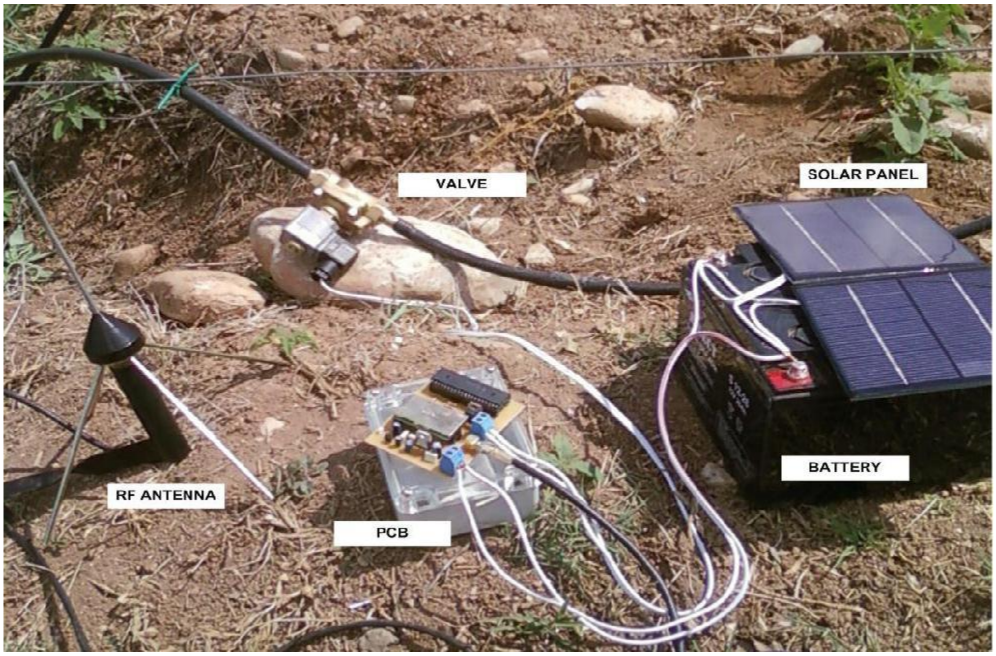


Figure 8. Application of the valve unit.

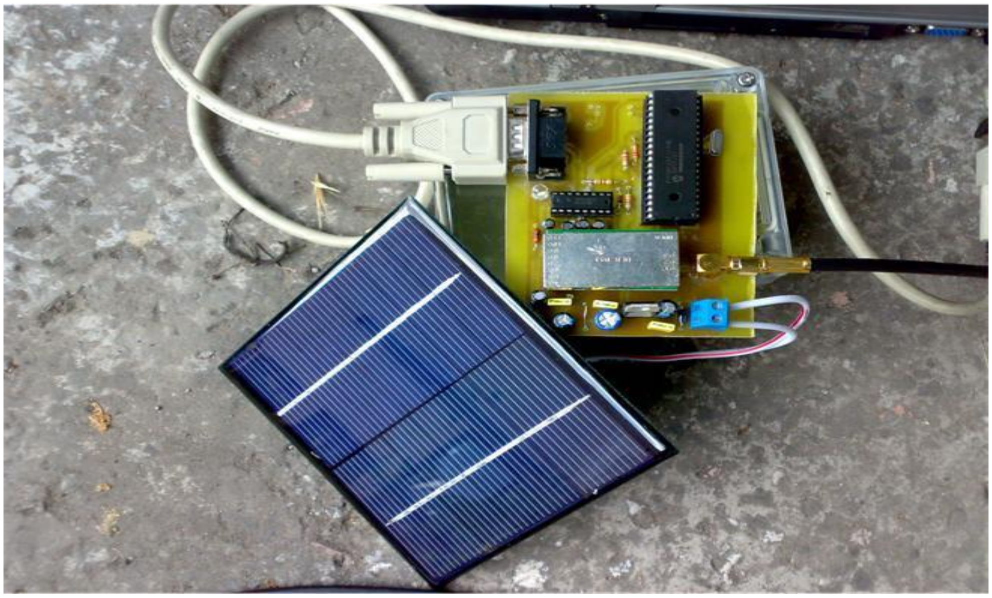


Figure 9. Application of Base station unit.

far away from the dwarf cherry tree. Figure 11 shows the position of the soil moisture sensor. The location of the mounted sensor is demonstrated as a schematic diagram in Figure 12 with irrigation drippers. The irrigation system entirely has started to work and the ordinary data has been received by BSU during irrigation at time 09:00 to 11:30.

All of instantaneous the data have been recorded within 150 min per 3 s, a total of 3000 data have been taken and recorded. The curve regarding to the recorded data is shown in Figure 13. All the analog values taken from the soil moisture sensor is sensed by a PIC, and they are converted to real volumetric water content. The conversion equation is given in Equation 1 (Decagon, 2009). The analog to digital converter (ADC) is referred to an analog value sensed by a PIC microcontroller.

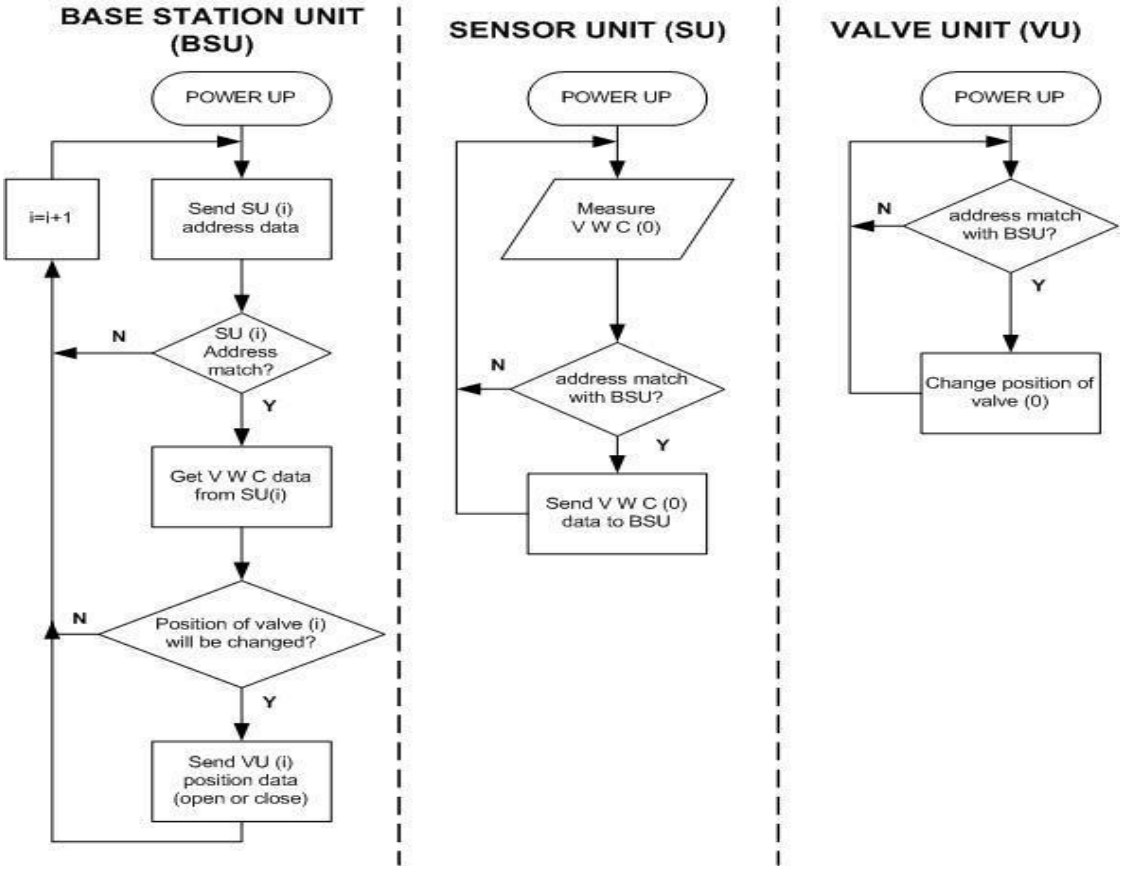


Figure 10. Software flow charts of units.

Figure 11. A picture of the mounted sensor while irrigating a dwarf cherry tree.

$$VWC(m^3/m^3) = 1.17 * 10^{-9} * ADC^3 - 3.95 * 10^{-6} * ADC^2 + 4.90 * 10^{-3} * ADC - 1.92 \quad (1)$$

The characteristic curve related with the VWC and time follows circa linearity. In the first hour, increasing of the

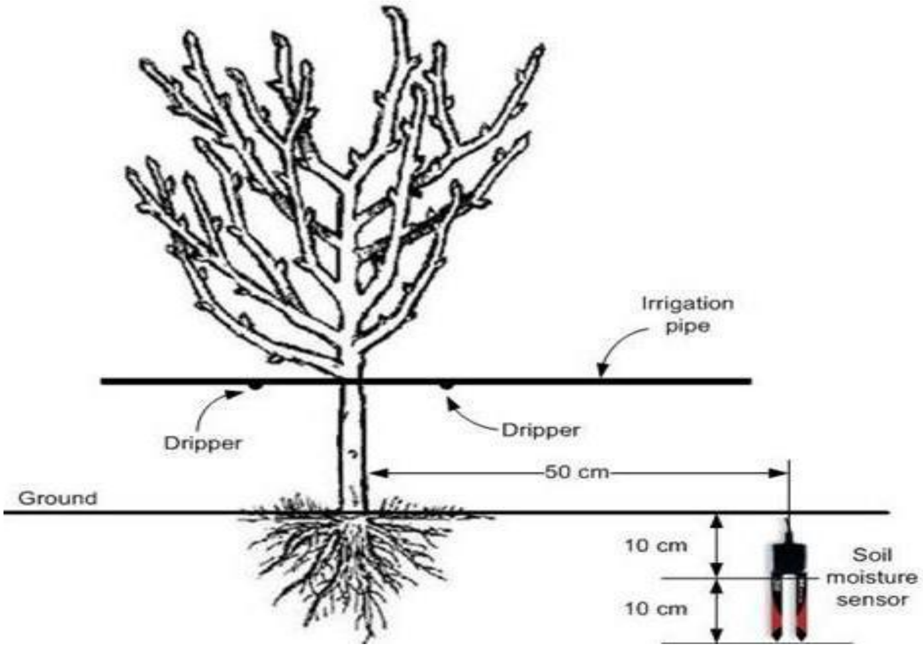


Figure 12. Location of the soil moisture sensor in this application.

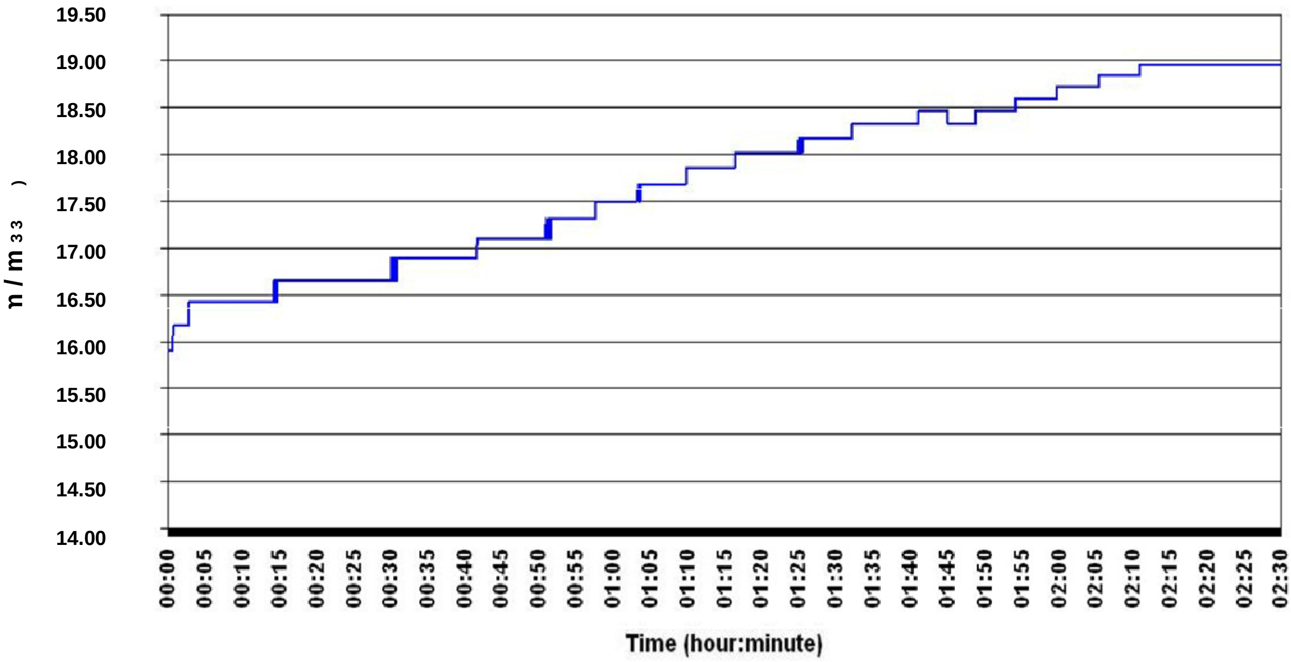


Figure 13. The curve of the recorded Volumetric Water Content (VWC) versus the time values.

curve is changed slowly; however, some ripples are being seen at passing up level as shown in Figure 13.

THE COST OF THE EQUIPMENTS

The cost of all electronic components and devices of the developed system is given in Table 1. As an example the BSU contains somewhat fundamental components and its price is about $ 96. As it is affordable, it can be used by growers in their own agricultural irrigations. In the system all of component was selected low cost materials. So that it can be use all of commercial application. The item prices of each equipment which were used in the application are shown in Table 1.

Table 1. The cost of the electronic components and devices.

Equipment	Unit price (USD)		
	BSU	SU	VU
Wireless module	40	40	40
Antenna	27	27	27
PIC	8	8	8
Electronic component	5	6	5
PCB	5	5	5
Sensor	-	125	-
Valve	-	-	45
Solar panel	11	11	22
Battery	-	-	60
Total (USD)	96	222	212

CONCLUSION

In this study, a wireless data acquisition network was implemented and applied to irrigate dwarf cherry trees. The developed irrigation automation system can be proposed to be used in several commercial agricultural productions since it was obtained in low cost and in reliable operation. This application of sensor-based site-Specific irrigation has some advantages such as preventing moisture stress of trees, diminishing of excessive water usage, ensuring of rapid growing weeds and derogating salification.

If different kinds of sensors (that is, temperature, humidity, and etc.) are involved in such irrigation in future works, it can be said that an internet based remote control of irrigation automation will be possible. The developed system can also transfer fertilizer and the other agricultural chemicals (calcium, sodium, ammonium, zinc) to the field with adding new sensors and valves.

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