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A Low Cost Capacitive Soil Moisture Measurement and Datalogger System

Düşük Maliyetli Bir Kapasitif Toprak Nemi Ölçüm ve Veri Kayıt Sistemi

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Abstract

Water resources, which are indispensable for agriculture, industry and domestic use, are under threat today. In order to use water and soil resources efficiently and sustainably, it has become an important need to develop new systems and methods that can detect the moisture content of the soil. With the developing technology and different techniques, the moisture content of the soil began to be measured more accurately, reliably and quickly. One of these techniques is measuring soil moisture with high-precision and low-cost capacitive sensors. In this study, an example system for measuring and recording soil moisture was designed using the Arduino microcontroller board and capacitive sensors. In the study conducted in a climate-controlled greenhouse, a very high negative correlation was found between sensor and gravimetric measurement values. The regression relationship between sensor values and gravimetric measurement values was examined and R^2 values between 85.6% and 95.0% were obtained.

Keywords: Soil moisture, capacitive moisture sensor, arduino

Özet

Tarım, sanayi ve evsel kullanımın vazgeçilmezi olan su kaynakları günümüzde tehdit altındadır. Su ve toprak kaynaklarının verimli ve sürdürülebilir şekilde kullanılması için toprağın nem içeriğini tespit edebilecek yeni sistem ve yöntemlerin geliştirilmesi önemli bir ihtiyaç haline gelmiştir. Gelişen teknolojiyle birlikte farklı teknikler sayesinde toprağın nem içeriği daha doğru, güvenilir ve hızlı bir şekilde ölçülmeye başlandı. Bu tekniklerden biri de toprak neminin yüksek hassasiyetli ve düşük maliyetli kapasitif sensörlerle ölçülmesidir. Bu çalışmada Arduino mikrodenetleyici kartı ve kapasitif sensörler kullanılarak toprak nemi ölçümü ve kaydedilmesine yönelik örnek bir sistem tasarlanmıştır. İklim kontrollü bir serada sistem ile yapılan çalışmada sensör değerleri ile gravimetrik ölçüm değerleri arasında çok yüksek negatif korelasyon bulunmuştur. Sensör değerleri ile gravimetrik ölçüm değerleri arasındaki regresyon ilişkisi incelenmiş ve %85.6 ile %95.0 arasında R^2 değerleri elde edilmiştir.

Anahtar Kelimeler: Toprak nemi, kapasitif nem sensörü, arduino

Introduction

Water is essential for its roles in growing food, domestic use, industry, tourism, and sustaining the earth's ecosystem. However, this essential resource is under threat. Growing national, regional and seasonal water shortages around the world pose serious challenges for national governments and the international development and environmental communities (Rosegrant et al., 2002).

The moisture content of the soil directly affects plant growth, the distribution of plant nutrients along the soil profile, soil aeration, infiltration and runoff. The mechanical properties of the soil such as plasticity, consistency and swelling-shrinkage are also a function of moisture content. Therefore, determining the moisture content of soil is a basic need in soil, hydrology and engineering studies (Öztaş, 1997). Detailed information about the water content in the soil profile is of interest to many disciplines. In this context, dynamic hydrological processes such as infiltration and capillary rise in the soil can be examined. Irrigation time and amount of water to be applied can be determined by water use efficiency tests. Evapotranspiration can be calculated from the change in the water content of the soil profile when infiltration, sedimentation and runoff are known (Halbertsma et al., 1987). In order to use water and soil resources more efficiently, it is inevitable to develop new devices and develop new methods to measure soil water content (Özbek & Kaman, 2014). With the advancement of technology, soil water content has begun to be measured more accurately and reliably with the help of different techniques. Thus, with the right techniques, it has been ensured that the volumetric soil moisture content can be monitored, repeated measurements can be taken, and fast and time-dependent accurate and reliable measurements are taken (Uytun et al., 2013).

The methods used in soil moisture determination are divided into two groups as direct methods based on the principle of determining the mass of water according to their functions, and indirect methods based on the principle of measuring any soil property dependent on soil moisture content (Öztaş, 1997). Direct methods are gravimetric. In these methods, water in the soil is removed from a soil sample by evaporation, washing or chemical reaction, and moisture is determined from the removed amount (Öztaş, 1997). The biggest disadvantage of direct methods is that it is not possible to take more than one sample from the same point and it causes damage to the soil profiles in the trial plots. In the case of taking a large number of samples, it causes the formation of macropores in the soil, which may cause the soil moisture regime to change (Kutilek & Nielsen, 1994; Öztaş, 1997). Another disadvantage of direct measurement methods is that the differences in moisture content of soil samples taken at different times will reflect both the variation in soil moisture and the variation arising from the heterogeneous structure of the soil. The most important feature of the gravimetric method is that it is a standard method used for the calibration of indirect methods (Öztaş, 1997).

In indirect soil moisture measurement methods, the changes in certain physical and physicochemical properties of the soil depending on the amount of water are taken as basis. In most of these methods, moisture determination can be easily made either by permanent sensors placed in the soil or by sensors placed in special slots opened in the soil at the time of reading. The most common of these indirect methods, in which the water content of the soil is determined by sensors, are time domain reflectometers (TDR), neutron meters, tensiometers, conductivity sensors (grained matrix sensors and gypsum blocks, etc.), thermal sensors, frequency domain reflectiometers (campbell FDR) and capacitive sensors. (Uytun et al., 2013).

The capacitive method is based on measuring the capacitance of the dielectric medium of a capacitor. Conductive plates or rods placed in the ground form a capacitor structure. The soil-water-air mixture acts as the dielectric medium of this capacitor (Halbertsma et al., 1987). Materials that can store energy when an external electric field is applied are called "dielectrics". In other words, the dielectric structure can be studied by monitoring the changes in the capacitance of the medium (İyibakanlar & Oktay, 2007; Dean et al., 2011; Mander & Arora, 2014).

In electromagnetism, the dielectric constant is also called the insulating constant. It is expressed as a coefficient for measuring the ability of a material to store electrical charge on it. It is a measure of the effects of an electric field or how an insulating medium is affected Every material has a dielectric constant value. The dielectric constant (ε) ranges from 1 to 81. The dielectric constant of water molecules with dipolar moment is 81. The lowest value is for air and is 1. The dielectric constant value of the soil in the solid phase varies between 3 and 5.

In a mineral soil, when most of the pores are filled with air and the rest with water, the ε value of the medium is between 3-6. On the other hand, when a large part of the pores is filled with water and the rest with air, it varies between 40-50. Soil consists of solid, liquid and gas phases. In a case where the solid phase value is constant, the ε value of the soil is a function that directly indicates the moisture content (Anonymous, 1995; Kutilek & Nielsen, 1994; Hartmann, 1996; Öztaş 1997; Fidan and Korkmaz, 2018). Bryan and Sanders (1928), developed a method for measuring the dielectric constant of air in high-frequency fields and analyzed the effect of temperature on the dielectric constant of air. They concluded that even at high temperature conditions, changes in the dielectric constant of air were minimal (Physical Review, 1928).

Capacitor structures can be used as sensors in numerous applications. This method is called the capacitive method and changes near the sensor surface can be measured. In addition, this method has different advantages over other methods. Measurements with a capacitive sensor do not carry the potential health risks of radiation-based methods. They are also relatively simple compared to radio frequency (RF) based techniques. Capacitive sensors can be used to monitor moisture content in soil, moisture content in grain and paper, rain sensing. In addition, there are applications of proximity, acceleration, angular velocity, position, touch, liquid level and biomedical sensors based on the capacitive method to detect physical changes. Advances in microelectronics have made capacitive sensors popular and more affordable in devices used to monitor the water content of soil "in situ" (Fares & Alva 2000; Fares & Polyakov 2006; Dean et al., 2011; Narmadha et al., 2012; Mander & Arora, 2014).

The biggest advantages of Arduino are that it uses open source code, has an extremely simple microprocessor circuit, and has the necessary software package to program the system. The use of open-source code is one of the most important reasons for Arduino's popularity. Thus, the codes written are not kept confidential and users can easily access these codes (Koçak & Kırbaş, 2016). There is an ATmega2560 microcontroller on the Arduino Mega2560. There are 54 digital input/output pins. In addition, 15 of these pins can be used as pulse with modulation (PWM) output, 16 as analog input and 4 as serial port hardware (UART). Operating at 16 MHz, the board has a USB connection, an external DC power supply input. It can be powered by USB, AC/DC power supply or a battery (Kusriyanto & Putra, 2016).

In the light of the above the literature, a microcontroller-based system that can be measure soil water by capacitive method has been developed and tested in the greenhouse.

Material and Methods

Material

The research was carried out in a climate-controlled greenhouse located in the campus of the Soil Fertilizer and Water Resources Central Research Institute in Ankara. The soil used in the experiment was sieved with a 2 mm sieve. The results of the soil analysis are given in the Table 1.

Table 1. Physical and chemical properties of the soil used in the experiment

Field capacity (%)	28.1
Wilting point (%)	15.2
Bulk density(g cm^{-3})	1.24
Saturation (%)	62
Soil textural class	CL (clay loam)
EC in water saturated soil (dS m^{-1})	0.62
pH in water saturated soil	7.78
$CaCO_3$ (%)	18.4
P_2O_5 (%)	11.4
K_2O (%)	118
Organic matter (%)	1.89
Total C (%)	3.25
Total N (%)	0.12
Soil organic C (%)	1.1
Soil inorganic C (%)	2.21

The developed system consists of an Arduino Mega 2650 board, a data storage unit with a SD card, a LCD screen, a real time clock (RTC), four low cost capacitive soil moisture sensors, a power supply and microcontroller code. In addition, it is possible to easily add additions such as temperature sensor, air humidity and temperature sensor to the system. General view of the system is given in Figure 1. The algorithm of the code and principal schematics are given in Figure 2.

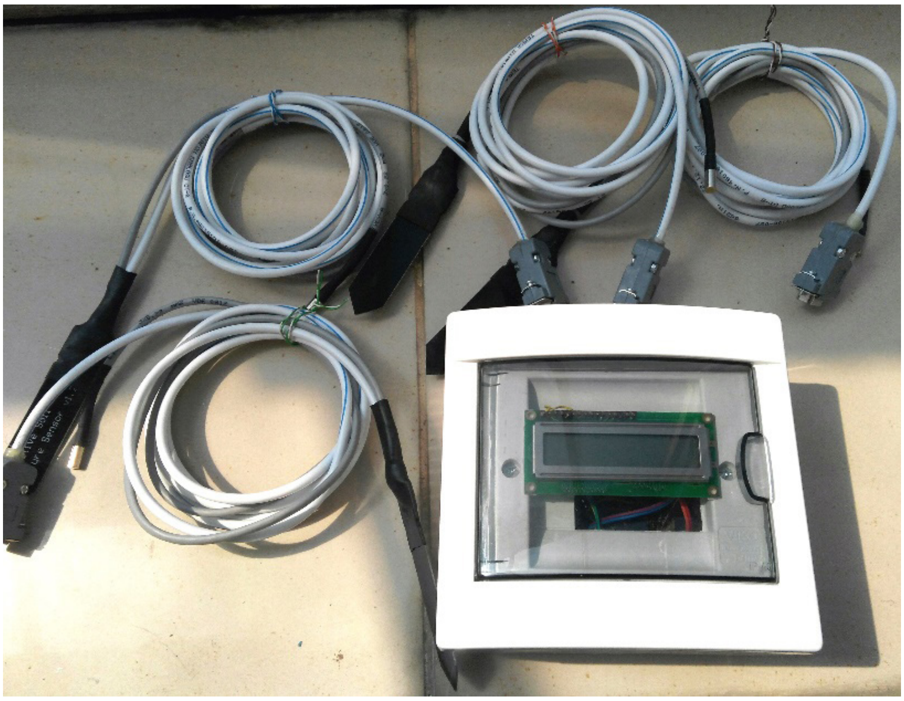

Figure 1. General view of the system

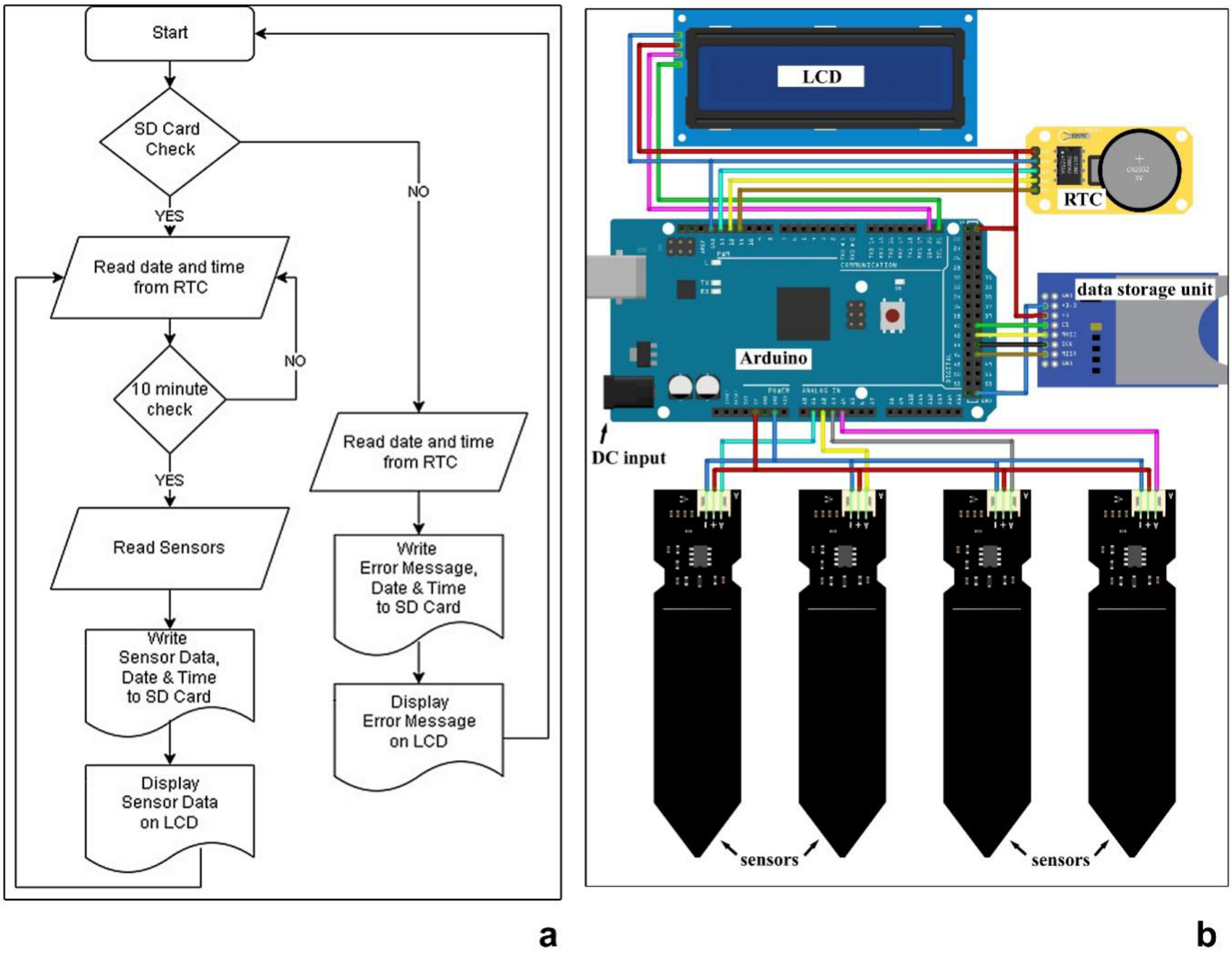

Figure 2. Algorithm (a) and principal schematics of the system (b)

The sensors used in the system are Capacitive Soil Moisture Sensor v1.2 and do not use electrical resistance detection like other low-cost sensors on the market. Instead, it measures soil moisture levels by sensing capacitance that changes according to the water content in the soil. The sensor works as a capacitor in a fixed frequency square wave oscillator circuit built with a 555 Timer IC. It converts the measured capacitance values into electrical signals in the range of 1.2 - 3.0 V. Thus, it can be connected to the analog input pin of a microcontroller such as Arduino. The sensor is coated with a corrosion-resistant material to ensure a long service life (Anonymous, 2022).

The microcontroller code of the system was written in the Arduino Development Environment (IDE) based on the C / C++ programming language and uploaded to the Arduino Mega 2560. The analog values taken from the moisture sensors in the range of 0-5 Volts are saved to the memory card by performing analog-digital conversion (ADC) with 10-bit resolution. Therefore, the sensor data is in the range 0-1023 since it is 10-bit. Wire.h, LiquidCrystal_I2C.h, SPI.h, SD.h and DS1302.h libraries are used in the microcontroller code.

Method

The study was based on the determination of water content by the gravimetric method. An adequate quantity of the soil, characterized by the properties listed in Table 1, was collected an subjected to drying in an oven at 105°C for 24 hours. After cooling, 2000 grams of dry soil was placed in each pot. 4 flower pots with a hole in the bottom were used. Sensors values was recorded for dry soils in each pots. Then, distilled water was added to the pots and it was waited until the weight decreased to 2562 grams for each pot, that is, the field capacity from Table 1 (% 28.1 = 562 g). Sensors values was recorded for wet soils in each pots. For the gravimetric evaluation, the amount of water in the range of 0-562 grams was taken as the basis, since it was 2562 grams when 2000 grams of dry soil was at field capacity.

The sensor values are in the range of 0-1023, since the analog-digital conversion is 10-bit resolution. When the wet soil weight drops to 2562 grams, the capacitive moisture sensors were placed in the pots and analog value measurements were made for the sensors in each pot (Table 2). Then, the soil in each pot was waited until it weighed 2000 g. This period lasted for 17 days under the conditions of 28°C average temperature and 25 % average relative humidity to arrive almost dry soil about 2059-2063 grams. For the accuracy of the measurements, temperature and humidity were selected from the most suitable and stable values in the existing greenhouse during the period when the experiment was carried out. Pots were weighed once a day. The sensors were not removed during the measurement period. Soil moisture was recorded on the memory card for a period of 10 minutes during the system measurement period. Thus, sensor values that coincide with the weighing time could be obtained. After the measurement studies were completed, the memory card was removed from the system and the file containing the data was transferred to the computer environment and the values corresponding to each weighing were extracted. In all given values, empty pot weight values are excluded from the calculation.

Table 2. Digital values (10-bit) collecting from sensors

Sensor&Pot	1	2	3	4
Field Capacity	305	352	327	317
Dry soil	745	768	766	754

Regression analysis was performed between the weight and sensor values obtained for each pot. Regression equations, R-square's and linear regression curves were obtained. Pearson correlation analyzes were performed between sensors measurement values and between pots weight values.

Results and Discussion

Weighing values obtained from 4 different pots and 4 different sensor values were subjected to normality test separately and it was understood that they did not show a normal distribution. According to the non-parametric Kruskal-Wallis tests, there is no statistically significant difference between the 4 different sensor values ($p>0.05$). Additionally, according to the Kruskal-Wallis test, there is no statistically significant difference between the weighing values obtained from 4 different pots ($p>0.05$).

Linear, quadratic and cubic regression relations and R^2's between all of four water contents and the all of four sensor values are given in Table 3. Anova summary of regression analyzes are given in Table 4. Amount of water (gram) is abbreviated as PT and sensor value as SN.

Table 3. The regression equations and R^2 values

Model	Regression Equation	S	R^2(%)	R^2(adj.)
Linear	$PT = 2962 – 1.130\ SN$	59.2849	85.6	85.4
Quadratic	$PT = 2217 + 1.732\ SN – 0.002554\ SN^2$	45.9321	91.5	91.2
Cubic	$PT = 4605 – 12.44\ SN + 0.02409\ SN^2 – 0.000016\ SN^3$	35.6026	95.0	94.7

Table 4. ANOVA summary of regression analyzes

Model	DF	SS	F	P
Linear	1	1462952	416.24	0.000
Quadratic	1	100456	47.62	0.000
Cubic	1	59380	46.85	0.000

Thus, equations suitable for estimating water amount of a soil with known field capacity with sensors have been obtained. After the regression analysis between water contents and sensor values R-squared values 85.6 - 95.0 have been found (Table 3). Linear quadratic and cubic regression curves are given in Figure 3, 4 and 5 respectively.

According to the results of Pearson's correlation analysis, there was a very strong negative correlation (-0.925) was found between sensor measurements and changes in amount of waters (p<0.01).

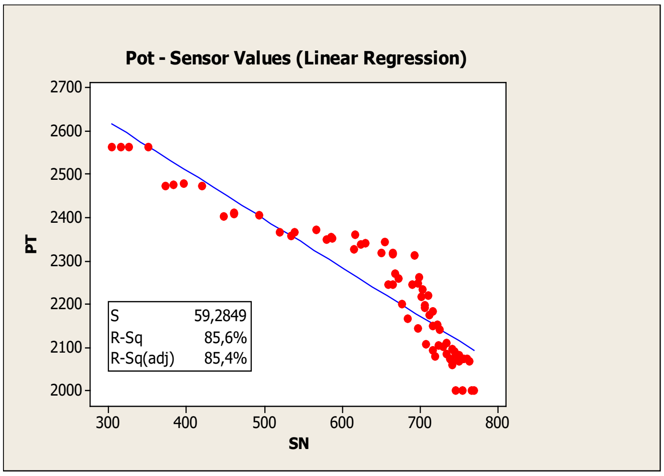

Figure 3. Linear regression curve

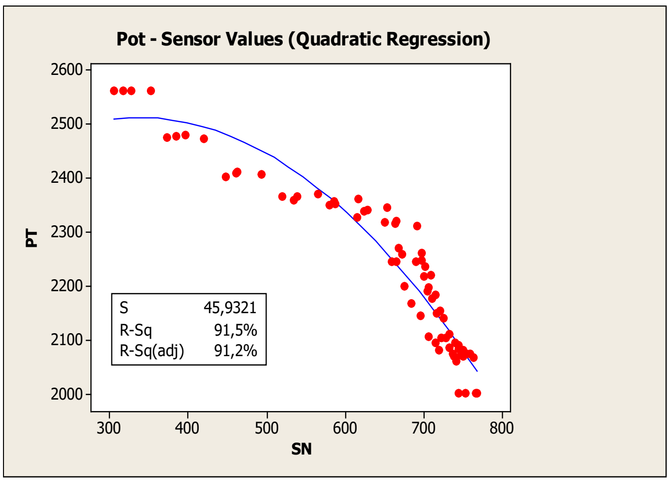

Figure 4. Quadratic regression curve

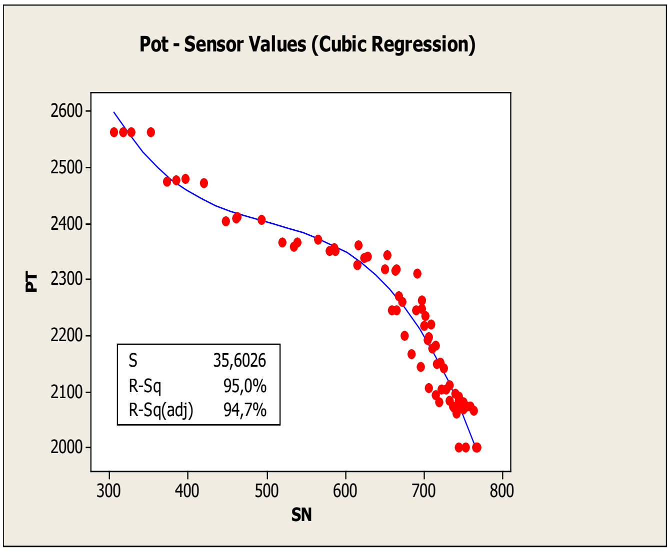

Figure 5. Cubic regression curve

Placidi et al. (2020), found correlation coefficient of -0.945 (very high negative correlation) between gravimetric and sensor results in their study with a similar low-cost capacitive moisture sensor and using silica sand as the material.

Muzdrikah et al. (2018), in their study with a similar low-cost capacitive moisture sensor and using soil with sandy loam structure as material, found the correlation coefficients between gravimetric and sensor results in the range of -0.976 to -0.986 (very high negative correlation).

Conclusion

In this study, it is aimed to create a low-cost system that can provide soil moisture measurement and digital recording of measurements by using capacitive soil moisture sensors and arduino platform. For this, a system has been created by connecting capacitive soil moisture sensors, real time clock (RTC), data recording unit (SD card) and LCD screen to Arduino Mega 2650 microcontroller board. A C/C++ programming language-based microcontroller code was written in Arduino IDE for the system. The moisture changes due to water loss in the analyzed soil samples and the digital data obtained during these changes were compared.

Since the study was at the prototype level, it was tried in a small number of pots. It has been shown that a fairly simple sensor and an open-source microcontroller platform can be effective through verification with gravimetric measurements of soil moisture. The system was able to record data for 17 days without any problems. Such sensors and system need to be tested for a long time in different soil types and field conditions.

In order for low-cost and practical measurement systems to be used commercially, future studies should first be carried out under fully controlled conditions and then continued under field conditions. It is expected that the moisture requirement in the soil can be measured and monitored with inexpensive microcontroller platforms such as Arduino in order to use water in a more controlled manner in agriculture. It is seen that the Arduino platform is a practical and inexpensive platform that can contribute to the development of systems in agricultural moisture measurement studies and, accordingly, irrigation automation. The system shows the potential to be used in monitoring water use in greenhouses. With additional changes and additions to be made; the system that can operate in field conditions, can detect environmental variables other than moisture and has the potential to be used in irrigation control has been obtained.

Author Contribution

MYP: Conceptualization, hardware arrangements, microcontroller code design in ArduinoIDE, greenhouse study, data collection, statistical analysis, writing (original draft preparation), writing (review and editing); **AÖ:** Writing (editing). All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

Ethical statement

The authors declared that this article complies with research and publication ethics.

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