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Probe-based Semi-permanent Soil Humidity Sensor

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Abstract: The modern agricultural environment has the problems of an aging rural population and a decreasing rural labor population. Recently, smart farms based on information and communication technology have been studied to address environmental issues in agriculture. The smart farm consists of three parts: a data collection unit, a processing unit, and a control unit. Among them, the data collection unit is responsible for collecting necessary information through various sensors in the smart farm. Among the various sensors, the soil humidity sensor is an essential sensor for measuring the moisture in the soil, which is essential for cultivating various crops. However, the soil humidity sensor released as a prototype is vulnerable to corrosion because the probe part of the sensor is in direct contact with the soil. Therefore, the sensor needs to be replaced at regular intervals. To solve this problem, we propose a replaceable probe-type soil humidity sensor that can be maintained inexpensively by replacing only the probe part when corrosion occurs. Experiments are conducted to verify the applicability of the proposed sensor in an actual agricultural environment and its superiority compared to the legacy sensor. Specifically, this study utilizes easily available soil humidity sensor that uses easily available household items such as stainless-steel chopsticks as a probe and verify its applicability through experiments. We propose a method of increasing the usability of the proposed sensor through usability tests in soils of various properties, tests for accurate data measurement even when replacing sensor probes, and tests for minimizing noise in measured values. Finally, we verify that the proposed sensor can be used for a longer time without corrosion through a durability comparison experiment with legacy sensors.

Keywords: Soil Humidity; Sensor; Agricultural IoT; Semi-permanent; Smart Farm; IoT

Introduction

The decline in agricultural economic power due to an aging rural population and the decrease in the rural labor force is a problem that needs to be solved in modern society. The rural population has been declining for decades, according to the U.S. Census Bureau's rural census. Since the mid-1990s, the decrease in the population growth rate in rural areas and the migration of population from rural to urban areas have been the causes of the decline in the labor force. A decrease in the rural labor force is the background to an increase in idle farmland, and the neglected idle farmland is devastated within a few years, causing damage to the agricultural economy.

Smart farms incorporating information and communication technologies such as real-time crop monitoring and automatic watering machines are being researched to overcome these agricultural problems. Smart farm technology can obtain data related to the growth of crops in real time, and provides an environment in which the farm can be operated with less manpower by providing an automatic control system. However, there are operational difficulties due to the high initial construction cost and maintenance costs, such as sensor replacement. Compensating for the replacement of sensors used in smart farms can reduce smart farm maintenance costs, thereby reducing the burden of introducing smart farms (Li *et al*., 2014; Cromartie, 2017; O'Grady & O'Hare, 2017; Wang *et* *al*, 2018).

In general, a smart farm consists of three parts: a data collection unit that collects various information within the smart farm, such as environmental information and image information; a data processing unit that stores, processes, and analyzes data; and a control unit that controls equipment based on the analysis information. The data collection unit may be composed of various sensors according to user requirements. Sensors used in the data collection unit include temperature and humidity sensors, a carbon dioxide sensor, and a soil humidity sensor that collects soil moisture content data. Soil humidity sensors measure the amount of moisture in the soil, which is an important factor for plant growth. Soil retains moisture through the surface charge and surface tension of soil particles. Because water has viscosity due to surface tension and surface charge, when soil and water are combined, the movement of molecules is not free compared to general water. Because water has a polarity, water in the soil facilitates chemical reactions and makes minerals and organic nutrients readily available to plants, and helps water to be stored in the soil or reach the ends of the plant stems by viscosity. Soil moisture can generally be expressed as volume ratio (water capacity), percentage (%), and moisture tension (pF). The moisture content is expressed as W (%) =100 (Vw/Vs), where Vw is the total moisture content of the soil, and Vs is the total volume of all soil components (Collado *et al*, 2019; Marshall *et al*, 2012; Eller and Denoth, 1996).

Measuring soil moisture content in smart farms is crucial for crop growth management. Smart farms use various types of soil humidity sensors to measure the amount of moisture in the soil. Methods for the soil humidity sensor to measure the amount of moisture in the soil include time domain reflectometry (TDR), frequency domain reflectometry (FDR), and the permittivity method using soil properties. The permittivity method measures water content by passing an electric current between two probes in a sensor made of a metal conductor adjacent to soil and water. Since the probe part is continuously exposed to moisture and electric current, it is vulnerable to corrosion when used for a long time. The corroded probe of the soil humidity sensor has the potential to cause damage to moisture-sensitive crops because it cannot measure the normal soil moisture content due to a change in the current.

To solve this problem, coating the probe part of the sensor to prevent corrosion or replacing the sensor at regular intervals is mainly used. Sensor replacement must be done preventively before corrosion, and a short corrosion cycle is costly. The corrosion protection technique through the sensor probe coating has the disadvantage of lowering the measurement accuracy and sensitivity because it interferes with the movement of electrons between the probes. In the case of the legacy soil humidity sensor, sensitivity cannot be adjusted because the resistance impedance value between the probes is designated as a specific value, or the sensitivity is set only within the range of the maximum and minimum of analog values because the sensitivity of the sensor is adjusted using an analog variable resistor (Anderson and Sitar, 1995; Bittelli, 2011).

In this study, we propose a method of reducing the maintenance cost of the soil humidity sensor, which is an essential sensor for smart farms, and use it for a long time without corrosion. Four experiments are conducted to confirm the availability of the proposed sensor. First, in order to reduce the maintenance cost of replacing the sensor, we experiment to measure the amount of power transfer due to the anode difference between the two probes using metal materials that are easily available in our daily life as candidates. This experiment checks whether the probe can be replaced when corrosion occurs on the probe part of the sensor. Second, the necessity of adjusting the resistance impedance value of the sensor is confirmed based on the relationship between the change in the soil humidity sensor value and the pore size between the soil particles. Third, it is confirmed that the sensitivity of the sensor can be adjusted by replacing the resistance through an experiment on the relationship between the resistance size and the value of the soil humidity sensor. Subsequently, a multiplexer-based winding resistance selection circuit that automatically sets the resistance for sensor sensitivity control is proposed. Fourth, the proposed soil humidity sensor generates noise in the measured data value because the input value is unstable. The possibility of minimizing noise is verified through an experiment comparing noise generation with and without capacitors using the bypass capacitor principle. Finally, the durability of the proposed sensor is verified by conducting a durability comparison experiment on corrosion between the legacy sensor and the probe-based replaceable sensor.

Related Works

Methods for measuring moisture in soil include the electrical resistance method, Time Domain Reflectometry (TDR), Frequency Domain Reflectometry (FDR), the neutron scattering method, and the thermal diffusivity-based double probe method.

Electrical Resistance Method

The electrical resistance method uses the principle that the electrical resistance of the soil changes according to the moisture content. Measure the electrical resistance between the electrodes when water equilibrium is established between the soils. Soil with high moisture content has low resistance, and low moisture content has high resistance. However, the higher the moisture content in the soil, the greater the error of the measured value. In addition, the probe-based sensor has a disadvantage in that the probe part is in direct contact with the soil and corrodes (Santos *et al*, 2023; Shigeta *et al*, 2018).

TDR and FDR Sensors

The TDR sensor uses a very high frequency (1.0~3.0GHz), and the intensity of the flowing electromagnetic wave varies according to the degree of permittivity in the soil. The intensity of the voltage or current applied in the circuit is converted into time according to the intensity of the reflected wave and converted into the direct volumetric moisture content of the soil. Measured soil humidity is expressed as volumetric moisture and provides a stable measurement value with high specific volume accuracy. The FDR sensor is a method of using a high-frequency, corresponding to 3 to 100 MHz, generated by measuring the change in the resonance frequency. Measure soil moisture content by measuring the return time of the wave. However, the cost of the sensor is high compared to the dielectric constant-based sensor (Croney *et al*, 1951; Topp *et al*, 1980).

Neutron Scattering Method

In the neutron scattering method, when high-speed neutrons with an energy of 1 million electron volts or more are absorbed from the radioactive material into the soil, the neutrons are slowed and degraded due to elastic collisions with the nuclei of hydrogen atoms. Hydrogen is the only element with a low atomic weight in soil, which effectively slows down neutrons faster than other elements in the soil. Hydrogen in the soil is usually in the form of water, with increasing neutron density in the solid, liquid, or vapor state. Soil humidity is measured as the number of slow neutrons per unit of time, averaged over the volume of the soil and expressed as a ratio of the number of neutrons in the measurement medium. The neutron scattering method has the advantage of being more accurate than the gravitational method and has a much smaller standard error compared to the electrical resistance method. However, the cost is high compared to the gravitational method and permittivity-based sensors (Böhme *et al*, 2013).

Thermal Diffusivity-based Double Probe Method

There are dual-probe thermal capacity sensors developed to provide volumetric heat capacity and thermal properties measurements such as thermal conductivity and thermal diffusivity. Among them, the dual probe sensor for measuring the thermal diffusivity of the soil measures the thermal conductivity and volumetric heat capacity of the soil. It compares the estimates by summing the heat capacity of the soil components. As the humidity of the soil increases, the heat diffusivity tends to increase, but there is a disadvantage that it approaches or decreases as the humidity continues to increase. Also, there is a limit to field measurement due to high power consumption (Visvallingam and Tandy, 1972).

Materials and Methods

In this paper, we propose a semi-permanent soil humidity sensor through four experiments. First, a probe candidate verification experiment of the permittivity sensor is conducted. Based on the measured data, we check whether the existing sensor can be replaced, and a candidate with the smallest standard error is selected. Second, to determine the minimum measurable resistance of the selected candidate, data are measured in each environment when the soil is dry, when the soil is generally wet, and when the soil is submerged in water. Third, by conducting a data change experiment according to soil composition, it is confirmed that sensor sensitivity adjustment is necessary according to the soil environment. Then, a multiplexer-based winding resistor selection circuit is proposed. Fourth, to address the noise issue in the measured values of the proposed soil humidity sensor, a comparison test of noise generation according to the presence or absence of a capacitor is conducted based on the bypass capacitor principle.

Probe Candidate Verification for Permittivity Sensor

The procedure for the experiment is as follows. A candidate group is set to construct a probe of a sensor using the permittivity method. The candidate group consists of a commercially available conductor for easy replacement, a pencil lead made of a clip and graphite, chopsticks, a blade clip, a jumper wire, an aluminum can, and a cutter blade. Afterward, to determine if the sensor probe can be replaced, a total of eight candidates is placed in an underwater environment, and an experiment is conducted to measure the amount of electron movement using the anode difference. Finally, by setting the measurement cycle to 1 second, soil humidity data is collected 120 times per sensor. Table 1 and Fig. 1 show the results of summarizing the average, minimum, maximum, and standard deviation of the data for each candidate group. In the candidate group, the standard deviation value of stainless-steel chopsticks was the smallest, and the standard deviation of the cutter blade core, aluminum can, and blade clip was small in that order. The candidates with the most significant margin of error are pencil leads and paper clips. As a result of the experiment, it can be confirmed that electrons can be moved in all candidate groups and can be substituted for existing sensors. However, it was confirmed that the required resistance value was different for each candidate group. Therefore, when replacing the sensor, the sensor's sensitivity should be adjusted to maintain a constant value.

Table 1. Mean, Minimum, Maximum, and Standard Deviation Value for Each Candidate Group.

Candidate	Mean	Min.	Max.	Standard Deviation
Paper Clip	781.734	718	811	15.736
Pencil lead	580.006	594	568	13.716
Stainless Chopsticks	593.200	486	496	1.207
Slide Clip	958.284	932	982	7.381
Jumper cable	968.666	936	979	22.077
Scratched Aluminum Cans	832.107	820	839	4.308
Knife blade refill	831.759	824	838	2.585

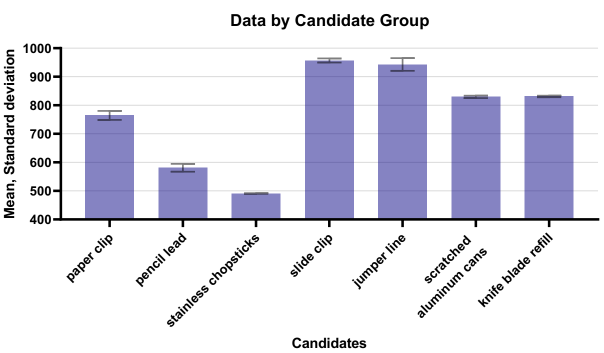

Fig. 1. Mean, standard deviation value for each candidate group

Table 2 shows the values extracted based on the hygrometer value of the soil hygrometer sensor HMM-200 to confirm the data change according to the resistance of the stainless-steel chopsticks with the smallest standard deviation among the seven candidate groups. The HMM-200 sensor is a multifunctional soil moisture meter that measures soil moisture, soil acidity, temperature, and EC (Electrical Conductivity) of the soil. This sensor extracts the soil humidity in the measurement range of the normal moisture content of 0-50% of the soil moisture meter at 0.8-second intervals, which makes it possible to measure very low moisture content ranging from 0 to 8%. The results of reading data using five resistors (220KΩ, 1KΩ, 10KΩ, 100KΩ, and 1MΩ) in a sawdust environment with hygrometer values of 2.4%, 8.8%, and 14.4% measured with HMM-200 are shown as minimum, maximum, and arithmetic mean values. Humidity values of 2.4%, 8.8%, and 14.4% correspond to when each soil is dry, when the soil is normally wet, and when the soil is submerged in water, respectively. If a low resistance, such as 220Ω, 1KΩ, or 10KΩ, is used, data cannot be read at low humidity, such as 2.4%. In general, wet soil, such as 8.8%, a value less than 400, was measured, confirming that the standard value of 700 measured by the existing sensor was not met. Therefore, it can be confirmed that stainless-steel chopsticks can be used in real life based on the overall data value, provided that, on average, 100KΩ or more is used, as shown in Table 2.

Table 2. Experimental results to find the minimum range available for stainless chopsticks-based soil humidity sensors.

Humidity	Resistance	Min	Max	Average
2.4%	220Ω	0	0	0
	1KΩ	0	0	0
	10KΩ	0	2	0.38462
	100KΩ	280	296	286.7976
	1MΩ	688	707	699.2537
8.8%	220Ω	18	20	19
	1KΩ	87	88	87.64912
	10KΩ	375	381	378.038
	100KΩ	778	793	787.4375
	1MΩ	905	908	906.7738
14.4%	220Ω	97	99	97.72619
	1KΩ	265	267	266.3095
	10KΩ	503	506	504.1071
	100KΩ	764	768	765.4524
	1MΩ	853	860	856.369

Fig. 2. Experimental environment where cultured soil and clay sand are mixed

Table 1. Minimum and maximum, mean, standard deviation according to the ratio of cultivated clay soil and cultured soil.

Sensor	Soil Composition Ratio *(Clay sand : Cultured soil)*	Min	Max	Average	Standard Deviation
SEN0114	0 : 10	480	630	589.2388	36.97354
	2 : 8	504	582	545.224	14.5525
	3 : 7	516	582	552.8806	17.4392
	5 : 5	404	528	498.5473	28.29956
	7 : 3	343	458	426.5174	26.07529
	8 : 2	258	401	358.373	30.8299
	10 : 0	115	186	156.393	12.48078
FC-28	0 : 10	754	855	805.7761	28.6612
	2 : 8	923	964	948.492	10.8804
	3 : 7	861	943	919.5635	22.44863
	5 : 5	839	911	879.204	21.40431
	7 : 3	963	973	968.9552	1.988212
	8 : 2	966	981	976.761	3.56268
	10 : 0	1015	1019	1017.055	0.843795
WaveShare Soil Moisture Sensor	0 : 10	449	563	541.4577	20.85616
	2 : 8	271	411	362.629	632.50254
	3 : 7	347	494	450.7716	40.4454
	5 : 5	239	318	297.4677	17.69836
	7 : 3	134	181	168.607	8.510567
	8 : 2	119	161	150.428	6.75322
	10 : 0	27	50	41.26866	3.969567
Stainless Chopsticks	0 : 10	759	787	774.93532	7.4518988
	2 : 8	297	686	632.50254	30.717047
	3 : 7	602	701	646.39086	14.784317
	5 : 5	525	583	557.07463	9.7562943
	7 : 3	303	423	373.9204	25.385697
	8 : 2	160	197	181.67164	7.7962582
	10 : 0	27	61	47.119403	6.2940982

Data Change Experiment According to Soil Particle Composition

The measurement principle of the soil humidity sensor proposed in this paper is the amount of electron movement according to the moisture content in the pores between the particles constituting the soil. In order to measure the change of sensor data according to the particle thickness constituting the soil, a data change experiment is carried out. In order to compose a soil environment with various inter-particle pore sizes, data is measured by mixing cultured soil and sandy soil in the ratio of 0:10, 2:8, 3:7, 5:5, 7:3, 8:2, 10:0. Fig. 2 shows the soil used for the actual experimental environment. Similar to the actual soil environment, the culture soil contains 25% rice bran, 20% red pepper seed meal, 53% green sawdust, and 2% organic matter. Existing sensors SEN0114, FC-28, WaveShare soil humidity sensor, and stainless-steel chopstick sensor are used to measure data values. Table 3 shows the results of each sensor for each soil ratio as the minimum, maximum, arithmetic mean, and standard deviation values. Moreover, Fig. 3 shows the mean and standard error of the data in Table 3. The x-axis of the graph is the clay sand : cultured soil ratio, and the y-axis is the measured soil humidity value. Through the graph error bar, it can be seen that the tolerance of all data is small. Therefore, it can be seen that the error of the measured value of the sensor is not affected by the particle thickness. However, the graph shows that the soil humidity value increases or decreases according to the composition ratio of the soil. When the mass of small-grained soil is higher than the ratio of the cultured soil, the pore space in the soil particles is widened. Therefore, the electron mobility is free, resulting in a higher soil humidity value. The reason the graph of the FC-28 sensor is inverted is that it measures the resistance value, not the amount of electron movement. The experimental results show that it is necessary to adjust the resistance value according to the composition of the soil.

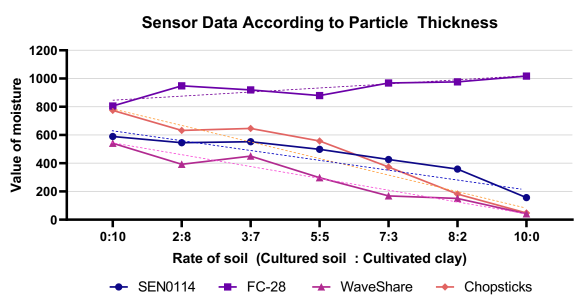

Fig. 3. Graph of data average according to the ratio of cultivated clay soil and cultured soil

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Multiplexer-Based Automatic Resistance Selection Circuit Study

Stainless steel chopsticks with the smallest standard error are selected from the test results among the bipolar sensor candidates. Adjust the resistance so that the chopsticks have the maximum value when measured in water.

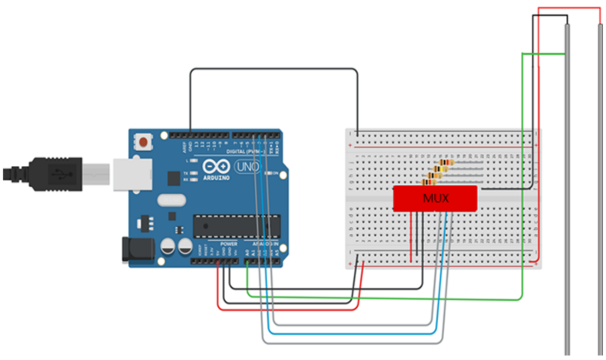

Fig. 4. Multiplexer-based automatic-resistance-setting wiring diagram

Unlike the conventional sensor that controls the sensitivity through an additional circuit with a variable resistor, a multiplexer-based winding resistor selection circuit is implemented as shown in Fig. 4. The multiplexer is a data selector that selects one of several input lines and passes binary information of the selected input line to an output line. Therefore, the multiplexer-based winding resistor selection circuit automatically selects the resistor with the smallest error after comparing the data value for each resistor with the default value set by the user using the multiplexer. Therefore, the resistance value can be adjusted when the ratio of components constituting the soil changes or the surrounding environment, such as air temperature and humidity, changes. Suppose the resistance value can be adjusted using Fig. 4. In that case, there is an advantage in that the appropriate electric conduction can be applied in an actual farm environment where the electric conduction value of the sensor may vary. Fig. 5 shows the change of the measured value according to the resistance of the stainless-steel chopstick-based soil humidity sensor connected to the 16-channel multiplexer in an underwater environment. The x-axis means the size of the resistance used, and the y-axis, representing the average value of soil humidity, approaches 0% moisture as the value converges to 0, and approaches 100% moisture content as it converges to 1023. The range of resistance uses 16 types of resistors from 1KΩ to 22MΩ, and it can be seen that the higher the actual resistance, the higher the current flow between the Medium. Therefore, it can be confirmed that if the resistance value is appropriately assigned to each candidate group, it can be used as a soil humidity sensor in various environments of actual farms.

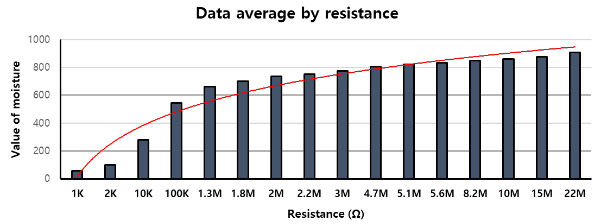

Fig. 5. Data values according to the size of each resistance

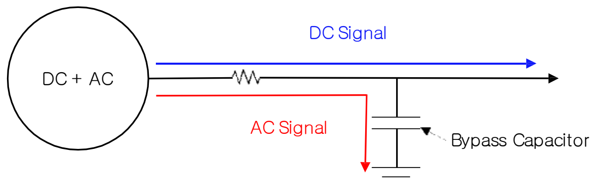

Fig. 6. Bypass Capacitor Principle

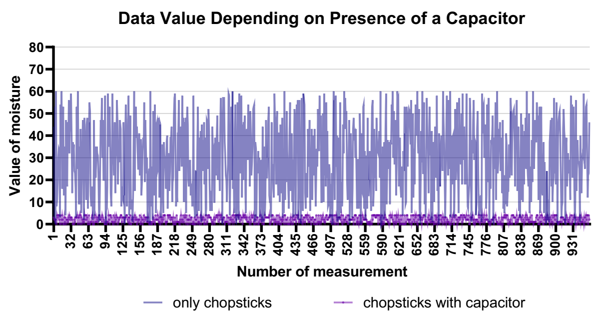

Fig. 7. Noise Comparison Graph According to the Presence or Absence of a Capacitor

Noise Removal Using Bypass Capacitor

In the chopstick-based soil humidity sensor, the input data value is unstable, and noise occurs in the measured value. As a solution to this, a method of minimizing the unstable value by using a capacitor is used. A capacitor consists of two electrodes with a narrow gap and a thin dielectric between them. Since noise is usually generated from the power supply, the low-frequency AC signal is grounded through a parallel capacitor to minimize the noise. In this paper, the Arduino Uno supplies power to the sensor, and the PWM frequency of the Uno with a voltage of 5V is fixed at 980Hz or 490Hz, indicating that the frequency of noise generated from the power supply is also small. If the noise frequency is small, it should be minimized by using a capacitor with a large capacitance in µF. Therefore, in this paper, the noise or low-frequency signal in the power source is grounded using the bypass capacitor principle based on the 1uF capacitor. As shown in Fig. 6, a DC (Direct Current) signal does not pass through parallel capacitors in an electronic circuit. However, only low-frequency AC (Alternating Current) signals pass through and are grounded to minimize noise (Aravind *et al*, 2015). To prove whether the actual noise is reduced, a pull-up circuit strong against noise is built using stainless steel chopsticks, and experiments are conducted with and without capacitors. Noise can be seen when there is no moisture in the soil than when there is moisture, so the test is carried out by installing the development sensor in dry soil. Fig. 7 is a graph showing the effect of the capacitor on the soil humidity sensor. The x-axis represents the number of measurements, and the y-axis represents the measured soil humidity data value. It can be seen that the noise is significantly reduced when the capacitor is present.

Fig. 8. Developed Soil Humidity Sensor (Vacuum chopsticks on the top, stainless chopsticks on the bottom)

Developed Sensor Design

Fig. 8 is a semi-permanent soil humidity sensor configured with a chopstick-based probe. The developed sensor measures the amount of moisture in the soil by adopting the permittivity method using the properties of the soil. The VCC voltage is applied to one part of the chopstick probe, and the electrostatic current received through the dielectric constant in the other part is transferred to the Microcontroller Unit (MCU) as an analog input signal. The chopstick-based soil humidity sensor is designed to be used in a variety of environments by automatically selecting the resistance according to environmental changes. In addition, it can be easily changed with an object made of a conductor that is readily available on the market, using a replaceable probe method to prevent corrosion.

One of the requirements for fabricating a semi-permanent soil humidity sensor is the sensor's strong durability against corrosion. This is because a lower corrosion rate reduces the frequency of sensor replacement, which reduces additional maintenance costs and manpower for replacement. In the case of the legacy sensors SEN0114 and FC-28, after analyzing the measured soil humidity data, a normal value is initially measured, and an inaccurate value is measured after a specific period. This is because the probe part of the sensor is in direct contact with the moist soil, and at the same time, an electric current is flowing through it, which results in faster corrosion.

Results and Discussion

Experimental Environment and Design

We evaluate the superiority of the proposed semi-permanent soil humidity sensor by comparing its durability, composed of stainless-steel chopsticks and vacuum chopstick-based probes, with that of the legacy sensors SEN0114 and FC-28.

Table 4. Experimental environment

Date	September 07 ~ December 07 (3 months)
Candidates	FC-28, SEN0114, Stainless Chopsticks, Vacuum Chopsticks
Soil	Cultured soil + clay sand
Pot	Cup of plastic (20oz)
Water Supply Cycle	100ml per 5 days

Fig. 9. Measurement of soil humidity

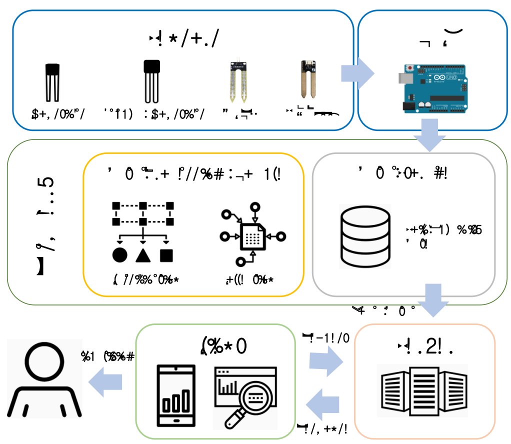

Fig. 10. System Flow Chart

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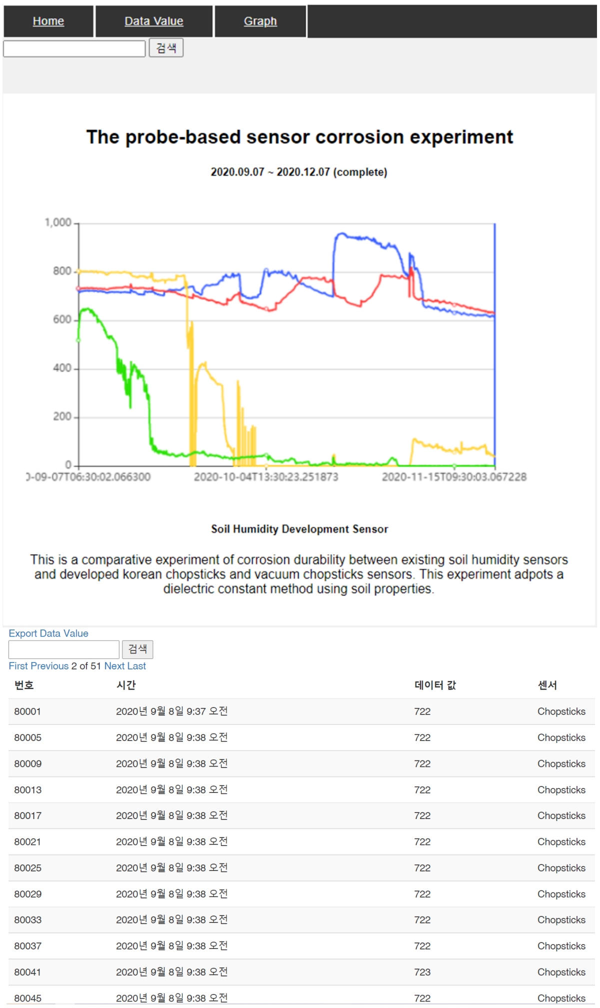

Fig. 11. Web Server-based Monitoring System

In this paper, to assess the durability of the legacy sensor, a comparison experiment was conducted on the corrosion durability of the legacy soil humidity sensor and the developed sensor. Table 4 shows the experimental environment. The measurement cycle was once every 5 seconds, the soil was cultured, and a 20-oz plastic cup was used as a flowerpot. The data were measured by mixing cultured soil and masa soil in a 50:50 ratio to simulate the real environment. The experiment was conducted for a total of 3 months, from September 7th, with watering of the pots occurring once every 5 days. Fig. 9 shows the actual measurement of soil humidity by each sensor. One MCU is connected to each sensor to supply power, and the data value is transmitted through serial communication. Fig. 10 shows the system configuration for the experiment comparing the durability of the proposed soil humidity sensor and the legacy sensor over time. Four sensors are connected one by one to the MCUs, which Raspberry Pi controls. The soil humidity data is transferred in the order of sensor, MCU, and Raspberry Pi.

The data collected from the sensor is classified in the Data Processing Module and loaded into the database. To monitor the sensor data stored in the database in real time, a web server-based on the Django web framework was built, and the stored sensor data can be checked in real time in the form of graphs and tables through the web interface. Fig. 11 shows the visualization of real data in graph and table format on a web page. By entering the date and time in the data table, you can search for data in that time zone, enabling accurate data analysis. Furthermore, if we want to extract data values, we can extract the measurement result data set in CSV format.

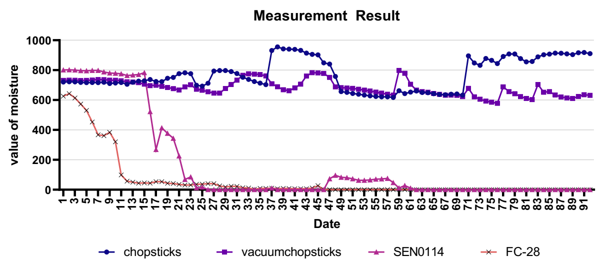

Fig. 12. Graph of the experimental result

Fig. 13. Image of Sensor Corrosion

Experimental Results and Discussion

Fig. 12 is a graph of the results of the corrosion resistance comparison test. The x-axis represents the measured days, and the y-axis represents the average daily soil humidity value, measured at 5-second intervals. In the graph, the sharp drop in the sensing values of FC-28 and SEN0114 means that the probe part of the sensor is corroded. Abnormal data values were measured 5 days after the start of the experiment for FC-28 and 14 days after the start of the experiment for SEN0114. For stainless steel chopsticks and vacuum chopsticks, the soil humidity value rapidly increased after 36 days and 58 days after the start of each experiment. This implies that the probe part of the sensor is corroded, resulting in abnormal data. The FC-28 sensor corroded faster than SEN0114 because the probe part in contact with the soil was not coated. Therefore, in the experimental result graph of Figure 12, the FC-28 probe measured the abnormal value faster than the SEN0114. The durability of the proposed sensor was compared with that of the conventional sensor based on the time of corrosion. Compared to FC-28 and SEN0114 sensors, the durability of the stainless chopstick-based soil humidity sensor increased by 61.11% and 75.86%, respectively, and the durability of the vacuum chopstick-based soil humidity sensor increased by more than 86.11% and 91.38%, respectively.

Conclusion

In the real farm environment, the role of the soil humidity sensor is crucial, and crops may be damaged if abnormal data are measured. The reason for the abnormal measurement is that the probe part of the sensor is corroded, and many sensors on the market have low corrosion resistance. Therefore, in this paper, the problems of the legacy soil humidity sensor released as a prototype are presented, and a semi-permanent soil humidity sensor based on chopsticks that secure them is proposed. The problems of the legacy soil humidity sensor and the characteristics of the proposed sensor that improve it are as follows. First, in the case of the legacy soil humidity sensor, the probe part is vulnerable to corrosion because it is in direct contact with the moisture in the soil. Therefore, it is necessary to replace the sensor periodically. To solve this problem, we designed the proposed sensor as a conductor-based replaceable probe made of a readily available material. Second, when the measurement environment is changed, the impedance value of the resistor is fixed, or the variable resistor's value is limited. Due to the sensitivity control, there was a problem that the reference value of soil humidity could not be set in various environments. Therefore, it was proved that the value of resistance and soil humidity has a proportional relationship through the experiment of varying the resistance values. Thereafter, the change in sensor data according to the particle size was measured by varying the ratio of cultured soil and decomposed granite soil in each pot. The result of the experiment showed that the soil humidity value increased or decreased depending on the soil particles. Therefore, the issue was solved by implementing a multiplexer-based selection circuit and automatically setting the appropriate resistance according to the conductor or the surrounding environment. Finally, the legacy sensors SEN0114 and FC-28 have low corrosion resistance. According to the durability comparison experiment conducted for 3 months, the durability of the stainless chopstick-based soil humidity sensor compared to FC-28 and SEN0114 sensors was 86.49% and 62.16%, respectively, and the durability of the vacuum chopstick-based soil humidity sensor was 89.36% and 70.21% or more, respectively. Therefore, it is concluded that the durability of the proposed sensor is excellent.

The soil humidity sensor proposed in this paper has stronger durability than the legacy sensor, and cost reduction was achieved by replacing the probe part in case of corrosion. In addition, the appropriate resistance can be automatically set according to the conductor or the surrounding environment by implementing a multiplexer-based automatic setting wiring diagram. In conclusion, the developed sensor is more suitable for application in the real environment than the legacy sensor used in this paper.

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Author's Contributions

All authors equally contributed to this study.

Ethics

This manuscript is an original work. The corresponding author declares that no ethical concerns are associated with this submission.

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