Design and Fabrication of an Intelligent Irrigation Control System

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Abstract: - This paper describes the design and fabrication of an intelligent Irrigation control system that allows intelligent control of the water applied to the field at right amounts and times. The system should have the capabilities to measure the water content in the soil so water can be applied as needed. The WATERMARK soil moisture sensor based on the measurement of the soil tension will provide the measurement of the water content. The system measures the soil tension, soil temperature and rain status and records the data in a file for future reference. It will apply water to field if a certain level of soil water tension is reached. This intelligent Irrigation control system is suitable for universities, research centers and farms where a control of the soil water content is required. The system can be used to study the water requirements for crops so irrigation can be scheduled efficiently.

Key-Words: - Irrigation systems, Soil tension, Agriculture, WATERMARK, System design

1 Introduction

Using the water in the farm for irrigation is one of the most water consumptions in the planet. Irrigation water management requires timely application of the right amount of water. Competition for water, high pumping coasts, limited water resources and concerns for environment are making good irrigation management more important. In the world, water development for agriculture is a priority, but poorly designed and planned irrigation water management procedures and practices undermines efforts to improve livelihoods and exposes people and environment to risks. By far, one of the largest losses of the plant materials in the farm is the direct result of the improper irrigation scheduling. Irrigation too little can cause bad or weak yields; on the other hand, irrigation too frequently can cause water run off and leaching of nitrates and fertilization materials bellow the root zone. There are many types of irrigation control systems available in the market. The most common types are; Digital controllers using microcontrollers and analog controllers. These controllers are based on the measurement of the soil water tension. Soil water tension, soil water suction, or soil water potential are all terms describing the energy status of soil water. Soil water tension is a measure of the amount of energy with which water is held in the soil and represents the energy required to extract water from the soil. This is expressed in negative pressure. There are many types of sensors in the market that can be used to measure the soil tension. Some of these sensors are based on resistance principle and some based on capacitance principle.

1.1 Digital Controllers

This type of controllers uses digital electronic circuits to digitize the analog signal from the soil tension senor and control the irrigation pump. The soil tension sensor is embedded in the soil and provides analog signal of the tension level. By converting the analog signal into a digital form using an AD converter, the microcontroller can determine the water requirement and apply water accordingly. The water is required in the field when the level of the soil tension reaches a high level point entered to the system manually through a keypad or programmed in the microcontroller software. Water is applied to the field by switching the irrigation pump ON. In some systems, the pump will remain ON until the soil tension drops bellow the irrigation start level. In other systems, the interval of irrigation is set using an internal timer in the microcontroller or by means of using external timer. Figure 1 shows an example picture of a digital controller.

1.1 Analog Controllers

This type of controllers uses analog electronic circuits to compare the soil water tension level expressed in an analog form with a threshold value and based on the result the controller switches the pump ON if required. In most cases, the threshold is implemented using a variable resistor with a scale represents different soil wetting conditions. Figure 2 shows an example of the analog controllers.

Fig.1 Digital Controller

Figure 2. Analog controller

2 Soil Tension Measurements

There are several ways and techniques that can be used to monitor or directly measure soil water tension, these techniques include:

2.1 Tensionmeter

Tensiometers are used to measure soil water tension in the field. Tensiometers are water-filled tubes with hollow ceramic tips attached on one end, and a vacuum gauge (or mercury manometer) and airtight seal on the other end. The device is installed in the soil with the ceramic tip in good contact with the soil at the desired soil depth. The water in the tensiometer eventually comes to pressure equilibrium with the surrounding soil through the ceramic tip so tension readings can be taken. The tensiometer is shown in Figure 3.

Fig.3 Tensiometers

2.2 Porous Blocks

Porous blocks are made of materials such as gypsum, ceramic, nylon, and fiberglass. The blocks are buried in intimate contact with the soil at some desired depth and allowed to come to water tension equilibrium with the surrounding soil. Once equilibrium is reached, different properties of the block which are affected by its water tension may be measured. One of the more common types of porous blocks are electrical resistance and heat dissipation blocks. Figure 4 shows an example of Porous blocksPlease, leave two blank lines between successive sections as here.

Fig.4 Porous Blocks

2.3 Watermark Blocks

The Watermark block, or granular matrix sensor, is a new style of electrical resistance block from Irrometer Corporation (Watermark Soil Moisture Sensor, Irrometer Co., Riverside, CA, USA). The Watermark block, is relatively a new product on the market similar to the old gypsum blocks can provide plant growers and researchers with an accurate and stable means to determine soil water tension for crops. It consists of a granular matrix supported in a metal or plastic screen and a wafer of gypsum embedded in the granular matrix. The electrodes are embedded in the granular fill material and the measured electric conductivity between the embedded electrodes gives a value for the water tension inside the sensor. This sensor was used to implement the intelligent irrigation control system described in this paper as it provides accurate measurements. Figure 5 shows an example of the watermark sensor.

Fig.5 Watermark sensor

The WATERMARK sensor measures the the soil tension in the range from 0 KPa to 200 KPa. The equation relating the resistance to water tension is as expressed by the equation Eq.1. The range is divided into three regions for accurate results:

1. For $R \leq 1$ KOhm:
   $P = 20*[R*(1+0.018*(T-24))-0.55]$
2. For 1 KOhm $< R \leq 8$ KOhm:
   $P = (4.093 + (3.213 * R)) / (1 - (0.009733 * R) - (0.01205 * T))$
3. For $R > 8$ KOhm:
   $P = 2.246 + 5.239 * R * (1 + 0.018 * (T - 24)) + 0.06756 * R ^ 2 * (1 + 0.018 * (T - 24)) ^ 2$ (1)

As can be seen in the equation, the soil temperature is required in order to get the tension reading correctly.

3 The Proposed Control System

The proposed system in this work is a computer based control system. The purpose of using computer-based control system is because that offers distinct advantages over analog control, including accuracy, flexibility, speed and coast. In addition to the normal control task, a computer can perform supervisory functions in addition to reading data from a keyboard, displaying data on a screen and logging data into storage files for future analysis and reference. The system is based on the Soil Water Tension measurement and rain condition. As the system is a computer-based system, it consists of a software and hardware. The control actions and calculations are performed by the system software, while the hardware is used as an interface to the analog signals to the system. In this irrigation system, the design plan is based on getting a soil tension measurement periodically to guide the control system to switch On or Off the irrigation pump.

3.1 Control Strategy

The control strategy to guide the irrigation process is based on defining two set points for the soil tension and the status of the rain condition. The first set point is the high tension set point and indicates the soil tension at which irrigation should start, and the second set point is the low tension set point and indicates the soil tension at which irrigation should stop. This enables the system to keep the soil moisture between upper and lower limits and makes the soil tension to go through cycles of wetting and drying which is desirable to improve the oxygen content and ventilation of the soil. The irrigation can only be started during specific times in the day. These times are called irrigation time windows.

3.2 The Excitation of Watermark Sensor

Generally, the Watermark resistance and calibration curves relate the resistance to the soil tension. This resistance is far away from an Ohmic resistance. In a physical point of view, electric conductivity in fluids is affected by the electrolysis reaction. Therefore it's not possible to use normal Ohmmeters as the direct current used for excitation would start electrolysis reaction in a few milliseconds. This effect results in bubbles reducing the effective electrode area, which is an important factor in measuring electric conductivity. Continuous DC currents must not be allowed to flow through the wet part of the circuit, or else irreversible reactions occur on the metal surface that spoils the readings. AC excitation avoids these problems, by reversing the polarity of

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the current many times per second, so that no net reaction takes place at either electrode. Therefore a special interface circuit is needed to measure the electrical resistance of the Watermark block sensors.

4 Hardware Development

The hardware consists of a Digital Board, Analog Board and Power supply board in addition to a rain sensor and the wiring and power switches. The Digital board is a multi channel analog to digital converter with serial RS232 capability to communicate with the computer to send and receive data between the analog board and the system software. The analog board consists of an interface circuit for the soil tension sensor which requires AC excitation as discussed in section 2.2 and shown in Figure 6. The SPAN and Zero of the soil sensor circuit are adjusted such that the R_s value which gives zero volts at $V_{tension}$ output is 500Ω and the full scale which gives 5V is 15kΩ. This range of R_s corresponds to a soil tension range from 0KPa to 100KPa. Figure 7 shows the temperature interface circuit using LM35 temperature sensor. The output of this circuit is 0.1V/C°.

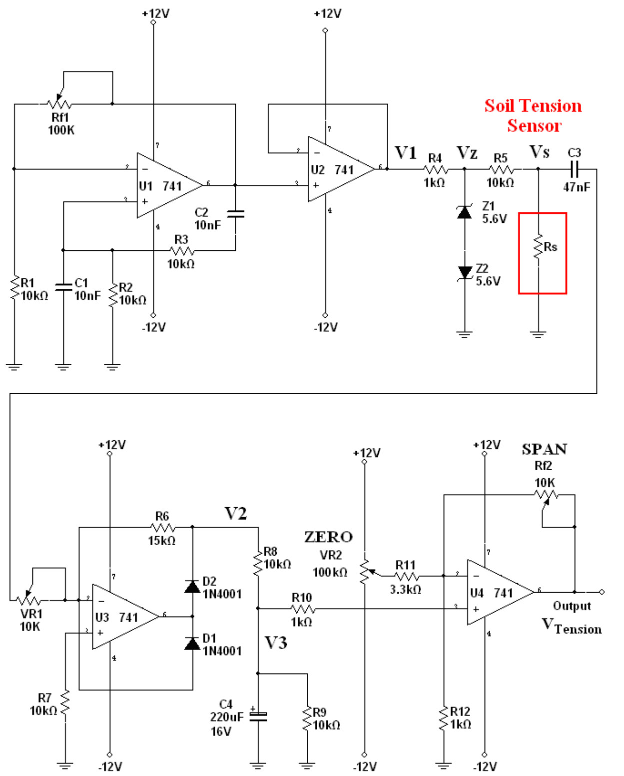

Fig.6 Soil tension interface circuit

5 Software Development

The software is written using visual basic 6 from Microsoft©. The software has a serial communication capability to communicate with the hardware to send and receive data. The Software consists of a Graphical User Interface (GUI) and Software Core. The GUI consists of a main form and a form for serial communication port settings. The main form contains fields for the irrigation status, sensors status, set points and irrigation times. The system core consists of visual basic modules to implement the WATERMARK calibration Eq.1 and the system overall calibration as detailed in the next section. The software reads the soil tension sensor, rain sensor and soil temperature sensor and compares with the set points and irrigation times and switches the pump ON and OFF is required. The main window of the system software is shown in Figure 8.

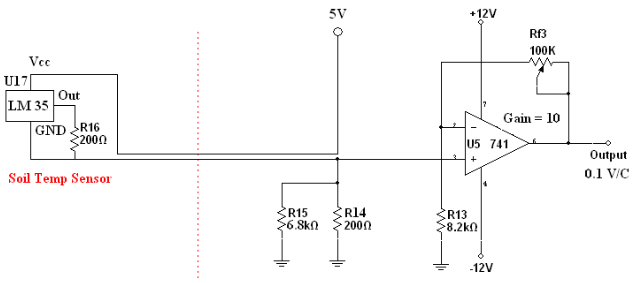

Fig.7 Temperature circuit

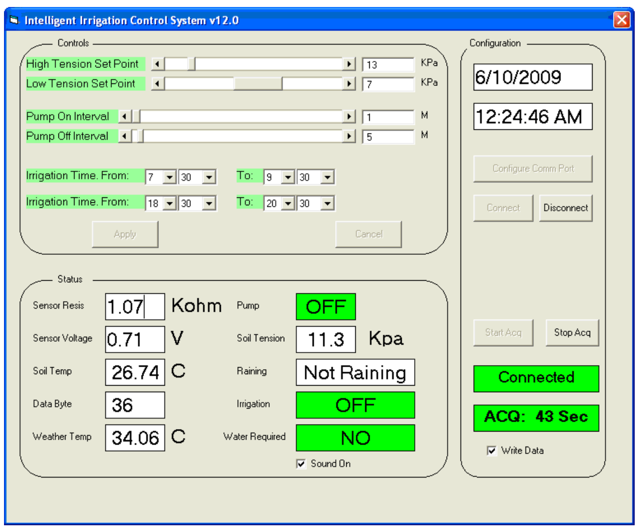

Fig.8 The Main window for the GUI

6 Software Development

The system is just a fluid resistance measuring system using AC excitation. Therefore the functionality of the system can be verified using known values of standard resistors. As the soil tension circuit is constructed of active components, the overall gain need to be evaluated. Making the evaluation using the theoretical calculations involves considerable errors because of accumulated components tolerances. Therefore, an overall calibration is used to evaluate the gain. A simplified block diagram of the soil tension interface circuit is shown in Figure 9. It can be seen that the total gain (G_T) results from the rectifier circuit gain (Gr) and the Zero and Span circuit gain (G_z). The sensor circuit can be simplified as shown in Figure 10, where VR_1 is the input resistance of the rectifier circuit.

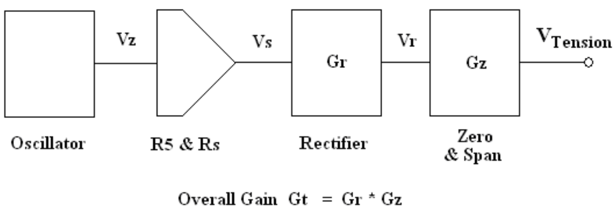

Fig.9 Soil tension circuit block diagram

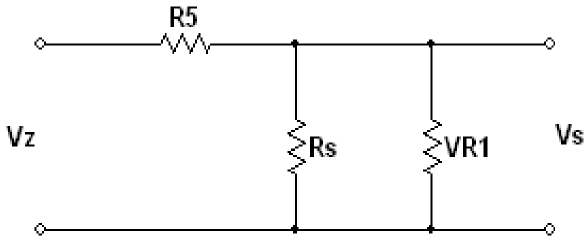

Fig.10 Sensor Circuit

The output from the sensor circuit (V_S) is as follows:

$$V_s = \frac{V_z R_s VR_1}{R_5(R_s + VR_1) + R_s VR_1} \quad (2)$$

Where the output from the Zero and Span circuit ($V_{Tension}$) is as follows:

$$V_{Tension} = G_z G_r V_s + V_{zero} \quad (3)$$

or:

$$V_{Tension} = G_t V_s + V_{zero} \quad (4)$$

Solving the Eq.4 For R_S after substituting for V_S from Eq.2, the Eq.5 is obtained:

$$R_s = \frac{R_5 VR_1 (V_{zero} - V_{Tension})}{VR_1(V_{Tension} - G_t V_z - V_{zero}) + R_5(V_{Tension} - V_{zero})} \quad (5)$$

Eq.5 shows that R_S can be calculated from the reading of $V_{Tension}$. Using a multimeter, R_5 found to be 10.1KΩ, VR_1 was 7.7KΩ and V_Z was 6.2V, while V_{zero} is the circuit output when R_S is zero (short circuit) and was -0.748V. The lift constant is G_T, the total gain, which need to be evaluated. Solving Eq.5 for G_T, the equation Eq.6 is obtained:

$$G_T = G_1 + G_2 \quad (6)$$

$$G_1 = \frac{R_5 VR_1 (V_{zero} - V_{Tension})}{-R_s VR_1 V_z}$$

$$G_2 = \frac{R_s(-VR_1 V_{Tension} + VR_1 V_{zero} - R_5(V_{Tension} - V_{zero}))}{-R_s VR_1 V_z}$$

By using standard known resistors as R_S and measuring $V_{Tension}$, G_T can be calculated as seen in Table 1.

Table 1 $V_{Tension}$ recordeds

R_S (Test) KΩ	$V_{Tension}$	Calculated Gt (Eq.6)
0	-0.748	#DIV/0!
0.498	0.003	2.737
1	0.626	2.751
2.05	1.617	2.761
3	2.26	2.755
4.02	2.8	2.761
5	3.2	2.758
6.81	3.77	2.765
8.08	4.06	2.762
10	4.41	2.763
12.38	4.73	2.763
13.97	4.9	2.764
14.99	4.99	2.763
Gt Mean Value =		2.759

The mean value for G_T is 2.759. After calculating C_T, Eq.5 can be used by the software to calculate R_S from the reading of $V_{Tension}$. This is done in the system module of the software core. Table 2 shows the values of the test resistors as displayed on the system main window when using a value of 2.759 for G_T. Figure 11 shows the error percentage of the resistance measurement which is less than 2%.

Table 2 Comparison of known resistors

Rs (test)	Rs (System)	R_S Error %
0		
0.498	0.49	-1.61
1	1	0.00
2.05	2.06	0.49
3	2.99	-0.33
4.02	4	-0.50
5	5.02	0.40
6.81	6.81	0.00
8.08	8.11	0.37
10	10.12	1.20
12.38	12.45	0.57
13.97	14.19	1.57
14.99	15.09	0.67

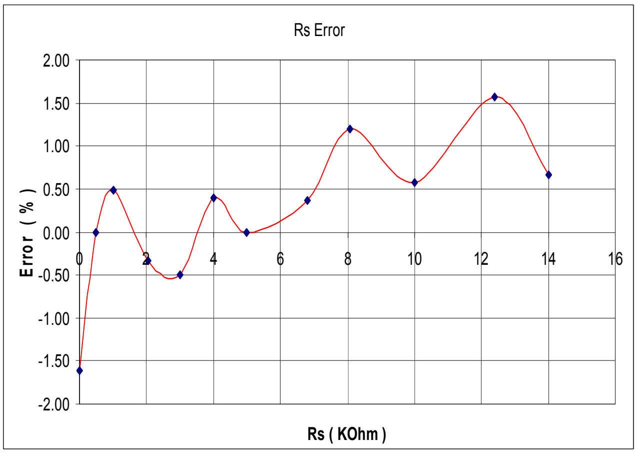

Fig.11 Error percentage of the resistance measurement

7 Conclusion

The intelligent irrigation control system has been successfully designed and fabricated. The components used in this work are simple and cheap. The software programming is simple and can be implemented easily. The system works in a very accurate manner. It can measure the resistance of the standard resistors as well as the fluids resistance. The system interfaces the WATERMARK soil tension and uses the reading to schedule the water to the field. WATERMARK sensor calibration provides measurements of the soil tension which is used by the software to start and stop water application to the field. In general the system works adequately as anticipated in the design process. Finally, this system should be further developed so that it will have more features and can be used to monitor and schedule water to more than one area of the field.

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