DESIGN AND EVALUATION OF A LOW-COST AUTOMATIC CONTROL DEVICE FOR PRESSURIZED IRRIGATION SYSTEM

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Abstract

Using the simple home gardener's soil moisture sensor, a low-cost automatic control device for pressurized irrigation system has been designed and evaluated.

A prototype of the device equipped with two moisture sensors was first tested and calibrated in the laboratory with sandy clay loam soil contained in plastic growing bags before operating it under actual field conditions. Using a 2.54-cm diameter pipe as soil sampler, moisture content from each soil sample was determined by the gravimetric method. A 1.5-kw electric motor was installed to pump water through a 63-mm polyethylene mainline pipe serving two irrigation blocks of Naan 501-U model sprinklers. Wired together with the motor and electric-remote control valves, the sensors received feedback from two probes made from a fabricated TW wire #10 buried at a depth of 20-cm in the soil

Performance parameters were highly significant using two-way analysis of variance. The performance of the device was totally controlled by the adjustment of the wiper arm of the 10-kΩ trimmer resistor given by the multiple regression equation:

$$\mathbf{MC = 27.65 - 1.9023\,R + 0.6638\,T \text{ with } R^2 = 96\%}$$

For laboratory test: **MC = 28.31 –1.9023 R**

For field test: **MC = 28.97 – 1.9023 R**

Laboratory and field tests revealed that the device can operate the system satisfactorily well. It can respond to any change in soil moisture by turning the driven units ON once the desired moisture was depleted and OFF when attained.

The device was fabricated at a cost of P5,660.00. It can also provide a total cost of operation and break-even point lower than that of the system automatically controlled by commercially available controllers. It performs better by eliminating problems on over-irrigation, under-irrigation and unnecessary irrigation.

1. Introduction

Irrigation, the ancient agricultural technique of artificially supplying water to land to sustain crop's growth, may have been practiced as early as 5,000 BC along the banks of such regularly flooding rivers as the Nile. Ancient remnants of these structures have been found in Egypt, Babylon, China, Phoenicia, Peru, Mexico, India, and the United States.

There are two key engineering innovations in irrigation, which served as basis for modern irrigation that permits irrigation of lands lying above the areas normally reached by floodwaters. These are the development of diversion dams and the invention of water-lifting machines.

Water distribution systems are of two broad types: surface and closed-conduit systems. In surface irrigation systems, the entire land surface may be flooded with water or water may be restricted to small ditches called furrows.

Historically, the early use of closed-conduit system was confined only to greenhouses. The technique, as we know it today, is not practical for field crops until the introduction of low-cost plastic tubing in the early 1940s. Another significant step in the evolution of pressurized irrigation took place in Israel in the later 1950s, when long-path emitters were greatly improved. During this period, researches and pilot field demonstrations of this system were undertaken. Now, pressurized irrigation is used on about 1.2 million hectares in fields, orchards, and greenhouses throughout the world, about one-third of which is in the United States.

Closed-conduit systems, also known as pressurized irrigation systems, use pipes to distribute water over wide areas or to the ground area around each plant permitting frequent light irrigation that maintains the desired uniform application and level of moisture in the soil. Sprinkle and trickle together represent two broad classes of this kind of irrigation system, which is widely practiced in the deserts of the United States, Australia, and the Middle East.

Pressurized irrigation offers special agronomic, economic, and agrotechnical advantages for efficient use of water and labor. This new irrigation technology reaps the promise of modern irrigation: higher yield of quality products at a reduced production cost.

As irrigation technology continues to develop and improve, more and more of the routine activities involved will be taken over by automated systems. Even a simple irrigation system can be placed under computer control and programmed to respond to a variety of environmental conditions.

Automatic pressurized irrigation systems, whether sprinkle or trickle, have a great advantage over manual control. They offer complete independence from watering chores, release time for leisure, provide continuity of the watering schedule even during owner's absence, save water, time and labor. The use of an automatic controller to maintain an efficient watering and fertilizing program is a basic requirement for these systems.

With reference to the type of actuator employed between the controller and the remote control valve, there are two types of automated systems: hydraulic and electric. Using 24-hr clock timers, electrically automated systems employ electricity to be transmitted from the controllers. The controller then activates the start of the watering cycle at preset time duration and preset days through external wires (tubing for hydraulic control systems). When a controller station energizes the solenoid, the magnetic force lifts its actuator off the exhaust port. The pressure of the water in the upper chamber is relieved through the exhaust port which allows the main pipe line pressure to force the flexible diaphragm up, opening the valve. A master valve circuit (pilot valve for hydraulic control system) is also installed at the entrance to the entire system to prevent "backflow" or "backpressure".

Systems controlled in this manner are, however, unable to control the problems on under-irrigation, over-irrigation and unnecessary irrigation. Though they accurately operate as programmed, they are incapable of detecting the optimum amount of water to be applied after an unexpected rain or previous irrigation or whether water application is really needed. They are reprogrammed seasonally.

Eliminating these problems would require the use of a device that is based on soil moisture to control the system instead of a timer. This paper presents how much a device has been designed and fabricated at low cost, and its performance evaluated.

1.1 Objectives of the study

The study aimed to design and evaluate a low-cost automatic control device for pressurized irrigation system. Specifically, it intended to:

1. design and test a low-cost automatic control device for pressurized irrigation system using soil moisture sensor as the main trigger mechanism;
2. establish the performance parameter of this mechanism;
3. validate the performance of the device to actual field conditions; and
4. study the economic advantage of the system.

2. Materials and methods

A prototype of the device (Figure 1) was designed and fabricated with two moisture sensors based on the mechanism of a typical home gardener's soil moisture detector or sensor. The sensors were actually resistance bridge circuits that compare the resistance of the soil with reference values of the trimmer resistor setting as indicated by the two LEDs (light emitting diode).

Figure 1. The prototype of the device.

Powered by a 9V-battery when used as moisture sensor in home gardening, the device was designed to drive other components of a pressurized irrigation system like a 220-VAC electric motor and 6-A, 24-VAC electric remote-control valves using power relays. The electric motor was tasked to provide irrigation water to the system that must be triggered by a relay synchronously connected with the other driven units. One of the solenoid valves served as a master valve. The master valve, which is a necessary element of automated pressurized irrigation, comes before series of valves to release pressure along the pipe network.

The probes were inserted into two pieces of rubber at 5 cm apart to prevent them from short-circuiting. These pieces of rubber were laid flat in the soil at 20 cm depth, the average plowing and rooting depth of crops.

The device was first tested and calibrated in the laboratory with sandy clay loam soil contained in plastic growing bags and then operated under actual field conditions.

Using a 2.54-cm diameter pipe as soil sampler, moisture content from each soil sample was determined by the gravimetric method. A 1.5-kw electric motor was installed to pump water through a 63-mm polyethylene mainline pipe serving two irrigation blocks of Naan 501-U model sprinklers.

Performance parameters were evaluated statistically using two-way analysis of variance by comparing the means of soil moisture determined from laboratory and field tests at different resistance settings of the trimmer resistors of each sensor.

The economic and other features of the device were compared with other alternative methods of irrigation adjusted in hectare basis per year based on a 1,500 m^2 area. These alternatives were the traditional method, manual method or zero-level automation, and fully automated method using commercially available control. Cost of operation in terms of fixed and variable costs were analyzed to present a break-even point analysis. Savings from water, labor, cost of electricity, and utilization in using the low-cost automated system instead of the other methods were highlighted. Other advantages and non-quantifiable features of the device such as the capacity to eliminate problems related to irrigation and other qualities that facilitate easy operational management were likewise used as criteria of comparison.

3. Results and discussions

3.1 Pre-testing

The device was first pre-tested using a set of test lights with colors red for the electric motor, blue for the master valve, yellow for the first sensor and white for the second sensor. Pre-testing was based on the resistor setting as shown in Figure 2. By short-circuiting the probes of each sensor, the functionality of the device was indicated by the switchover of the LEDs of the sensors.

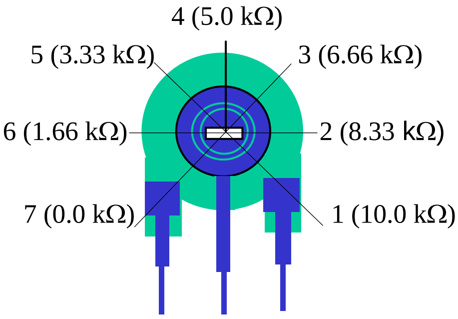

Figure 2. The trimmer resistor setting.

3.2 laboratory testing

Laboratory tests were conducted using dry sandy clay loam soils contained in plastic growing bags. The soil was taken from the field where the automatic control device was installed as shown in Figure 3. Test started with sensor 1 by sprinkling the soil in the bags with water manually and slowly, based on the setting used in pre-testing. For the first setting, with the highest resistance at 10 kΩ and therefore with the least water requirement, the lowest moisture was 7.08%. The average of three trials was 8.01%. For the second setting at 8.33 kΩ, the average moisture was 13.31%.

Everything went well for the other settings for the two sensors. However, on the sixth setting with resistance of 1.66 kΩ, the two sensors were not able to stop the driven units. The system operated continuously. Further investigation done by adjusting the setting backward revealed that it was at approximately 2.26 kΩ resistance that the system will function correctly. The equivalent soil moisture of the resistance was about 24 %. Soil moisture was also taken at the last setting with 0 kΩ. Data are tabulated in Table 1.

Figure 3. The laboratory set-up

Table 1. Summary of soil moisture content (%) of different tests at different resistance settings.

Resistance (kΩ)	SOIL MOISTURE CONTENT LABORATORY TEST Sensor 1	Sensor 2	Mean	FIELD TEST Sensor 1	Sensor 2	Mean	MEAN
10.00	8.01	8.15	8.08	12.12	11.91	12.02	10.05
8.33	13.31	12.78	13.05	13.45	13.53	13.49	13.27
6.66	15.88	14.57	15.23	16.53	15.23	15.88	15.55
5.00	18.74	17.53	18.14	18.23	17.98	18.11	18.12
3.33	21.95	21.26	21.61	22.25	22.75	22.50	22.05
1.66	26.17	24.89	25.53	27.77	24.99	26.38	25.96
0.00	30.92	29.2	30.06	28.35	27.58	27.97	29.01

3.3 Field testing

The results of the laboratory testing were verified under actual field conditions. As in the laboratory test, the device was responsive to every change in soil resistance. As the sprinklers (Naan 501-U model) emitted water as shown in Figure 5, it consequently turned OFF the system once the pre-set soil moisture was reached. At the sixth setting with 1.66 kΩ resistance, the system failed to stop and continuously operated as what had been observed in the laboratory test. However, soil moisture was determined up to the last settings.

It was found out that for this particular soil as what had been discovered in the laboratory test, the maximum resistance setting is about 2.62 kΩ, which is approximately equal to 24 %.

To test its endurance, the device was left switched ON and unattended for one month. It was observed that the device can operate the system satisfactorily well. It can maintain the pre-set soil moisture by turning the driven units ON once the desired moisture was depleted and OFF when attained.

Figure 4. The sprinkler system automated by the device.

3.4 Statistical analysis

Two-way analysis of variance revealed highly significant differences among the means of the sensors for the different resistance settings, types of test and their interaction.

The performance of the device was totally controlled by the adjustment of the wiper arm of the 10-kΩ trimmer resistors with an estimated regression equation (Figure 6):

MC = 27.65 - 1.9023 R + 0.6638 T with R^2 = 96%

For laboratory : **MC = 28.31 –1.9023 R**

For field test: **MC = 28.97 – 1.9023 R,**

Where MC = moisture content; R = resistance setting; T = type of test

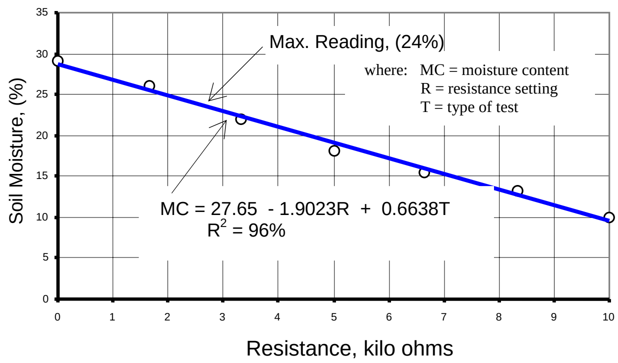

Figure 5. Estimated linear relationship of the soil moisture and resistance

3.5 Cost Analysis

The device was fabricated at a cost of P5,660.00. When the data, which were based on actual observations from a 1,500 m^2 field, are adjusted to hectare-per-year basis, the cost of the device with four sensors for four irrigation blocks would be P6,420.00. For a hectare with complete pressurized irrigation system automated by the device, costs equal P201,692.00, with electricity and labor amounting to P1,530.00. The breakeven point of the device is also lower than the commercially available controllers.

Comparison with the traditional method of irrigation revealed that the device can save as much 3,534 kw-hr electrical consumption, 2,274 hours labor, and 27,918 m^3 water delivered per hectare per year.

4. Summary and conclusions

A prototype of a low-cost automating device was fabricated, tested, and calibrated using sandy clay loam soils. The device uses soil moisture sensor as the main trigger mechanism by employing the dependence of the electrical resistance of the soil on its moisture content. Dry soil exhibits higher resistance than wet soil.

The performance of the device is totally controlled by the adjustment of the wiper arm of the 10-kΩ trimmer resistors with an estimated regression equation:

MC = 27.65 - 1.9023 R + 0.6638 T with R^2 = 96%

The device effectively automates pressurized irrigation systems. It allows easy two-probe profiling of the soil water content and can keep the level of water in the soil close to the optimum even when left unattended.

The device costs P 5,660.00. Break-even point is lower than that of the system controlled by commercially available automatic controllers.

The device also performs better than any of the alternatives studied in eliminating problems of over-irrigation, under-irrigation and unnecessary irrigation.

5. Recommendations

Based on the results, the following are recommended for further study:

1. Improvement of the casement of the device by providing easier system of adjustment. A dial type adjustment control should be graduated and calibrated. Casement should have provision for more sensors or controls for future extension in the farm.
2. The effects of different soil types, topography, climate, and vegetation especially on high-value crops employing the different types of pressurized irrigation.

3. The effects of the performance of the device on different resistor settings to determine how the maximum soil moisture of 24% can be increased to meet the requirements of crops with higher water requirement and soils with higher field capacity.
4. The effects of different depths of probe setting, configurations, materials, length and size of wire probes.
5. The economic viability of pressurized irrigation systems automated by the improved device.

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