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AUTOMATED IRRIGATION SYSTEM USING THERMOELECTRIC GENERATOR AS SOIL MOISTURE DETECTOR

Jazelle Paula M. Bathan[1], Ma. Carla Angelica R. Belen[2], Paula Jianelli M. Lao[3], Jasper C. Tiu[4], Enrique M. Manzano[5]
[1,2,3,4]De La Salle University
[5]ECE Department, De La Salle University

Abstract: This paper shows the design and fabrication of a Thermo-electric generator (TEG) and the implementation of an automated irrigation system using this TEG as a soil moisture detector. The TEG inserted in two heat exchangers is capable of finding the thermal difference between the air and the soil that establishes a relationship with the soil's moisture condition. Being able to obtain the soil moisture level from the TEG's output, a microcontroller is used to automate the irrigation system. The irrigation system adapts to the soil area's condition it irrigates based from the moisture it detects via the TEG. The water consumption of the soil is controlled by the automated irrigation system based on the soil's condition and therefore, promotes water conservation compared to that of the water consumption of manual irrigation system. It also optimizes plant growth in that it waters it to the correct moisture level at the right time.

Key Words: Automated Irrigation Systems; TEG; Soil Moisture Sensor, Instrumentation Amplifier; Microcontroller

1. INTRODUCTION

Manual irrigation systems do not promote water conservation that result to too much water or too small amount of water in the soil thus poor plant growth. Automated irrigation systems are capable of determining and maintaining the right amount water for the soil. In this work two TEGs were used as the soil moisture sensors (one as a control and the other in the plant area) that produced voltage-differentials proportional to the relative wetness or dryness of the soil compared to a control. A PIC microcontroller performed the data acquisition as well as the control of the water pumps in irrigation. Solar energy was used to power the entire system.

2. METHODOLOGY

Loam soil well represents most of the different irrigating fields here in the Philippines; therefore, the group decided to conduct the study under this type of soil. The solar panel was used to power the whole irrigation system. The TEGs with the heat exchangers for the air and for the soil were implemented and used as soil moisture detectors. The rubber tube with holes on its surface for water to pass through, and where the pump had been connected was buried as well in the ground. A water pump submerged in a pail as the source of water was used, which connected to the buried pipes and the water source. The switching conditions of electromechanical relay were tallied under different temperature differences and levels of soil moisture. The group designed an algorithm where the microcontroller was programmed to check the actual moisture of the soil, and then compare it with the desired amount of moisture and determine whether or not it will irrigate. Switching time between the opening and closing of the electromechanical relay was observed, as well as the efficiency of water being pumped. A series of tests had been done under the simulation of different weather conditions.

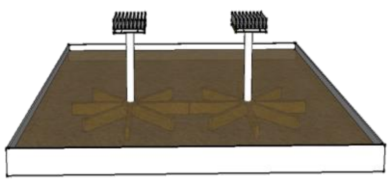

Figure 1. Thermoelectric Generator heat exchanger structures submerged in the soil.

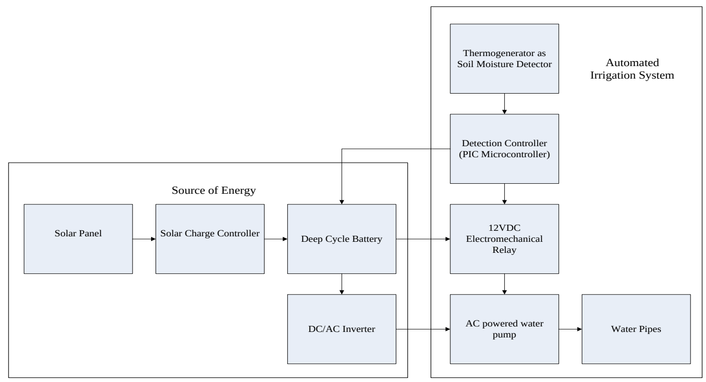

Figure 2. Complete project design layout

3. Set-up and Operation

In this study, the whole implementation of the automated irrigation system took place inside a controlled room set-up to vary easily the lighting and temperature conditions of the surrounding. As for the testing area, the set-up covered 4 square meters of land area contained in a wooden box. The TEG heat exchanger structures were submerged in the soil to provide the necessary TEG output voltages based from the thermal difference of air and soil as seen in Figure 1. The voltages are amplified and fed to the microcontroller to process whether the soil will require irrigation or not.

The whole system mainly has two parts - the energy source system and the automated irrigation system. The automated irrigation system includes the soil moisture detector which is the TEG, the detection controller which is the PIC 16F877A microcontroller, the water pump system comprising of AC powered water pump, electromechanical relay and water pipes. The solar energy system consists of the solar panel, the solar charge controller, the deep cycle battery for storage and DC/AC inverter. The complete design layout is seen in Figure 2.

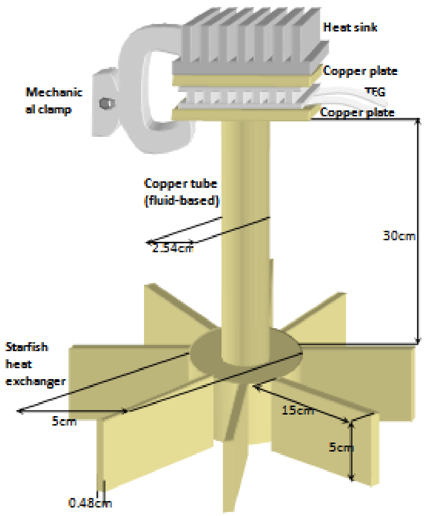

Figure 3. TEG heat exchangers frame structure.

Figure 4. Designed Solar Energy System.

Irrigation System

The automated irrigation system comprises of the following components: the TEG heat exchangers, the instrumentation amplifier, the PIC16F87AA microcontroller, the monitoring circuit and the water pump system. The TEG heat exchanger is seen in Figure 3.[15][16][17]. It is made of two heat exchangers, an aluminum heat sink for the air and a starfish shaped copper heat sink for the soil. A thermocouple is inserted between the copper plates at the top that generates a voltage reading depending on the temperature difference between the air and the soil. The vertical copper tube serves as the medium of heat transfer from the soil heat exchanger to the hot side of the thermocouple. For the voltage output to be fed to the PIC microcontroller, an instrumentation amplifier is employed. The PIC microcontroller processes an algorithm that determines whether irrigation is necessary or not. The algorithm considers the external factors such as lighting and temperature condition in making decisions. The water pump system controlled by the PIC is simply comprised of two AC submersible water pumps connected to rubber tubes surrounding the soil area. A monitoring circuit, in the form of a 20x4 character LCD display is used to see TEG values as well as the room's temperature and the sampling and irrigation time period. The whole process is done continuously wherein TEG outputs are being sampled from time to time to check the soil moisture level.

Energy Source System

For this study, the group opted to use solar energy as a means of power source. A small-scale solar energy system was utilized since the water pumps and the hardware circuits only require low power consumption. As seen in Figure 4, the whole system comprises of a 5W 12V monocrystalline solar panel, a solar household controller, two 12V 7A solar batteries and a power inverter. All of which are connected to each other and are terminated to the inverter that supplies the AC power supply.

4. DATA AND RESULTS

The automated irrigation system set-up is designed to test the efficiency of the TEG as a soil moisture detector. The TEGs were tested at different setups and conditions with the results tabulated in the following Tables.

TABLE 1
DRY-DRY SETUP

Temp in °C	DRY in V	DRY in V	SUM of Voltages in V
30.0	2.93	2.92	5.85
29.5	2.93	2.93	5.86
29.0	2.93	2.93	5.86
28.5	2.94	2.93	5.87
28.0	2.94	2.93	5.87
27.5	2.94	2.93	5.87
27.0	2.93	2.92	5.85
26.5	2.92	2.91	5.83
26.0	2.91	2.90	5.81
25.5	2.90	2.89	5.79
24.5	2.90	2.88	5.78

TABLE 2
DRY-WET SETUP

Temp in °C	DRY in V	WET in V	SUM of Voltages in V
30.0	2.97	2.96	5.93
29.5	2.97	2.96	5.93
29.0	2.97	2.96	5.93
28.5	2.97	2.97	5.94
27.5	2.97	2.97	5.94
27.0	2.97	2.97	5.94
26.5	2.97	2.96	5.93
26.0	2.96	2.96	5.92
25.5	2.95	2.95	5.90
25.0	2.94	2.94	5.88

TABLE 3
WET-WET SETUP

Temp in °C	WET in V	WET in V	SUM of Voltages in V
30.0	2.98	2.98	5.96
29.5	2.98	2.98	5.96
29.0	2.97	2.97	5.94
28.5	2.97	2.97	5.94
28.0	2.97	2.97	5.94
27.5	2.97	2.97	5.94
27.0	2.97	2.97	5.94
26.5	2.96	2.96	5.92
26.0	2.95	2.95	5.90
25.5	2.94	2.94	5.88
24.5	2.93	2.93	5.86

All data used for the analysis have been gathered for five months of continuous experimentation, starting from February till June, to achieve reliable and effective data evaluation. The group decided to use a controlled room to simulate the whole experimentation. Given a controlled room to control the lighting and ambient temperature conditions, the group was able to come up with four different set-ups matching to real outside weather conditions. These condition set-ups are: 1. With bulb and without air-conditioning unit pertaining to a sunny condition and a temperature range above room temperature (27°C), 2. With bulb and with air-conditioning unit pertaining to a sunny condition and a temperature range below room temperature, 3. Without bulb and with air-conditioning unit pertaining to a cloudy and breezy condition and a temperature range below room temperature, and last 4. Without bulb and without air-conditioning unit pertaining to a cloudy yet humid condition and a temperature range above room temperature. These set-ups have been observed simultaneously through room thermometer during the experimentation to guarantee the relevance of each to outside weather conditions. Initially the irrigation system set-up is subjected to each of the condition set-ups obtaining sets of data in terms of air temperature, soil temperatures of both soils, conductivity level of wet soil, TEG's direct output and TEG's buffered output of both soils and the instrumentation amplifier output. The group observed the evident relationship between the given data at different weather conditions.

In general, TEG's direct and buffered outputs have direct relationship with the soil temperature. In which these soil temperatures are subjected to different weather conditions and variations such as the sun's presence and temperature variation. The voltage output of the instrumentation amplifier on the hand relies on its two inputs, and for this study are the V_{DRY} and V_{WET} buffered outputs. If the two TEG's buffered outputs have big and distinct gaps, then the output of the instrumentation amplifier measures a high value.

Actual Irrigation Data

The group tested the both TEGs in both dry soils. The two tables above are the maximum buffered voltages produced from the instrumentation amplifier when the set-up is DRY-DRY and DRY-WET. Based on Table 1 and Table 2, the buffered voltages from the DRY-DRY set-up are generally lower than the voltages produced from the DRY-WET set-up. The dry soil has no water content, thus the change in the condition of the environment does not really affect the temperature of the soil. The temperature of the dry soil is very close in the temperature of the air. Also, in the dry-dry setup, since both basins have the same condition, they output the same direct voltage output thus decreasing their difference from each other. On the other side, wet soil is colder than dry soil, thus its temperature is farther than the temperature of the air. Because of this, it output higher direct voltage output, thus, the instrumentation amplifier outputs higher voltages. The group also tested the TEGs in both wet soil as shown in Table 3. The direct voltage is higher when the soil is wet, thus both have high buffered voltage output. The buffered voltage output of only decreased when the air temperature is low.

After getting the buffered voltages for the dry and wet soil, the group tested the irrigation in the plant box. Table 4 shows the data where the pump irrigates and where it also stopped.

The group measured 2.93 volts as the highest buffered voltage value for dry soil and a buffered voltage range of 2.94 to 2.98 volts for wet soil. The group tested the irrigation at the sunny

TABLE 4
ACTUAL IRRIGATION

TEG1	TEG2	SUM	Irrigate?
2.93	2.93	5.86	YES
2.93	2.93	5.86	YES
2.93	2.93	5.86	YES
2.93	2.93	5.86	YES
2.93	2.93	5.86	YES
2.93	2.93	5.86	YES
2.93	2.93	5.86	YES

TEG1	TEG2	SUM	Irrigate?
2.93	2.93	5.86	YES
2.93	2.93	5.86	YES
2.93	2.93	5.86	YES
2.93	2.93	5.86	YES
2.93	2.93	5.86	YES
2.93	2.93	5.86	YES
2.93	2.93	5.86	YES

TEG1	TEG2	SUM	Irrigate?
2.93	2.93	5.86	YES
2.93	2.93	5.86	YES
2.94	2.94	5.88	NO
2.94	2.94	5.88	NO
2.95	2.95	5.90	NO
2.95	2.95	5.90	NO
2.95	2.95	5.90	NO
2.95	2.95	5.90	NO

condition which normally the condition where soil is dry. The initial value of the buffered voltage when the soil is dry is 2.93 volts. At this temperature, the pump will start to irrigate. The program is set to irrigate every 15 seconds and have a delay time of 45 seconds to sample another data. The group used two pumps for the testing. For every 15 seconds, the two pumps released 0.5 liters. Based on our testing, the pump irrigates 16 times. The buffered voltage output is higher when the soil has a higher level of water content at sunny condition. The buffered voltage then increased to 2.94 volts at the next sample, thus the pump did not irrigate. The group observed the soil and from it looks outside and under, the soil is already wet.

5. CONCLUSION

Throughout the course of study, the group was able to implement a design on an automated irrigation system that uses a thermoelectric generator as a soil moisture sensor that uses the temperature difference between the air and the soil as a basis for irrigation. The group was able to successfully prove that soil temperature has a direct relationship with soil moisture or water content.

The group has studied and formulated when to and when not to irrigate given certain conditions: the air temperature high and the soil dry, the air temperature high but the soil wet, the air temperature low and the soil wet, and the air temperature low but the soil dry. The group has analyzed the gathered data and has deduced also that irrigation generally depends on available soil moisture and water content.

The group has connected irrigation to available soil moisture, and the group has related irrigation with the buffered voltages of each thermocouple for both wet-dry and dry-dry soil conditions. For the wet-dry soil condition, an increase in the sum of the buffered voltages indicates an increase in the deviation of the dry soil from the optimal water level, therefore a need for irrigation; while a decrease in the sum indicates the soil need not be irrigated. In a dry-dry soil condition, an increase in the individual buffered voltages of each TEG indicates the soil is becoming more wet and approaching the optimal moisture level, neglecting the need for irrigation. The individual buffered voltage is dependent on the direct voltage from the thermocouple, and the direct voltage is dependent on the temperature difference between the air and the soil. The group has then concluded that any change in the temperature of the soil implies a direct change in the voltage from the thermocouple; thus, proving an objective of the study which is to detect soil moisture content using the voltage generated by the thermoelectric generator as basis for distinction.

The group has implemented an automated system that only irrigates according to the proper needs of the soil; thus, saving water consumption and improving water efficiency and use. Ideas from the following references has helped the group develop the project by blocks.

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