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Soil Moisture Control System for Lettuce Seeds: Time-based Alternative Approach

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***Abstract*— The utilization of lettuce leaves as a nutritious dish has made its demand relatively high. This research presents a moisture control method to optimize seed growth for lettuce. The prototype system has been developed using Arduino Mega, DF Robot soil moisture humidity sensor, and DC spraying pump for testing three different control scenarios, the open loop control system (time-based), the Proportional control system, and the combination of open loop and Proportional control method as an alternative. The results show that each control method can achieved the desired moisture of rockwool at 60%. Also the combination of open loop and Proportional control can lessen energy usage of the system up to 51% compared to common open loop method.**

***Index Terms*— energy efficiency; lettuce; moisture control; open loop; Proportional control.**

I. Introduction

As one of the most demanded vegetable commodities, lettuce (Lactuca sativa L.) has been cultivated both using conventional and hydroponic methods. The hydroponic method aims to increase productivity, especially in narrow land, research shows that the hydroponic cultivation method for lettuce plants is feasible and still provides financial benefits[1][2]. Temperature and humidity are environmental variables that are very important to consider in cultivating hydroponic lettuce in a greenhouse system. Lettuce growth will be optimal in the air temperature range of 25°C to 28°C and humidity ranging from 60% to 78%. Unstable temperature and humidity conditions may cause the plants to wilt and interfere with the development of seedlings[3][4]. In order for lettuce plants to germinate properly, soil humidity needs to be maintained at a value of 60%[5]. Control of soil moisture is generally done by spraying water as needed, to achieve the desired humidity level[6], [7].

For commercial use, automatic spraying devices are generally time-based (e.g., Spraying Systems co, PulsaJet, AutoJet, AQUALIN, Yardsmith and Universal)[8], the user will be asked to set the desired spraying hours, and in some products, the length of time can also be adjusted according to user needs. Even though there have been many studies that have developed based on closed-loop systems using sensors and microcontroller, such as the DHT 11 sensor,[9]–[11] the open-loop spraying system is still considered efficient and commonly used. On the other hand, in closed-loop control schemes, proportional control systems are also widely used for various industrial applications[12]–[15], this control system was chosen because it is relatively simple and easy to fine-tune[16].

This research will examine the effectiveness of time-based automatic spraying (open-loop control) in terms of maintaining the desired soil or rockwool moisture value, with the addition of a proportional control method (closed-loop) when the spraying schedule is executed. It is hoped that the combination of these control methods can improve the performance of similar spraying systems that are already on the market, especially in term of energy conservation. This system will be built using Arduino Mega microcontroller, DF Robot soil Moisture humidity sensor, real-time clock (RTC), and actuator in the form of a DC spraying pump, and Micro SD Module for data logging purpose.

II. Methods

A. Block Diagram of Component

The system is developed based on Arduino Mega 2560, to operate the system properly, the main component used for this research is shown in the Figure 1. below.

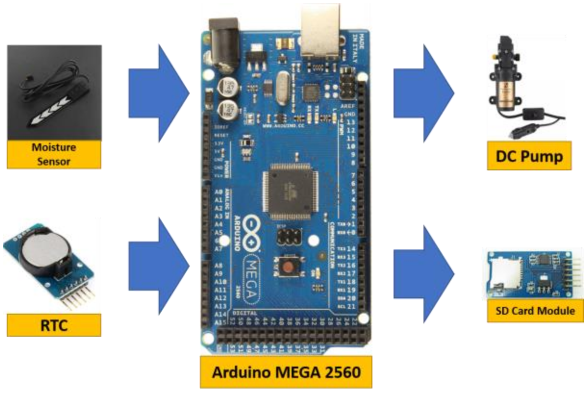

Figure 1. Main Components of System

The main parts of the system shown in Figure 1 are as follow:

1. Arduino Mega 2560 works as a place to process all the data used to drive the mini pump, as well as process data from sensors.
2. Moisture sensors are used to read the humidity in the planting medium for control purposes and logging data.
3. Time RTC is used as a spraying time marker which is then set in the Arduino program which will later be forwarded to the DC pump actuator.
4. The DC pump is used to carry out the process of spraying water from the water storage area to the planting medium through a PVC hose. The use of the pump is assisted by a noozle outlet to produce water in the form of a light mist.

B. *Block Diagram of Control System*

This research use both open loop and closed loop control system for different scenario of experiments. The setpoint is set to 60% of soil humidity. The open-loop control diagram is shown in Figure 2.

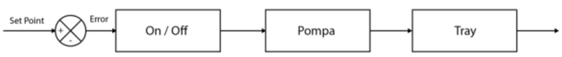

Figure 2. Open Loop Control System

In the open loop control method, the operation time must be set before, in order to activate the spraying mechanism to achieve setpoint. RTC is used to give accurate time of operation. Close loop control method is used for continuously regulate the humidity. The closed-loop control diagram is shown in Figure 3.

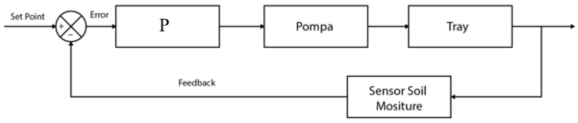

Figure 3. Closed Loop Control System

The closed-loop control system used proportional method, with the gain of proportional (Kp) is obtain through several experiments and performance evaluation. The proportional control system implemented in this study is the time-proportional method, which can be found in industrial temperature controllers such as Autonics products[17], when the control signal output (CO) from proportional control = 100%, the system will be active for 5 seconds, or according to the following equation.

$$T_s = C0.5second \quad (1)$$

with T_s is time of spray.

C. *Hardware Design and System Feature*

The system is build using galvanized iron material, with three segments for seedling cultivation. The three-dimensional design of the soil moisture control system is shown in Figure 4 below.

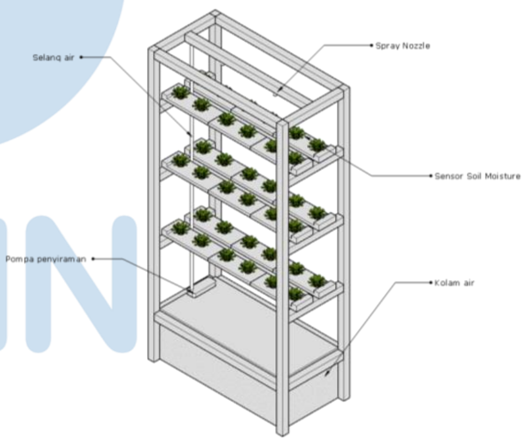

Figure 4. 3D Design of System

The specifications for this soil moisture control system are as follows:

1. The dimensions are 1.8 meters x 1 meter.
2. Using 220 VAC power
3. Using 12VDC power supply
4. Using a 6mm Plastic Nozzle
5. Using the Arduino Mega 2560 Microcontroller
6. Using the waterproof DF Robot Soil Moisture Humidity Sensor
7. Using Real Time Clock is an electronic clock in the form of a chip that can accurately calculate time (from seconds to years) and maintain/store data of that time in real time.

8. Using a MicroSD Module as a data logger storage of spraying record.
9. Using LCD I^{2}C 20x4 as display
10. Using a 12V 100 PSI SINLEADER Pump.
11. There are 3 modes in 1 sprinkle system:
    - Mode 1: Time Base (Open loop control)
    - Mode 2: Continous control (proportional control)
    - Mode 3: Combination of Time-Base and Proportional control
12. Three-segment for seedling cultivation.

III. Results and Analysis

The experiment was carried out in January-February 2023, in the Undip Vocational School area, the system was placed in a semi-outdoor area which still got sunlight and a little bit of rain during rainy days. The interval of data acquisition is 1 minute.

A. *Open Loop Experiment*

Open loop testing is carried out to see the effect of the actuator on changes in the variable to be controlled, namely soil moisture. The results of this experiment will be used as a reference for choosing the duration of plant spraying. The experiment is conduct at 09.00 WIB, from the initial humidity condition of 30% to reach the desired setpoint value of 60%. The result of experiment is shown in Figure 5.

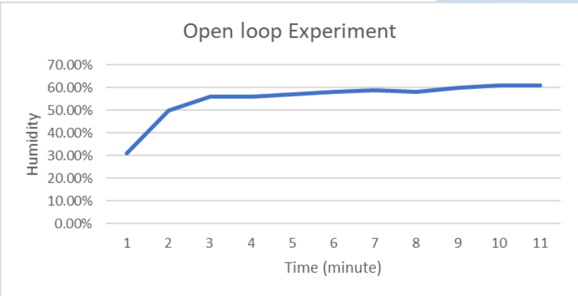

Figure 5. Open Loop Test Results

Based on the Figure 5, the actuator can achieve the desired setpoint within 10 minutes, therefore we based the spraying duration for open loop control in accordance with the result.

B. *Mode 1: Time Base (Open Loop Control)*

Open loop testing is carried out to see the effect of the actuator on changes in the variable to be controlled, namely soil moisture. The results of this experiment will be used as a reference for choosing the duration of plant spraying. The experiment is conduct at 09.00 WIB, from the initial humidity condition of 30% to reach the desired setpoint value of 60%. The result of experiment is shown in Figure 5.

TABLE I. Mode 1: Time Base (Open Loop Control) Test Result

Day	1st Watering (09.00-09.10)		2nd Watering (15.00-15.10)	
	Start Humidity (%)	End Humidity (%)	Start Humidity (%)	End Humidity (%)
1	41	65	48	64
2	51	67	55	68
3	53	73	52	68
4	55	73	59	76
5	51	74	56	68

The test results show that a time-based automatic watering system can bring soil moisture to an ideal value (60% -78%), but if it is expected that the system "only needs" to reach a lower threshold value of 60%, then the system experiences energy wastage and less optimal.

In this test, monitoring was also carried out at other than the time of spraying, at 13.00-14.00 and 17.00-18.00, to monitor the soil humidity outside of spraying schedule. In general, soil moisture is maintained at the ideal plant value, but on certain day, especially during hot weather, humidity can drop less than the recommended ideal value. As on the second day of testing at 13.00-14.00 the soil moisture dropped to a value of 53% as shown in Figure 6 below.

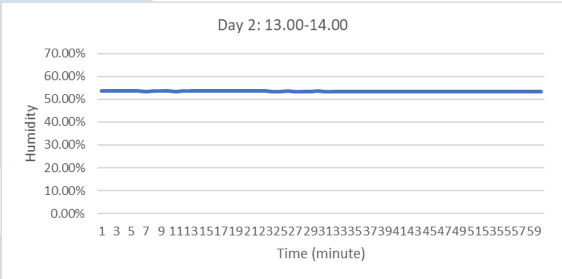

Figure 6. Soil Humidity Day 2 13.00-14.00

C. *Mode 2: Continous Control (Proportional Control)*

In Mode 2, experiments is carried out using several proportional gains (Kp). The test was carried out 5 times with an initial value of humidity = 43% and set point of 60% with duration of 1 hour. The results of the test will be evaluated by selecting the best settling time (ts) and root mean square error (RMSE) values. The results of the test are shown in Table 2 below.

TABLE II. Proportional Control Test Results

Test	Kp	ts (minute)	overshoot (%)	RMSE %)
1	2	20	0	5,80
2	3	18	0	3,80
3	4	13	0	7,11
4	5	6	0	2,48
5	6	4	0	3,64

Based on the result, the proportional control system can achieve the desired humidity of 60% with no overshoot occurred. The Kp value of 5 is choosen, because it gave the minimum RMS, the transiet response of Kp value = 5 shown in Figure 7.

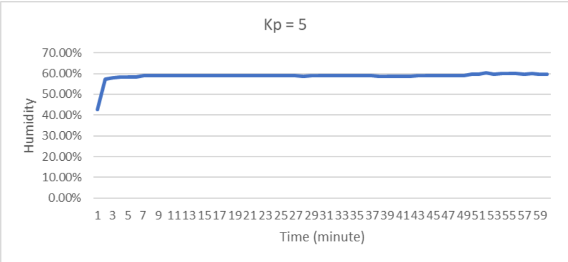

Figure 7. Proportional Test Result with Kp = 5

D. Mode 3: Combination of Time-based and Proportional Control

A closed loop control system that is carried out continuously will be able to regulate soil moisture as desired. However, taking into account the results of the mode 1 test, that the humidity value can be maintained in the ideal range naturally, it is necessary to optimize the time-based method. In this mode, the proportional control system (with Kp=5) will be used simultaneously during the time-based method of spraying, specifically at 09.00-10.00 and 15.00-16.00. This is so that the system does not spray until it exceeds the ideal humidity threshold value = 60%. And the logical consequence is that there will be energy savings because the spray pump is not operating. To measure energy consumption when the system is operating, an energy meter is used. The tool will display the total power used and used as the basis for calculating the total energy consumption of the system. The measurement results from the energy meter when the system is operating is shown in Figure 8 below.

Figure 8. Power Measurement Result

The test show that the power used for operating the system is 44,1 watt.

The experiment of this mode is carried out for 5 days. The result of experiment on day one at 09.00-10.00 is shown in the Figure 9.

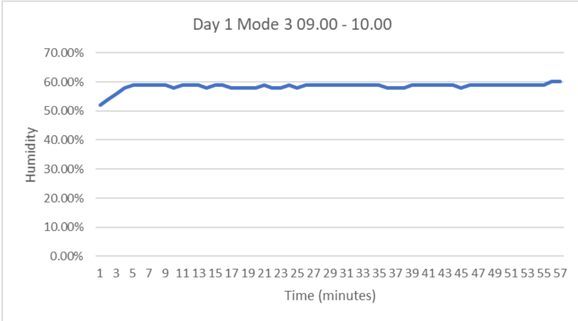

Figure 9. Result of Mode 3 Day 1 at 09.00-10.00

The Figure 9 shown that the system can relatively maintain the soil humidity at 60% during an hour period, and we can see the proportional control took over when the humidity drops too low or going too high (see red dash block). The experimental results obtained in 5 tests showed relatively the same results. The result of experiment on day one at 15.00-16.00 is shown in the Figure 10.

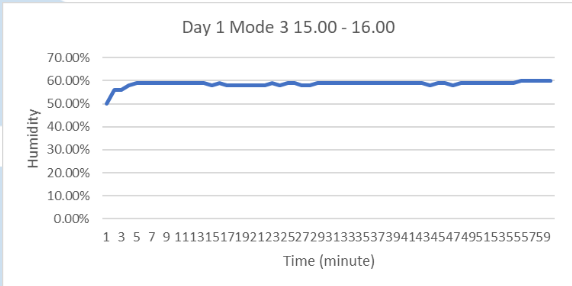

Figure 10. Result of Mode 3 Day 1 at 15.00-16.00

The result of experiment on day two at 09.00-10.00 is shown in the Figure 11.

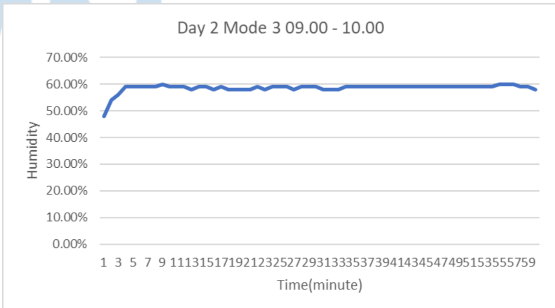

Figure 11. Result of Mode 3 Day 2 at 09.00-10.00

The result of experiment on day two at 15.00-16.00 is shown in the Figure 12.

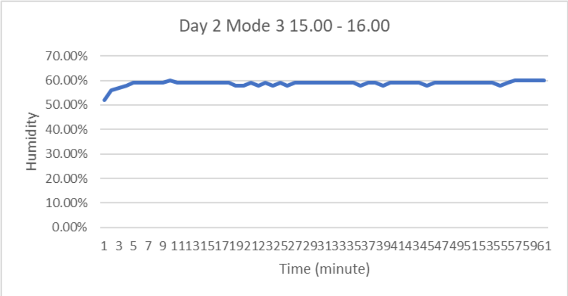

Figure 12. Result of Mode 3 Day 2 at 15.00-16.00

The active duration of the pump is also calculated to measure the total energy consumption when Mode 3 is run for 1 hour, the sample taken is the active time at 09.00-10.00. The calculation of total energy consumption for days 1 - 5 at 09.00-10.00 are shown in Table 3 below.

TABLE III. ENERGY CONSUMPTION OF MODE 3 AT 09.00-10.00

Day	Pump Active Periode (second)	Total Energy (Joule)
1	288	12,700
2	289	12,745
3	289	12,745
4	290	12,789
Average		12,745

The result shows the average energy consumption for Mode 3 is 12,745 joule while using Mode 1 with the duration of 10 minute spraying equal to energy consumption of 26,460 joule.

IV. CONCLUSIONS

The experimental results show that the designed system works well to control soil moisture which is ideal for the growth and development of lettuce seedlings. In particular, Mode 3 presents an alternative to time-based open-loop control that is commonly used, by combining it with a proportional control system, it can be seen that energy use can drop significantly from 26,460 joules to a value of 12,745 joules.

Although it looks promising the use of a time-based control system needs to pay close attention to the geographical location and weather of the farm itself. Closed cultivation methods such as greenhouses will be more effective in reducing environmental influences even though the investment costs may be greater.

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