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# Intelligent System and Renewable Energy: A Farming Platform in Precision Agriculture

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***Abstract*—**This study presents a small-scale water pumping system utilizing a fuzzy logic inference system attached to a renewable energy source. The fuzzy logic controller was designed and simulated in MATLAB fuzzy logic toolbox to examine the properties and characteristics of the input and output variables. The result of the simulation was implemented in a microcontroller, together with sensors, modules, and photovoltaic cells. The study used a grand rapid variety of lettuce, organic substrates, and foliar for observation of the capability of the device to irrigate crops. Two plant boxes intended for manual and automated irrigation were prepared with each box having 48 heads of lettuce. The observation of the system took 22-31 days, which is one harvest period of the crop. Results showed a 22.55% increase in agricultural productivity compared to manual irrigation. Aside from reducing human effort, and time, the smart irrigation system could help lessen some of the shortcomings of manual irrigations. It could facilitate the economical utilization of water, reducing consumption by 25%. The use of renewable energy could also help farmers reduce the cost of production by minimizing the use of diesel and gasoline.

***Keywords*—**Fuzzy logic controller, intelligent system, precision agriculture, renewable energy.

## I. Introduction

MOST of the Filipino farmers still live in rural areas and support themselves through agriculture, but water irrigation has become one of the significant factors in limiting the increase of the production yields. Water control and management are some of the priority concerns in irrigation systems. Of the Philippine's 30 million hectares of total land area, 47% is agricultural land [1] and has an average of 19.5% share in irrigated cropland [2] compared to the neighboring countries in the Asia Pacific region, such as China, Thailand, and Vietnam, 37.5%, 24.8%, and 30.8% respectively. Traditional farmers are using specific techniques of irrigations to irrigate the crops manually. Farmers water their farm manually with corresponding interval time; the soil needs water based on the crops they use and properties of soil like moisture and temperature. While using these techniques, some delays can occur because of some unavoidable reasons; then, it could affect the growth of the plants and leads to profit loss. There are several systems used to avoid the overwater and underwater of the farm.

Reference [3] mentioned that the automated irrigation system saves water even though the threshold value of each parameter is declared to control the quantity of the water. According to [4], the smart irrigation system proves to be useful in watering the garden by analyzing only the soil moisture in the ground. The experiment in [5] shows that the system has the capability of controlling the irrigation based on the feedback of the soil moisture. Also, the results of simulation in [6] show that the soil moisture and temperature are significant factors in designing a precise, smart irrigation system. Furthermore, [7] found out that the use of Sugeno-type of fuzzy inference system with sensing devices is reliable and effective in a smart irrigation system.

On the other side of the system, solar energy is one of the most promising sources of energy; its facilities are also easy to put up, scalable, and relatively unobtrusive. According to National Renewable Energy Laboratory [8], the Philippines has the potential to generate power of 4.5-5.5 kWh per square meter per day with the average solar radiation ranges from 128-203 watts per square meter based on geographic location and sunlight duration in the country. This technology is practical and appropriate to the consumers, where solar facilities can be installed as short as a few days or weeks. While other countries in South East Asia have embraced solar energy, the Philippines, despite its vast potential, is lagging in terms of policy implementation and deployment. Also, the solar pumping irrigation program is in the Agenda of National Irrigation Administration [9] to venture into new technologies that will be beneficial to farmers but also the environment and can help to tone down the cost of production as it minimizes the use of diesel and gasoline.

Lettuce (*Lactuca sativa*) was part of this experiment due to the water dependency of this crop [10] and considering the high commercial value in the country [11]. It was reported on [12] that the production of these yields was increasing at an average annual rate of 2.2%, but in 2015, there is a drop of production from 4061 metric tons to 3810 metric tons due to the dry spell (Fig. 1)

The study was conducted to automate the irrigation process using solar energy, which could reduce human intervention, help farmers optimize water use and increase the productivity of crops.

## II. Materials and Methods

There are several ways to irrigate a lettuce farm. A typical style/method for the farmers is the drip and sprinkler irrigation system. In this study, two plant boxes with rice straw (30 kgs)

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were prepared. The boxes measure 1 m wide x 1 m long and 7 in high. Fig. 2 shows the three substrates, namely garden soil (120 kgs), carbonized rice hull (20 kgs), and animal manure (60 kgs). They were mixed thoroughly and equally divided.

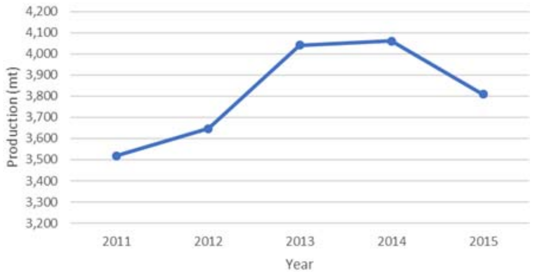


Fig. 1 Philippine lettuce production (2011 – 2015) (data taken from [12])

Fig. 2 Plant boxes of lettuce

Fig. 3 illustrates the plant lettuce with a planting distance of 25 cm between hills and 30 cm between furrows. Every emitter of the drip irrigation was surrounded by four plant lettuce so that the water distribution will be equal.

Fig. 3 Lettuce with a drip irrigation system

The smart irrigation system is integrated with multiple modules and sensing devices to provide an appropriate and sufficient amount of water to the crops.

*A. Drip Irrigation System*

This system is far more controlled than other irrigation systems like overhead and surface irrigation. The flow of water is very slow that it is easily absorbed into the ground. If a sufficient amount of water is needed in the field, the farmer can turn off the valve to stop the irrigation. In this order, there is little opportunity for excess water running off and being wasted [13]. One of the representations of a drip irrigation system is shown in Fig. 4.

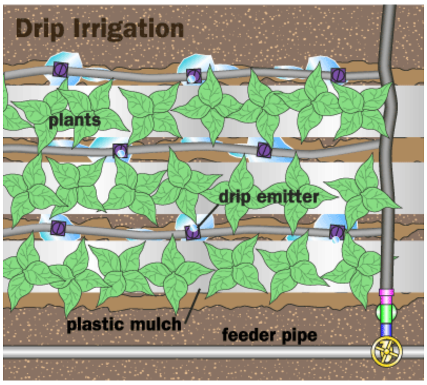


Fig. 4 Drip Irrigation system

*B. Arduino*

The Arduino Uno is an ATmega328P microcontroller board based on a dual-inline-package (DIP). It has 16 MHz quartz crystal, a power jack, a USB connection, an ICSP header, and a reset button. It can be power with an AC-to-DC battery. It contains needed support in a microcontroller for projects considering the number of pins (output/input) on this device [14].

*C. Soil Moisture*

The soil moisture sensor used (FC-28) has two conducting plates. The first plate was connected to the +5 Volt supply through series resistance of 10 K ohm and the second plate was connected directly to the ground. It acted as a voltage divider bias network, and output was taken directly from the first terminal of the sensor pin. The output will change in the range of 0 – 5 Volt, in proportion with a change in the content of water in the soil. Ideally, when there is zero moisture in the soil, the sensor acts as an open circuit, i.e., an infinite resistance. For this condition, we got 5 V at the output [15].

*D. Temperature Sensor*

The DHT22 Digital Temperature and Humidity Sensor Module AM2302 is a low-cost humidity and temperature sensor that can returned values through a single wire digital interface [16]. This sensor validated in industry-based sensor like Pasco wireless temperature PS-3201, the result has a difference of between 0.2 and 0.5 °C.

*E. Micro SD Card and Real-Time Clock Module*

It enables transferring data to and from a standard micro SD card. It is used for data storing or data logging applications including an on-board voltage level conversion for easy interface with 3V or 5V devices.

*F. Motor*

This motor uses advanced electronic components and high-quality wear-resistant shaft. It is made of high-grade material, which is non-toxic, safe, energy-saving, durable, and friendly to the environment.

*G. Proposed System*

Fig. 5 presents the entire schematic diagram of the proposed system, including the solar energy source and controller. Fig. 6 illustrates the processes of the system, which includes data acquisitions, fuzzy inference system, and irrigation of the crops. Also, Table I shows the cost of materials of the smart irrigation system.

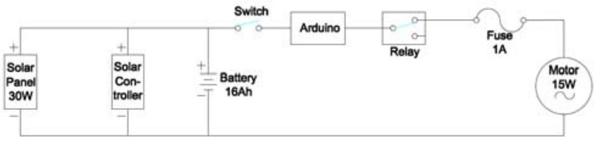


Fig. 5 Schematic diagram of proposed system for smart irrigation system

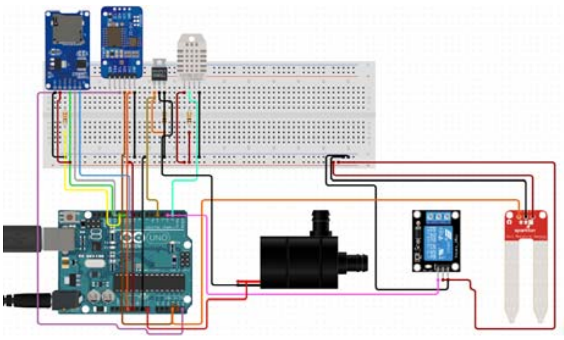

Fig. 6 Microcontroller together with sensors, modules and pump

TABLE I
ESTIMATED MATERIALS FOR SMART IRRIGATION SYSTEM

| Items | Cost |
|---|---|
| Solar Panel 30W | ₱1,300.00 |
| Solar Controller | ₱750.00 |
| Arduino Uno R3 | ₱450.00 |
| Deep Cycle Battery 16Ah | ₱1,200.00 |
| SD Card Module | ₱150.00 |
| Real Time Clock Module | ₱150.00 |
| Soil Moisture Sensor | ₱120.00 |
| Temperature Sensor | ₱120.00 |
| Single Channel Relay | ₱120.00 |
| Motor Pump 12V | ₱300.00 |
| Total | ₱4,660.00 |

1. Data Acquisition: Figs. 7 (a)-(d) represent the growth of the lettuce from week one to four with the use of a smart irrigation system.
2. Fuzzy Inference System: The fuzzy logic controller was designed and simulated in the MATLAB fuzzy logic toolbox to examine the properties and characteristics of the input and output variables (Fig. 8). In this model, the Sugeno type fuzzy inference system was utilized since this fuzzy system is more suitable in implementing microcontrollers due to the linear or constant output.

The moisture content of the soil has a vital role in the production of lettuce. Checking the moisture content of the soil must be done before the watering of the crops since the oversupply and undersupply of the water can cause damage to the plant. Soil water extraction and soil water balance are some of the factors used in designing this input variable (Fig. 9). Thus, it was measured in the analog-digital converter (ADC) value and calculated in percentage.


Fig. 7 Lettuce with smart irrigation system

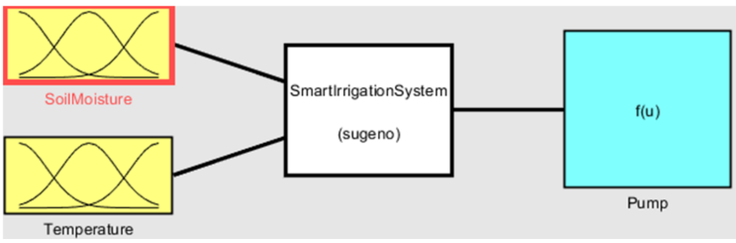


Fig. 8 Sugeno fuzzy inference system

The analog output of soil moisture changes the range of ADC value from 0 to 1023. Equation (1) was used to display the result of soil moisture in terms of percentage in the serial monitor.

$$MoisturePercentage=(100-((SensorAnalog/1023)*100) \quad (1)$$

Different seed varieties germinate best at certain temperatures. Lettuce temperature germination was set at 16-

24 °C. If the actuators generate greater than 35 °C, the system will set it into a maximum range of 35 degrees. Fig. 10 illustrates the membership function diagram of the temperature input variable, which is one of the considerations before watering the fields whereas Fig. 11 shows the decision support system combining the two input variables into two singleton outputs.

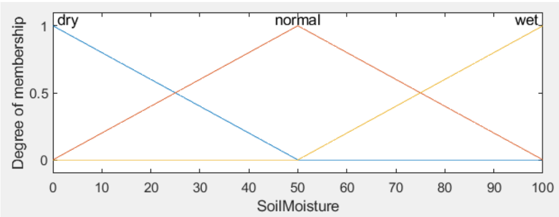


Fig. 9 Membership function for Soil Moisture

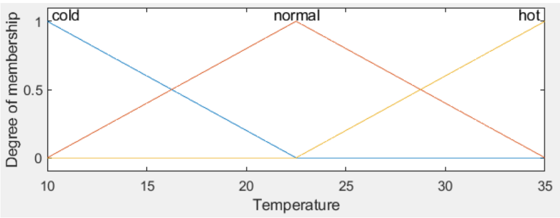


Fig. 10 Membership function for Temperature

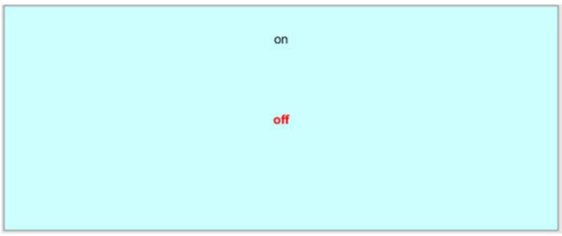


Fig. 11 Membership function for Pump

TABLE II
FUZZY SETS OF INPUT AND OUTPUT

| Universe of Discourse | Parameters: *Input* | Parameters: *Output* | *Linguistics Variable* |
|---|---|---|---|
| [ 0 100 ] | Soil Moisture | | dry, normal, wet |
| [ 10 35 ] | Temperature | | cold, normal, hot |
| [ 0 1 ] | | Pump | off, on |

1. If (SoilMoisture is dry) and (Temperature is cold) then (Pump is on) (1)
2. If (SoilMoisture is dry) and (Temperature is normal) then (Pump is on) (1)
3. If (SoilMoisture is dry) and (Temperature is hot) then (Pump is on) (1)
4. If (SoilMoisture is normal) and (Temperature is cold) then (Pump is off) (1)
5. If (SoilMoisture is normal) and (Temperature is normal) then (Pump is off) (1)
6. If (SoilMoisture is normal) and (Temperature is hot) then (Pump is on) (1)
7. If (SoilMoisture is wet) and (Temperature is cold) then (Pump is off) (1)
8. If (SoilMoisture is wet) and (Temperature is normal) then (Pump is off) (1)
9. If (SoilMoisture is wet) and (Temperature is hot) then (Pump is off) (1)

Fig. 12 Rule base for Pumping the irrigation system

Table II describes the universe of discourse and linguistic variables of input and output variables. Both input variables have three fuzzy sets, while the output variable has two constant outputs.

IF-THEN structure was defined in mapping the input to output in linguistics variable and the formulation of knowledge base rules on these membership functions (Fig. 12).

## III. EXPERIMENTAL RESULTS

In this section, the results of the experiment will be discussed and presented. The implementation of the smart irrigation system with solar energy and organic substrates was evaluated and observed by the farm technician, who determined whether the device produced enough water to the yields. By utilizing the smart irrigation system, the agricultural productivity of the farmers increased up to .23 kgs of lettuce and saved water up to 18 liters. Fig. 13 shows the crop ready for harvest.

Fig. 13 Crop ready for harvest

One of the sample results shows in Fig 14 that the valve of the motor will turn on.

```
Moisture : 35.29 %        Temperature: 26.40 *C
Output: 0.57
```

Fig. 14 The threshold value of output to activate the motor

Fig. 14 has an input value of 35.29% for soil moisture at 26.40 °C.

### *A. Finding the Membership Functions of the Input Variables*

Each value coming from the sensors has a corresponding fuzzy set. On this example, the input value of soil moisture belongs to dry and normal fuzzy sets while the temperature value reaches the normal and hot fuzzy sets.

### *B. Computing the Degree of Membership*

$$\text{if } (x \le a),\ f = 0 \tag{2}$$

$$\text{if } ((a \le x)\ \&\&\ (x \le b)),\ f = x - a / b - a \tag{3}$$

$$\text{if } ((b \le x)\ \&\&\ (x \le c)),\ f = c - x / c - b \tag{4}$$

$$\text{if } (c \le x),\ f = 0 \tag{5}$$

where x = input coming from the sensors, both fc-28 and dht22; a = starting point of the triangle; b = peak of the triangle; c = ending point of a triangle; f = degree of membership.

Equations (3) and (4) are used in computing the degree of membership for a fuzzy set of soil moisture and temperature:

Soil Moisture: f(dry) = 50 − 35.29 / 50 – 0 = 0.2942
f(normal) = 35.29 – 0 / 50 – 0 = 0.7058
Temperature: f(normal) = 35 – 26.4 / 35 – 22.5 = 0.688
f(hot) = 26.4 – 22.5 / 35 – 22.5 = 0.312

### C. Evaluating the Rules

Evaluation result in rule base was indicated below in which the firing strength was achieved by getting the minimum of the degree of membership of input variables:

$$w_i = \min(\text{trimf}(x), \text{trimf}(y)) \tag{6}$$

Equation (6) was used to compute the firing strength of each fuzzy rules, as shown in Table III.

TABLE III
FIRED VALUE FROM A MINIMUM DEGREE OF MEMBERSHIP OF INPUT VARIABLES

| Fuzzy Rules | Membership Function | | *Minimum* |
|---|---|---|---|
| | *Soil Moisture* | *Temperature* | |
| w1 | 0.70 | 0 | 0 |
| w2 | 0.70 | 0.68 | 0.48 |
| w3 | 0.70 | 0.31 | 0.22 |
| w4 | 0.29 | 0 | 0 |
| w5 | 0.29 | 0.68 | 0.20 |
| w6 | 0.29 | 0.31 | 0.09 |
| w7 | 0 | 0 | 0 |
| w8 | 0 | 0.68 | 0 |
| w9 | 0 | 0.31 | 0 |

### D. Defuzzification

The weighted average defuzzification method is used to calculate the weighted sum of each fuzzy set. The crisp value is set according to the weighted values and the degree of membership for fuzzy output, as determined in (7):

$$\text{FinalOutput} = \sum_{i=1}^{N} w_i z_i / \sum_{i=1}^{N} w_i \tag{7}$$

where N = Number of rules; $z_i$ = fuzzy output weight value for the output singleton.

## IV. CONCLUSIONS AND RECOMMENDATIONS

This kind of expert system could help farmers increase their productivity considering its capability in diagnosing the proper time of irrigation, controlling the oversupply and undersupply of water, and cutting off the losses. By using the developed smart irrigation system, farmers could reduce the usage of water and lessen human intervention since the system automates and regulates the watering of the crops.

A further experiment can make the system smarter by adding more inputs and factors to it, including the observation data during the rainy season. Moreover, applying of Internet of Things would help the accessibility of the data and machine learning to enhance the result of the decision support system.

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