Smart solar powered hydroponics system using internet of things and fuzzy association rule mining

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Abstract. Hydroponics is an alternative to limited space agriculture by involving electrical energy for irrigating nutrients for plants. Apart from using an AC power source, hydroponics can also use a DC power source which makes it more portable and can be placed in a location far from the PLN(State Electricity Company) electricity source. DC power sources also have the potential to be supplied by renewable energy sources such as solar power directly without AC / DC conversion. However, solar energy sources have a weakness in the influence of the weather. The study proposes the implementation of the Internet of Things (IoT) to classify the condition of energy sources in its implementation of solar energy powered hydroponics system. The research involves the development of IoT devices to collect energy data generated by solar cells and stored in batteries and environmental conditions, namely light intensity, temperature, and humidity. The proposed IoT system classifies conditions based on the remaining energy in the battery and current weather conditions using the Fuzzy Association Rule Mining (FARM) algorithm. The system also considers the remaining hours of the day, because at night solar energy cannot be produced. The simulation result shows the developed solar-powered hydroponics system capable to keep supplying energy for 24 hours with three 10wp solar cells and a 7Ah battery for the deep flow technique hydroponics with the 24 pot with 1-meter stand and 20watt water pumps. The IoT system capable to collect data and the proposed regression algorithm FARM is capable to do the regression with low error rates (0.06 mean absolute error and 0.24 mean square error) with three days of data. The FARM also capable to extract environmental data that affect the energy generation and usage with a high average of supports (0.29) and confidence (0.32).

1. Introduction
Hydroponics is an alternative to limited space agriculture by involving electrical energy for irrigating nutrients for plants [1]. Nutrition film technique (NFT) and deep flow technique(DFT) are two hydroponic methods that rely heavily on the volume and velocity of water flow with nutrients. To achieve optimal nutrient irrigation, a pump that is suitable for the hydroponic installation conditions is required [2]. This makes the placement of the hydroponic system limited by the distance from the electric power source, which is generally an alternate current (AC) type that supplied by State Electricity Company [3].
Apart from using an AC power source, hydroponics can also use a DC power source which makes it more portable and can be placed in a location far from the State Electricity Company’s electricity source [4]. DC power sources also have the potential to be supplied by renewable energy sources such as solar power directly without AC / DC conversion [5]. However, solar energy sources have a weakness in the influence of the weather [6].

The problem of solar powered energy source for the hydroponics system are: uncertainty of the number of generators and batteries needed to supply energy continuously; uncertainty in weather conditions such as light intensity, air temperature and humidity that affect energy production[7]; and optimization of the placement of solar panels so that they are not affected by changes in the sun's position [8].

2. Methodology
The IoT for the environment collects data of light intensity, air temperature, and humidity. The three environmental variables are collected as an effect on the conditions of energy production by solar panels and plant growth in hydroponics. The IoT for energy consists of the same two devices. One is for the energy produced by solar panels and the other is for the energy that is used from batteries. Data from the three IoT devices are transferred into the raspberry pi server which contains the FARM algorithm that aimed to process the fuzzy rule extraction and regression.

Data collection is divided into two stages. The first stage of the day time to collect environmental and energy data that are produced by solar cells as a precedent of the rule. The second stage at night to collecting energy consumption data from the battery as the dependent of the rule. The extracted rules for each precedent and dependent are used by FARM for the regression process. The regression results will be evaluated until the expected results are achieved. The FARM algorithm for energy related data modeling is adopted from our previous research [9]. The sequential data modeling by FARM also adopted from our previous research [10].

3. Results and Discussion
3.1. The IoT Development and system installation
The figure 1 shows the developed IoT devices with both includes 3.7v 18650 battery, voltage regulator, and mini solar cells. The IoT devices for environment data collection shown by (a) of figure 7 with DHT11 for air temperature and humidity and BH1750 for light intensity are connected through PCB connection. The IoT devices for energy data collection shown by (b) of figure 7 with ACS712 for DC current and voltage sensor are connected through PCB connection.

Figure 1. Developed IoT Devices.

The figure 2 shows the view of system installation for the deep flow technique hydroponics system with the 24 pot separated into 8 pot in four pipes and 1 meter stand. The view of whole system shown by (a) of figure 2, which three 10wp solar cells, water pumps and 7Ah batteries connected to the solar charge controller. The detail connection of solar charge controller with three 7Ah batteries and 10wp
solar cells shown by (b) of figure 2, which the parallel connection are conducted using 5 terminal wago connector. The solar cells are shown by (c) of figure 2, which installed on portable stand to show the portability of the system. The solar cells intentionally not placed on a roof or other high location in order to be able to observe the problem, especially effect of a sun position.

(a) The view of the whole system

(b) Batteries Installation

(c) Solar Cells Installation

Figure 2. The System Installation.

3.2. The Fuzzy Membership and FARM Regression

Table 1 and 2 shows the extracted fuzzy membership function from each IoT devices (environment and energy). The fuzzy membership function that used in the proposed method is asymmetric gaussian function that involving mean lower and higher standard deviation of the collected data. The asymmetric gaussian membership function are used due to its capability to define the variety of continuous numeric data.

| Attribute          | Fuzzy Index | $\sigma_1$ | $\mu$  | $\sigma_2$ | Days (%)  |
|--------------------|-------------|------------|--------|------------|-----------|
|                    |             |            |        |            | 1          | 2          | 3          |
| Air Temperature    | 1           | 27.5       | 29.3   | 30.7       | 65.34     | 54.56     | 49.89     |
| ($^\circ$C)        | 2           | 29.5       | 31.1   | 32.1       | 15.12     | 23.68     | 32.67     |
|                    | 3           | 31.3       | 32.8   | 34.2       | 19.54     | 21.76     | 17.44     |
| Air Humidity       | 1           | 30         | 40     | 43         | 62.23     | 44.45     | 43.53     |
| (%)                | 2           | 43         | 56     | 68         | 17.45     | 23.68     | 32.67     |
|                    | 3           | 65         | 75     | 87         | 20.32     | 31.87     | 23.8      |
| Light Intensity    | 1           | 20025      | 49872  | 62190      | 37.89     | 32.34     | 29.35     |
| (Lux)              | 2           | 9872       | 10267  | 20319      | 13.76     | 20.36     | 31.19     |
|                    | 3           | 92         | 6379   | 9892       | 12.43     | 16.32     | 11.23     |
|                    | 4           | 1          | 1      | 1          | 35.92     | 30.98     | 28.23     |

Table 1 shows the fuzzy memberships of each environment variables including light intensity in lux, air temperature in celsius degree and humidity in percent. Fuzzy index are sorted to the best environment condition for each variable according to its effect to the solar energy generation. The best environment condition are air temperature and humidity are lower than solar cells tolerance ($32^\circ$C and 70%) and light intensity is high as possible. Light intensity has four membership function because the number of fuzzy membership function depends on variance of the variable ranges and its has the higher variance (from 1 to 62190 lux).

The days column show the percentage of the data that reaches fuzzy membership threshold (0.5) for the three days (19 to 21 September 2020). Table 1 shows day 1 have the best weather condition which
have the lowest air temperature (65.34% between 27.5 and 30.7°C) and humidity (62.23% between 30 and 43%) and highest light intensity (37.89% between 20025 and 62190 lux). The day two and three has a similar percentage of fuzzy membership degree with only 5.762 of average differential.

**Table 2.** Fuzzy Membership of Energy Variables and Percentage per Day.

| Attribute          | Day (%) 1 | Day (%) 2 | Day (%) 3 | Fuzzy In-σ₁i | μᵢ | σ₂ |
|--------------------|-----------|-----------|-----------|---------------|----|---|
| Solar Voltage (Volt) | 11.67     | 13.12     | 16.01     | 43.21         | 38.76 | 40.08 |
| Solar Current (A)    | 4.52      | 8.98      | 11.68     | 43.65         | 39.48 | 30.98 |
| Battery Voltage (Volt) | 2.34      | 3.43      | 4.67      | 13.14         | 21.76 | 28.94 |
| Battery Current (A)   | 0.45      | 0.51      | 0.57      | 43.78         | 36.36 | 41.02 |
|                     | 0.23      | 0.34      | 0.46      | 43.25         | 39.12 | 34.65 |
|                     | 0.01      | 0.19      | 0.24      | 12.97         | 24.52 | 24.33 |
|                     | 10.12     | 11.25     | 12        | 69.23         | 32.89 | 46.1  |
|                     | 7.56      | 9.21      | 10.13     | 19.12         | 38.12 | 28.12 |
|                     | 5.64      | 6.30      | 7.67      | 11.65         | 28.99 | 25.78 |
|                     | 0.01      | 0.03      | 0.12      | 70.62         | 40.27 | 43.12 |
|                     | 0.54      | 0.62      | 0.67      | 18.32         | 39.17 | 31.32 |
|                     | 0.68      | 0.98      | 1.02      | 11.06         | 20.56 | 25.56 |

Table 2 shows the fuzzy membership function for energy variables including voltage in volt and current in ampere for both generated by solar cells and used from batteries. As described by table 1, fuzzy index shows the order of best condition for each variable. The days on table 2 also described the percentage of the data that reaches fuzzy membership threshold (0.5) for the three days (19 to 21 September 2020), which is in line with Table 1.

The solar voltages fuzzy index shows the order of maximum voltage of 10wp solar cells which is 17 volt. The solar currents fuzzy index shows the order of maximum current of 10wp solar cells which is 0.7A. Both solar voltage and current can archived best condition when environment condition are also in best condition (high light intensity and lower temperature and humidity). The best condition of both solar voltage and current shows the capability of the solar cells to generating energy. Full direct energy supply from solar cells are only possible when the batteries are approaching fully charged and best environment condition.

**Table 3.** Power Condition and Duration of The Energy Availability.

| Power Condition | Day (Hour) 1 | Day (Hour) 2 | Day (Hour) 3 |
|-----------------|--------------|--------------|--------------|
| Full Direct Power | 11.12        | 5.36         | 5.32         |
| Partial Battery Power (Low) | 2.15        | 5.67         | 5.67         |
| Partial Battery Power (High)   | 1.27        | 2.76         | 2.89         |
| Full Battery Power     | 9.46        | 10.21        | 10.12        |

The table 3 shows the power condition and duration of the energy availabilities for the three days. The full direct power are highest on day one because the error that have been described before (started with fully charged batteries in the morning). The reasonable duration also shown by day 2 and 3, which around 5 and half hours equally for full direct and low partial battery power. The full battery power shows the condition during night time, which impossible to generates solar energy. The day 2 and 3 shows reasonable duration for noon, early morning (high partial battery power) and night time (full battery power). The high partial battery power lowest in the day 1 and also affect the full battery power duration.
For the regression process will be done using data on day 1 and 2 as training data and day 3 as testing data. Because the error on the research procedure on day 1, the collected data on day one possibly caused noise for the learning process of the regression. But thanks to rule-based regression the problem can be solved by the concept of selecting the best rule.

Table 4. The Extracted Rules of FARM.

| ri  | Precedent | Dependent | Support | Confidence |
|-----|-----------|-----------|---------|------------|
| 1   | \{(T_1,T_2),(H_1,H_2),L_1\} | \{V_{i1},C_{i1},V_{o1},C_{o1}\} | 0.435   | 0.342      |
| 2   | \{(T_1,T_2),(H_1,H_2),(L_1,L_2)\} | \{V_{i1},C_{i1},V_{o1},C_{o1}\} | 0.345   | 0.453      |
| 3   | \{(T_1,T_2),(H_1,H_2),(L_1,L_2)\} | \{V_{i1},C_{i1},V_{o1},C_{o1}\} | 0.211   | 0.421      |
| 4   | \{T_2,H_2,L_1,L_2,L_3\} | \{V_{i2},C_{i2},V_{o2},C_{o2}\} | 0.153   | 0.234      |
| 5   | \{T_3,H_3,L_1\} | \{V_{i2},C_{i2},V_{o2},C_{o2}\} | 0.284   | 0.236      |
| 6   | \{T_3,H_3,L_3\} | \{V_{i2},C_{i2},V_{o2},C_{o2}\} | 0.271   | 0.352      |
| 7   | \{T_2,H_2,L_4\} | \{V_{i3},C_{i3},V_{o3},C_{o3}\} | 0.252   | 0.238      |
| 8   | \{T_2,H_2,L_4\} | \{V_{i3},C_{i3},V_{o3},C_{o3}\} | 0.346   | 0.263      |
|     | Average   |           | 0.287   | 0.317      |

Table 4 shows the extracted rules of collected data by FARM. The ri shows the rule index and each environment variable mapped as precedent and energy variable as dependent. The support and confidence are shown on the right side of each rules and the FARM reaches the high average support (0.287) and confidence (0.317). The extra bracket on the precedent shows the OR definition of the rules. The rule 1 and 2 shows the full direct power condition. Although has the same dependent FARM decides to separate the rules because the high support from both rules. The rule 3 to 6 shows the partial battery power with different environment condition. The rule 7 to 8 shows the full battery power in the night.

The regression process of FARM is carried out by defuzzification of extracted rules. Only the best rules that matched with test data will be used as defuzzification for each regression variables as shown as power condition on Table 5. The training data will have an advantage due to similarity between data from the day 2 and 3. The day 1 are possibly ignored due to dissimilarity with the data from day 3.

Table 5. The Regression Result.

| Power Condition                  | Regression |      |      |      |
|---------------------------------|------------|------|------|------|
|                                 | Prediction (p) | True (t) | Differential |
| Full Direct Power                | 5.33       | 5.32 | 0.01 |
| Partial Battery Power (Low)     | 5.67       | 5.67 | 0    |
| Partial Battery Power (High)    | 2.85       | 2.89 | 0.04 |
| Full Battery Power              | 10.11      | 10.12| 0.01 |
| Mean Absolute Error (MAE)       |            |      | 0.06 |
| Mean Square Error (MSE)         |            |      | 0.25 |

The regression result are shown by table 5 for the duration of energy availability. Day 1 and 2 are used as training data and day 3 are used as testing data. The differential between prediction and true data shown by last column, which there is zero differential for partial battery power duration. The low mean absolute error (MAE) with 0.06 and mean square error (MSE) with 0.25 are reached by FARM regression. This low error rate of regression are reached due to constant power consumption of electric water pump on hydroponic system and high similarity between data from day 2 and 3. In the future, research longer duration of data collection and more diverse data is needed to ensure the FARM capabilities as regression processor.
4. Conclusion
The solar-powered hydroponics system capable to keep supplying energy for 24 hours with three 10wp solar cells and 7Ah battery for the deep flow technique hydroponics with the 24 pot with 1 meter stand and 20watt water pumps. The IoT system capable to collect data and the proposed regression algorithm FARM is capable to do the regression with low error rates (0.06 MAE and 0.24 MSE) with three days of data. The FARM also capable to extract environment data that affect the energy generation and usage with a high average of supports (0.29) and confidence (0.32).

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