Smart pot implementation using fuzzy logic

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Abstract. The paper present automated plant watering system based on Internet of Things. This system is expected to replace conventional system where the plant watering is done manually by humans. The system will also be the sole problem of land constraints, especially in densely populated urban areas. The system uses Soil Moisture, DHT11 and also pH Meter sensors to obtain soil moisture, humidity and acidity (pH) soil data. Next will be done data acquisition by XBee which will be forwarded to gateway where filtering data be done. After that the gateway will send data to the hosting server that will run the fuzzy algorithm to govern the actuator to be able to do watering automatically. The result shows the success of the system of plant watering, where the plants treated with Smart Pot have a plant height of 23 cm and a leaf width of 6 cm, while the manually treated plant has a height of 19 cm and a leaf width of 4.5 cm.

1. Introduction

One of the purposes of urban agriculture is to produce quality and hygienic vegetables through self-help. However, the urban agriculture process takes time in crop tending. The factor of limited land also becomes an obstacle for the urban community to implement urban agriculture. There is a need for flexible planting methods that can optimize the limitations of land owned by the community. One of the solutions that can be implemented to address this problem is the cultivation of vegetable plants in pots. By using pots, the limited land owned can be more optimized. However, potted plants still requires routine tending that takes time and can interfere the routine daily activities. Therefore, the implementation of control system automation is expected to provide benefits in terms of efficiency, precision, and security when compared to manual methods. However, this technology must also be balanced with regular tending and monitoring to keep it running optimally. Supported by the concept of Internet of Things (IoT), the remote control system can be implemented by integrating system with the Internet, so as to facilitate the process of controlling and monitoring [1]. Previously there have been studies that automatically water plants such as research entitled “Automated Plant Watering System” [2]. In this study, the design of the plant watering process automatically uses the results of the acquisition of soil moisture sensors. In a subsequent study entitled “Implementation of an Automated Irrigation System”[3], the main aim of this paper is to develop an automated irrigation system based on sensors which are interfaced to the microcontroller unit. The sensors used in this paper are temperature and humidity sensor DHT11 sensor and soil moisture VH400. In this research we proposed the design of soil moist, temperature and humidity watering system using fuzzy logic. Fuzzy logic is used which has good control effectiveness in complex and changeable environment, as in the case of this study which uses three input parameters to determine watering decisions [4].
2. Basis of theory
This research took the reference from the research on vegetable plant monitoring system in urban areas that have been conducted [5]. The study monitored the condition of vegetable plants using soil moisture sensor, ambient light sensor, and HC-SR04, without getting weather condition data. The system built on the research used plant pots mounted on a modified table so that the actuator can water the plants in the pot. However, the test system conducted in the study only lasted 2 minutes so it is not long enough to see the growth of vegetable crops planted. Therefore, the urban agriculture automation system for potted vegetables in this study was designed to be able to monitor the condition of plants by acquiring moisture soil data and weather data where the vegetable plants are located. In addition, the system built on this research was also designed to work with longer duration, which is from seeds until vegetable crops can be harvested.

2.1. Internet of things
Internet of Things (IoT) is a concept where an object that has the ability to transfer data in the network between sensors without the use of interaction between humans and computers and use the Internet network as the basis of communication. The phase in the IoT implementation was divided into three phases, the collection phase, the transmission phase, and the management and utilization phase [6].

2.2. Wireless sensor network
Wireless Sensor Network (WSN) is a network consists of low-cost, easy to deploy, and efficient power consumption sensors. With sensor nodes consist of four main units namely data acquisition, memory and processing units, communication units, and power units, WSN proved to be useful in real-time data monitoring applications [7].

2.3. Sensor nodes
Sensor node components in this research were soil moisture, DHT11 sensor, pH meter sensor, Arduino Nano, and Xbee.

- **DHT11 Sensors**
  DHT11 is a sensor consisting of a digital output signal from the calibrated temperature and humidity of the room, which in this Smart pot system is used to obtain air temperature and Humidity data [5].

- **Soil Moisture Sensor**
  Soil Moisture Sensor is a tool used to detect soil moisture level. This sensor used two probes to pass current through the ground, and then the resistance was read to obtain soil moisture level. More water content made it easier for the soil to conduct electricity (small resistance), whereas dry soils are increasingly difficult to conduct electricity (large resistance) [9].

- **pH Meter Sensor**
  The pH meter sensor is a device used to detect acidity or pH levels [10].

- **Arduino Nano**
  Arduino is an open-source electronic platform designed to create interactive objects in various fields. The arduino board is able to read inputs obtained by sensors or buttons, which produce output for the actuator. This can be done by sending the instruction set to the microcontroller on the arduino board [11]. The arduino device used in this study was Arduino Nano with ATmega328 microcontroller located on sensor node for data acquisition process.

- **XBeex**
  Xbee is a brand of radio communication module developed by Digi International, which uses the Zigbee communication protocol specifications based on the IEEE 902.15.4 standard. The device
used in this study were two Xbee Series 2 with cable antenna type, has a range of 40 meters indoor or urban space and 120 meters outdoors. XBee on the sensor node was the end node, while the gateway was the node coordinator [12]. XBee on the sensor node was used to transmit data acquisition to the gateway.

2.4. Gateway
This Smart pot system used a gateway that serves to receive data acquisition sent from the sensor node that was forwarded to the next process to conduct data processing. Gateway consists of Wemos D1 Mini as WiFi ESP8266 module-based microcontroller and XBee Coordinator as module to receive acquisition data from sensor node through Zigbee. Parsing process was then conducted to the data received which was then converted into each data type.

2.5. Fuzzy logic
Fuzzy Logic is a branch of artificial intelligence where this system is usually applied to problems that contain elements of uncertainty. Fuzzy logic is a logic that can translate middle values into true / false logic, yes / no, high / low and so on.
In this fuzzy system all data from sensor node is used as a crisp input. And then it enter the fuzzification process where input is mapping into fuzzy membership function which will be processed by inference system. The Inference system will doing a reasoning as decision maker. This system consists of various rules that will conclude from the results of the correlation based on existing rules. Finally the data will be processed to the defuzzification process. It is the opposite stage of fuzzification, which returns the fuzzy set into a form of firm set obtained from the reasoning stage. The output from this defuzzification will produce a value from the fuzzy logic control system. Figure 1 illustrates a system based on Fuzzy logic [13].

Fuzzyfication
Fuzzification is a process whereby input from a strict value is mapped into a fuzzy set membership function which will be processed by a reasoning machine [14]. The fuzzy set has several operations that are specifically defined to combine and modify fuzzy sets. The membership value of a combination of fuzzy sets is called fire strength or $\alpha$-predicate.

Inference System and Evaluation Rule
At this stage the system will do reasoning for the value to determine the output form as the decision maker. In this system consists of various rules that will conclude from the results of the correlation based on existing rules [14].
• Defuzzification
   It is the opposite stage of fuzzification, which returns the fuzzy set into a form of firm set obtained from the reasoning stage. The output from this defuzzification will produce a value from the fuzzy logic control system [14].

2.6. Actuator
The actuator is a set of tools used to control a mechanism that is automatically controlled by a microcontroller. The system built on this research had an actuator node consisting of a Mini Wemos D1 device and a relay connected to a 5 V powered water pump [15]. The data read by the sensor was sent to the Fuzzy System in the server hosting. In the Fuzzy System, the data sent by the sensor was processed; the first step was fuzzification where the data from the sensor will be mapped to the fuzzy set and then inferencing was conducted with the basic rules that have been made for this Smart pot system. The last step was to defuzzification, which is set back the fuzzy set into firm set that determine the condition of the activation of actuator.

3. System design and result

3.1. System architecture
Smart pot system was built using the system architecture as in figure 2. The built system architecture implemented the WSN concept with the star topology, which is the node sensor connected directly to the gateway. Plant data acquisition process was performed on node sensors consisting of arduino nano microcontroller, xbee end node (transmitter), soil moisture sensor, DHT11 sensor, and pH meter sensor. Then using xbee communication, the acquired data was forwarded to a gateway consisting of a mini D1 wemos microcontroller that has been equipped with Wifi ESP8266 module, and xbee coordinator (receiver). At the gateway, data readings were conducted which then the data sent to the hosting server to be processed so that it can be utilized by the user. The actuator used a mini D1 wemos microcontroller to receive output from the data in the form of an action command to turn on or off which were connected to a relay module, and a 5 Volt water pump.

![Figure 2. Smart pot architecture.](image-url)
3.2. Fuzzy system design
The first step in the fuzzy logic process for smart pots is to map the membership function of each sensor. The sensors used are temperature sensors, humidity sensors and soil moisture. In this research the types of plants used are spinach which can grow optimally in moist soil conditions (wet soil), the climate conditions needed for the growth of spinach is rainfall that reaches more than 1,500 mm / year, full sunlight, air temperature around 17 -28 ° C, and 50-60% air humidity [12]. Based on the above requirements the sensors used in smart pots are temperature sensors, soil moisture sensors and air humidity sensors [16].

3.2.1. Fuzzification

a. Temperature membership function
The plant can grow well in temperature conditions of 17-28 ° C. which is the normal temperature of the plant. The temperature of 0-8 ° C is set as the condition of the left shoulder of the cold temperature and the temperature of 45-50 ° C is the condition of the right shoulder of the hot temperature. The temperature sensor used can read from a range of 0-50 ° C [17].

\[
\mu_{\text{ColdTemp}}[x] = \begin{cases} 
1, & 8 \leq x \leq 0 \\
\frac{17-x}{17-8}, & 17 \leq x \leq 8 \\
0, & 45 \leq x \leq 50 
\end{cases} 
\]

\[
\mu_{\text{NormalTemp}}[x] = \begin{cases} 
0, & 8 \leq x \leq 0 \\
\frac{x-8}{17-8}, & 17 \leq x \leq 8 \\
1, & 28 \leq x \leq 17 \\
\frac{45-x}{45-28}, & 28 \leq x \leq 45 \\
0, & 45 \leq x \leq 50 
\end{cases} 
\]
\[ \mu_{\text{Hot Temp}}[x] = \begin{cases} 
0, & 0 \leq x \leq 28 \\
\frac{x-28}{17-8}, & 28 \leq x \leq 45 \\
1, & 45 \leq x \leq 50
\end{cases} \tag{3} \]

b. Humidity membership function
The plant can grow well in conditions of air humidity 50-60% which is the normal air humidity of the plant. 0-25% air humidity is determined as the condition of the left shoulder low humidity and 75-100% air humidity is the condition of right shoulder high humidity. The air humidity sensor used can read from a range between 0-100 [18].

![Humidity Membership Function](image)

**Figure 4.** Humidity membership function.

The functions used to map humidity sensor inputs into fuzzy sets are as follows:

\[ \mu_{\text{DryHumid}}[x] = \begin{cases} 
1, & 0 \leq x \leq 25 \\
\frac{50-x}{50-25}, & 25 < x \leq 50 \\
0, & 50 < x \leq 100
\end{cases} \tag{4} \]

\[ \mu_{\text{NormalHumid}}[x] = \begin{cases} 
0, & 0 \leq x \leq 25 \\
\frac{x-25}{50-25}, & 25 < x \leq 50 \\
1, & 50 < x \leq 60 \\
\frac{75-x}{75-60}, & 60 < x \leq 75 \\
0, & 75 < x \leq 100
\end{cases} \tag{5} \]

\[ \mu_{\text{WetHumid}}[x] = \begin{cases} 
0, & 0 \leq x \leq 60 \\
\frac{x-75}{75-60}, & 60 < x \leq 75 \\
1, & 75 < x \leq 100
\end{cases} \tag{6} \]

c. Soil moisture membership function
The plant can grow well in moist soil conditions. To get the value of soil moisture from the type of soil used during the experiment carried out data collection of soil moisture in 3 dry soil
conditions, given 120 ml of water (5 seconds the pump is on) or moist, and given water until the soil conditions become muddy or wet [19].

Figure 5. (a) Dry soil, (b) normal soil, (c) wet soil.

Figure 6. Soil moisture membership function.

The functions used to map soil moisture sensor inputs into fuzzy sets are as follows:

\[
\mu_{\text{DryMoist}}[x] = \begin{cases} 
1, & 0 \leq x \leq 230 \\
\frac{672-x}{672-230}, & 230 < x \leq 672 \\
0, & 672 < x \leq 1000 
\end{cases} 
\]  

(7)

\[
\mu_{\text{NormalMoist}}[x] = \begin{cases} 
0, & 0 \leq x \leq 230 \\
\frac{x-230}{672-230}, & 230 < x \leq 672 \\
1, & 672 < x \leq 716 \\
\frac{801-x}{801-716}, & 716 < x \leq 801 \\
0, & 801 < x \leq 1000 
\end{cases} 
\]  

(8)

\[
\mu_{\text{WetMoist}}[x] = \begin{cases} 
0, & 0 \leq x \leq 716 \\
\frac{x-716}{801-716}, & 716 < x \leq 801 \\
1, & 801 < x \leq 1000 
\end{cases} 
\]  

(9)
3.2.2. Evaluation rules

Table 1. Fuzzy basic rules.

| Rule | Temperature | Moisture | Humidity | Pump Status |
|------|-------------|----------|----------|-------------|
| Rule 1 | COLD | DRY | DRY | ON |
| Rule 2 | COLD | DRY | NORMAL | ON |
| Rule 3 | COLD | DRY | WET | ON |
| Rule 4 | NORMAL | DRY | DRY | ON |
| Rule 5 | NORMAL | DRY | NORMAL | ON |
| Rule 6 | NORMAL | DRY | WET | ON |
| Rule 7 | HOT | DRY | DRY | ON |
| Rule 8 | HOT | DRY | NORMAL | ON |
| Rule 9 | HOT | DRY | WET | ON |
| Rule 10 | COLD | NORMAL | DRY | OFF |
| Rule 11 | COLD | NORMAL | NORMAL | OFF |
| Rule 12 | COLD | NORMAL | WET | OFF |
| Rule 13 | NORMAL | NORMAL | DRY | OFF |
| Rule 14 | NORMAL | NORMAL | NORMAL | OFF |
| Rule 15 | NORMAL | NORMAL | WET | OFF |
| Rule 16 | HOT | NORMAL | DRY | ON |
| Rule 17 | HOT | NORMAL | NORMAL | ON |
| Rule 18 | HOT | NORMAL | WET | ON |
| Rule 19 | COLD | WET | DRY | OFF |
| Rule 20 | NORMAL | WET | DRY | OFF |
| Rule 21 | HOT | WET | DRY | OFF |
| Rule 22 | COLD | WET | NORMAL | OFF |
| Rule 23 | NORMAL | WET | NORMAL | OFF |
| Rule 24 | HOT | WET | NORMAL | OFF |
| Rule 25 | COLD | WET | WET | OFF |
| Rule 26 | NORMAL | WET | WET | OFF |
| Rule 27 | HOT | WET | WET | OFF |

Table 1 show fuzzy basic rules on the system. This table is a combination of all statuses based on the results of sensing sensors temperature, humidity and soil moisture. This rules will provide information to the water pump whether it should turn on or not.

These basic rules is based on the characteristics of spinach plants that require moist soil for life. Therefore, if used for other plants, this rule must be reviewed. Based on the reference, obtained moist soil conditions at soil moisture values of 672-716. To maintain soil moisture remains in humid conditions. The basic watering rule is set to flush if the moisture sensor reads dry values, because dry soil needs water. If the temperature of the heat-readable sensor and moisture sensor
reads the normal or dry value in the basic rule, the water pump conditions are set. This hot
temperature can cause dry soil conditions.

3.2.3. Defuzzification
The following is the output function that will give the crisp output value. This output value will then
determine whether watering is needed that will activate the pump or not.

\[
\mu_{\text{NonactiveOutput}}[z] = \begin{cases} 
0.5-z & 0 \leq z < 0.5 \\
0.5-0' & z \geq 0.5 \\
0 & 
\end{cases} 
\] (10)

For the rules with Non Active pump, the value of \( z = 0.5 \times (\text{NonactiveOutput}[z] \times 0.5) \). Where
\( \mu_{\text{NonactiveOutput}}[z] \) is the membership value of each rule with the condition of the pump is off with a
minimum implicit function.

\[
\mu_{\text{ActiveOutput}}[z] = \begin{cases} 
z-0.5 & 0.5 \leq z \leq 1 \\
1-0.5' & z \geq 0.5 \\
0 & 
\end{cases} 
\] (11)

For rules with active pump, the value \( z = (0.5 \times \mu_{\text{ActiveOutput}}[z]) + 0.5 \). Where \( \mu_{\text{ActiveOutput}}[z] \) is
the membership value of each rule with an active pump condition with a minimum implicit function.

Defuzyfication:

\[
z = \frac{\text{rule1}z1+ \text{rule2}z2+ \text{rule3}z3+ \ldots + \text{rule27}z27}{\text{rule1}+ \text{rule2}+ \text{rule3}+ \ldots + \text{rule27}} 
\] (12)

3.3. Testing scenario
System testing is done by comparing the growth of height and width of spinach plants between
conventional systems (manual watering) and automatic watering systems using fuzzy systems each
one. Observation of plant growth was carried out for 21 days by taking the height and width value
each day.
3.4. Result

At the beginning of the system testing, the spinach plants on Smart pot and regular pot has the same plant height and leaves width, i.e. 6 cm height and 2 cm width. The soil used in Smart pot and regular pot was andosol soil, which is the highland soil added with manure. Watering in Smart pot was conducted automatically by the system according to the data processed obtained from the sensing process, while the spinach plant in regular pot, was watered 1 time a day in accordance with the guidelines of spinach plants cultivation. After the plant tending for 21 days, it was obtained that there are differences in plant height and leaves width in Smart pot and regular pot. In the smart pot, the planted spinach reached 23 cm height plant and 6 cm width leaves. While in the regular pot, the spinach plant reached 19 cm height plant and 4.5 cm width leaves. Below is the results of the measurement of plants height conducted at the initial testing in the 21 days after testing.

![Figure 8. Growth of the plant.](image)

![Figure 9. Plant height day 1 (a) smart pot – 6cm (b) regular pot - 6 cm.](image)
4. Conclusion

From the results obtained, it is evident that the watering process of the plant can be carried out automatically with the help of sensors to acquire data on environmental conditions of plants such as temperature, humidity and soil moisture. The acquisition results obtained from the sensor are then processed using fuzzy systems to determine whether or not a watering process is needed. From the experiments carried out, it was proven that the comparison of plant growth on smart pots can at least grow well like those who use ordinary pots which are watered once a day, even grow better.

References

[1] Marnisa Ramdhani 2015 Perancangan Sistem Monitoring Tanaman Bandung : Fakultas Informatika, Universitas Telkom: Tugas Akhir
[2] Drashti Divani, Pallavi Patil, Prof Sunil K Punjabi 2016 Automated Plant Watering System *International Conference on Computation of Power, Energy Information and Communication (ICCPEIC)* India
[3] U N V P Rajendranath, Dr V Berlin Hency 2015 Implementation of an Automated Irrigation System *International Journal of Applied Engineering Research*
[4] LIU Dan, Sun Jianmei, Yu Yang, Xiang Jianqiu 2016 Precise Agricultural Greenhouses Based on the IRT and Fuzzy Control *International Conference on Intelligent Transportation, Big Data & Smart City (ICITBS)* China
[5] B Dorsemaine, J P Gaulier, J P Wary, N Kheir and P Urien 2015 Internet of Things: A Definition & Taxonomy *9th International Conference on Next Generation Mobile Applications, Services and Technologies* Cambridge pp 72-77
[6] Eleonora Borgia 2014 The Internet of Things vision: Key features, applications and open issues *Computer Communications* vol 54 pp 1-31
[7] Pradashgoud, et al Patil 2011 Computational Intelligence and Communication Networks (CICN) *International Conference on Wireless sensor network for precision agriculture*
[8] DFRobot 2016 DHT11 Temperature and Humidity Sensor (SKU: DFR0067)
[9] DFRobot 2016 DHT11 Temperature and Humidity Sensor (SKU: DFR0067)
[10] DFRobot 2017 PH meter (SKU: SEN0161)
[11] Arduino 2017 Getting Started Introduction
[12] Robert Faludi 2010 Building wireless sensor networks: with ZigBee, XBee, arduino, and processing *O'Reilly Media, Inc* ch 1 pp 1-5
[13] Oguz, Pelin and Gokhan Ertas 2013 Wireless dual channel human body temperature measurement
device International Conference on Electronics, Computer and Computation (ICECCO) pp 52-55

[14] A Saelan 2009 Logika Fuzzy Institut Teknologi Bandung Bandung

[15] AFirdaus 2011 Perbandingan Paid Hosting dan Free Hosting Berdasarkan Fasilitas Backup yang Ada Universitas Diponegoro Semarang

[16] I Y Masturi 2016 Prototipe Otomasi Pengendalian Kadar Air Berbasi Fuzzy Logic Telkom University Bandung

[17] W Aji 2017 Penerapan Internet of Things untuk Tanaman dalam Pot Menggunakan ePot (Smart Pot) Universitas Telkom Bandung

[18] Nicos H Mateou and George Andrew Zombanakis 2009 Fuzzy cognitive maps face the question of the Greek current account deficit sustainability pp 523-534

[19] Manuela Panoiu, Caius Panoiu, Raluca Rob, Loredana Ghiorghioni 2010 System based on fuzzy logic for maintain optimum environmental conditions in a fir tree greenhouse The 14th WSEAS international conference on Systems: part of the 14th WSEAS CSCC multiconference vol II

[20] Darpan Anand, Manu Pratap Singh, Manish Gupta 2013 Application of Rule Based Fuzzy Inference System in Predicting the Quality and Quantity of Potato Crop Yield in Agra The Third International Conference on Soft Computing for Problem Solving vol 258 pp 211-223

[21] Drashti Divani, Pallavi Patil, Prof Sunil K Punjabi 2016 Automated Plant Watering System International Conference on Computation of Power, Energy Information and Communication (ICCPEIC) India