Application to Determine Water Volume for Agriculture Based on Temperature & Humidity Using Wireless Sensor Network

M. Udin Harun Al Rasyid, Entin Martiana Kusumaningtyas, Fajar Setiawan
Politeknik Elektronika Negeri Surabaya (PENS)
udinharun, entin{@pens.ac.id}, ffsetiawan@yahoo.co.id

***Abstract*—Tomato plant needs an environment with proper temperature and humidity condition. Amount of water is a parameter to control temperature and humidity in the planted area. So it needs a system which can determine the water volume. This research's objective is to create a decision support system which can help human to determine the volume of water for tomato and monitors environment condition in wireless. These systems is consisting of Waspmote Agriculture sensor node as a data taker from environment and use the data as input to the fuzzy logic method for the decision support. The system can send sensor values to the database in server in real-time. From the result of experiments conducted, this system can help human to control the humidity for the tomato plants using wireless sensor network.**

***Keywords*—Wireless Sensor Network; fuzzy tsukamoto; tomato watering; temperature; humidity**

I. INTRODUCTION

Precision agriculture uses intelligent decision support system to manage the agriculture plant. The environmental parameters such as temperature and humidity can be collected using sensor nodes. Each node is equipped with sensors, memory storage, microprocessor, batteries, and wireless communication to communicate to other nodes [1].

Temperature condition is very essential for the growth of tomato plants. The most ideal temperature for germination phase ranged between 25-30ºC, while the ideal temperature for the formation of the fruit's color ranged between 24-28ºC. On the other hand, if the temperature is too high, it can cause damage on fruit. Meanwhile the necessary relative humidity for the tomato's growth is above 80%. Low relative humidity can interfere the fruit's formation [2].

As noted above, tomato plants have proper temperature and humidity requirements in order to grow and bear fruit. There are several ways to control the temperature and humidity in the plant's environment. The easiest way is by spray water around the leaves of plants. The water needs must be met appropriately in order to give the right temperature and humidity for the plants. Several factors are used to determine the need for water on tomato plants; these are the air temperature and humidity.

To be able to monitor the state of temperature and humidity accurately and continuously, we need a system that can monitor the state of environment. This system is able to pass data which is the air temperature and humidity in a form that can be understood by humans. Then these results will be used in further process to obtain the volume of water required in accordance with the current state of environment as well.

Wireless Sensor Network (WSN) is a sensor communication network which is wirelessly connected to monitor physical conditions such as particular environmental condition and healthcare condition at different locations between the sensor and processing the data [3-4]. Waspmote agriculture board provides features for monitoring multiple parameters in the agricultural environment. There are several types of sensors, such as temperature and humidity for air or soil. This sensor technology can help to monitor the state of the temperature and humidity of the farm environment so as to provide the proper data. The data obtained from the sensor will be processed to obtain precise information about the proper water volume for the tomato plants. The process used the information from human knowledge.

Several researches have been done related to agricultural environment monitoring condition using WSN. Shu-Ming et al. [5] proposed application of WSN to realize the precision water irrigation based on the acoustic emission signal. The system proposed cluster based multi-hop routing algorithm to reduce the energy consumption node for transmitting data. The accuracy and decision making is decided based on an adaptive weighted data fusion mechanism. The simulation results by using PowerTOSSIM show that the node energy consumption is reduced.

Lima et al. [6] developed simulation environment applied to irrigation on a soccer field's soil. The system identifies areas which have low humidity level through data captured by humidity sensors. The humidity levels below 30% means a dry soil or low humidity, a level from 30% to 70% represents a normal soil condition, and level more than 70% means a soaked soil or high humidity. Then, the system only irrigates the low humidity areas to keep the field in adequate humidity level and save water resources. Satyanarayana et al. [7] implemented a WSN connected to a central monitoring system in monitoring various parameters in agriculture such as moisture, temperature, and humidity. The system aims to evaluate the temperature and humidity value of soil condition.

Patil et al. [8] presented intelligent control for irrigation system using WSN for precision agriculture based on fuzzy logic. The irrigation pumps on or off is controlled according to the desired moisture level in water resources. The system aims monitor soil moisture, leaf witness, temperature, and humidity level efficiently to utilize water and electricity resource effectively. The MATLAB simulation results show that the efficient of irrigation, saving water, and, electricity are increasing. Chaudhary et al. [9] analyzed the use of programmable system on chip technology to monitor and control several parameters of green house. The parameters of green house contain temperature, humidity, and CO2 value from WSN. Plant growth is influenced by temperature since higher radiation level may give a higher temperature. It is necessary to control and adjust the temperature at optimal level by photosynthesis radiation.

Hussain et al. [10] described the use of sensor network for improved water management to utilize the rain water, increase crop productivity, and reduce the cultivation cost. The system deployed sensor nodes into clusters such that each cluster contains four sensor nodes. The sensors sense parameters such as water level, soil moisture, pest and disease, and chemical measurement. Each cluster works independently to reduce congestion, increase data reliability and reduce the time to transmit data to its destination. Khan et al. [11] proposed water irrigation system based on combination of WSN and fuzzy logic as a replacement a traditional system with binary control. The irrigation system consists of soil moisture, temperature sensors, and intelligent controller using fuzzy logic approach. The system considered an on off controller with sensing inputs from field such as temperature and moistures. The fuzzy logic calculation shows that the watering duration is lesser than that of without fuzzy controller, hence resulting in efficient utilization of water resources.

This paper aims to analyze an application that we made whether it can help control the humidity or not. The application can determine the volume of watering plants based on environment's temperature and humidity condition, the output of the application is a number which is the water volume based on fuzzy logic.

II. The System Design

A. System Architecture

An application to determine the watering volume for tomato plant based on temperature and humidity is developed using wireless sensor network as shown in figure 1. Agriculture sensor node is a device which is built from Humidity and Temperature Sensor, Waspmote Agriculture 2.0 Board, and Waspmote 802.15.4. This sensor node will be placed in the tomato plant's area to collect data which is temperature and humidity condition from the area. And then, there is a gateway which is Waspmote Gateway 802.15.4 connecting those sensor nodes with a PC server. This gateway will transfer the tomato plant's environment data from the sensor node to PC server. The PC server has a task to send the data to all clients which is connected to the server for real-time monitoring by the client. On the client side, we will see the output of the program. The output is a web page which is showing the water volume for watering the tomato plant. The user can save the watering data for record.

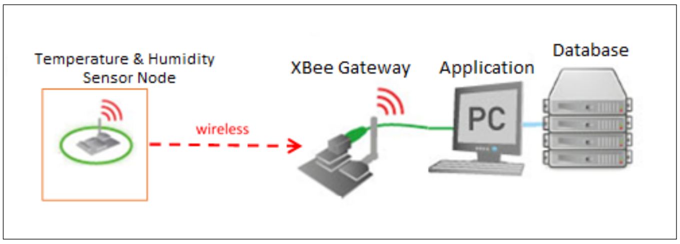

Figure 1. System Architecture

B. Component of the Project

The specifications of the hardware and software used in this paper are as follow:

a. Hardware

- Laptop ASUS A46CM
- Waspmote Agriculture Board, containing:
  - Humidity + Temperature Sensor (SHT75).
  - Waspmote Agriculture 2.0 Board
- Waspmote Starter Kit, containing:
  - Waspmote 802.15.4 Board.
  - Waspmote Gateway 802.15.4.
  - 2300 mAh Battery.
  - MiniUSB cable.

b. Software

- Windows 8.1 64-bit.
- Mozilla Firefox.
- Waspmote Pro IDE 4.
- VMware as server, with:
  - OS : Debian 7 64-bit.
  - Memory : 756MB.
  - Processors : 1.
  - Hard Disk : 15GB.

Figure 2 shows the installation of waspmote agriculture board on the plant area and figure 3 shows waspmote gateway installation on the PC server.

Figure 2. Waspmote Agriculture Board on planting area

Figure 3. Waspmote Gateway on PC Server

C. *Fuzzy Logic*

Fuzzy logic is a “counting” methodology with words as its variable (linguistic variable), instead of counting the numbers. Fuzzy logic is one of the fundamental parts of soft computing. It was first introduced by Lofti A. Zadeh, an Iranian scientist from the University of California at Berkeley in 1965.

Basic of fuzzy logic is fuzzy set theory. In the fuzzy set theory, the role of the degree of membership as a determinant of the presence of elements in a set is very important. Membership value or degree of membership becomes the main characteristic of reasoning by the fuzzy logic. In fuzzy logic there are four stages, namely:

1. Fuzzyfication: definition of fuzzy sets and determining the degree of membership of crisp input on a fuzzy set.
   For the fuzzification process, we used fuzzy sets that have been used in some existing studies with the same topic [8][11][12] and combine them to meet our system’s requirements.
   - Temperature variable

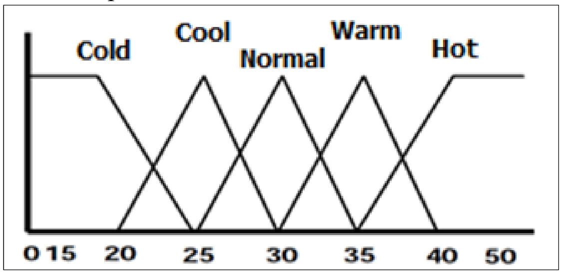

Figure 4 Temperature variable (on °C)

There are 5 members in the temperature collection, they are Cold, Cool, Normal, Warm, and Hot. Where,

- Cold = 15 °C – 25 °C
- Cool = 20 °C – 30 °C
- Normal = 25 °C – 35 °C
- Warm = 30 °C – 40 °C
- Hot = 35 °C – 50 °C

We use temperature value ranged from 15 °C - 50 °C, and then divide them into 5 members. The average range for each member is 10 °C. We create many member because temperature may vary widely, so we can get the right member for the calculation.

- Humidity variable

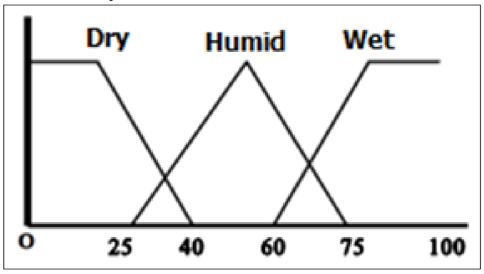

Figure 5 Humidity Variable (%RH)

There are 3 members in the humidity collection, they are Dry, Humid and Wet. Where,

- Dry = 0 %RH – 40 %RH
- Humid = 25 %RH – 75 %RH
- Wet = 60 %RH – 100 %RH

For the humidity variable, we create 3 members. The average range for member's values are 43%RH.

- Volume variable

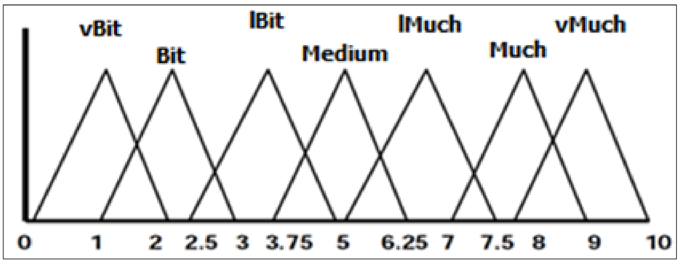

Figure 6 Valume variable (on 50mL)

There are 7 members in the volume collection, they are vBit, Bit, lBit, Medium, lMuch, Much, vMuch. Where:

- vBit (very bit) = 0 – 100 mL
- Bit = 200 – 150 mL
- lBit (little bit) = 125 – 250 mL
- Medium = 187.5 – 312.5 mL
- lMuch (little much) = 250 – 375 mL
- Much = 350 – 450 mL
- vMuch (very Much) = 400 – 500 mL

We create many member for the volume variable in order to give more precision in the application's output. The value's range for each member is varies from 100 - 125 mL.

2. Inference: evaluation of the rules to generate the output of each rule as shown in Table 1.

Table 1. Fuzzy rule

	Cold	Cool	Normal	Warm	Hot
Wet	vBit	Bit	lBit	Medium	lMuch
Humid	Bit	lBit	Medium	lMuch	Much
Dry	lBit	Medium	lMuch	Much	vMuch

For the fuzzy rule, we combine each member of temperature variable with each member of humidity variable. Each combination gives a result which is a member of volume variable using human reasoning. The reasoning is if the higher the temperature and the lower the humidity, the more water needed. Otherwise, the lower the temperature with higher humidity, the less water needed.

3. Composition: aggregation or a combination of the output of all rule.

4. Defuzzification: crisp output calculation.
The calculation is done by calculate average of all the z value with this formula: $z = \frac{\alpha_1 \times z_1 + \alpha_2 \times z_2 + \ldots + \alpha_n \times z_n}{z_1 + z_2 + \ldots + z_n}$
Where,
Z = the fuzzy output (water volume on 50 mL)
α_n = membership value for combination n
z_n = z value for combination n

Fuzzy method that will be used in this research is Fuzzy Tsukamoto method. In the Tsukamoto method, each consequent on the rules in the form of IF-THEN shall be represented by a fuzzy set with membership function monotonous [13]. As a result, the output of the inference of any rule is clearly given (crisp) based on α-predicate. The final result is obtained by using a weighted average. Since each rule infers a crisp output, the Tsukamoto fuzzy model aggregates output of each rule using weighted average and it can avoids the time-consuming defuzzification's process. Figure 7 illustrates a two-input single-output process of Tsukamoto model.

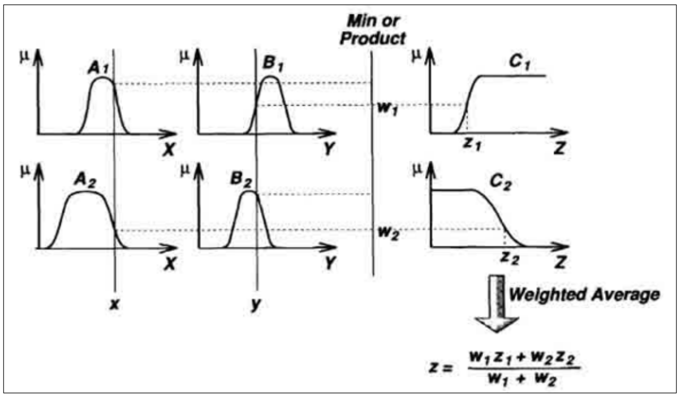

Figure 7. Fuzzy Tsukamoto model

D. MeteorJS and MongoDB

MeteorJS is an open-source real-time framework for javascript-based web application. MeteorJS is written using Node.js. MeteorJS is a cohesive development platform, a bundle of libraries and packages that are bound together as one to make a web-based application development process easier. This framework can be used to produces a cross-platform application, like web, Android, iOS. Meteor using DDP (Distributed Data Protocol) and publish-subscribe pattern to automatically share data changes to all connected client. For this project, we decided to use MeteorJS as its core because MeteorJS has an important feature which is called Live-page Updates. With this feature, the application can get the data changes without reload the page, so it can make faster data transactions if data inside database changed.

In this application, we integrates MeteorJS with MongoDB as its database. MongoDB is a document-based database with high performance, much space available and can run on small system. There are some difference terms or concepts between common sql and this database. A MongoDB hosts a number of databases. A database can hold a set of collections. Inside a collection there is a set of documents. A document is a set of key-value pairs. Documents have dynamic schema, it means that in the same collection do not need to have the same set on fields or structure, and in fields in a collection's document can have different types of data.

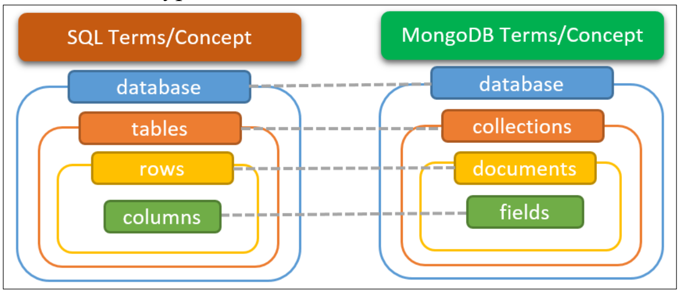

Figure 8. SQL and MongoDB concepts comparasion

E. Visualization Design

Figure 9 shows the main design of the application. The application has several main features. The features are can show the real-time chart and variable, show the needed water volume at that time and show the previous saved watering volume data. We are developing an application to determine the watering volume for tomato plant based on temperature and humidity using wireless sensor network. Agriculture sensor node is a device which is built from Humidity and Temperature Sensor, Waspmote Agriculture 2.0 Board, and Waspmote 802.15.4 uFL. This sensor node will be placed in the tomato plant's area to collect data which is temperature and humidity condition from the area. And then, there is a gateway which is Waspmote Gateway 802.15.4 uFL connecting those sensor node with a PC server. This gateway will transfer the tomato plant's environment.

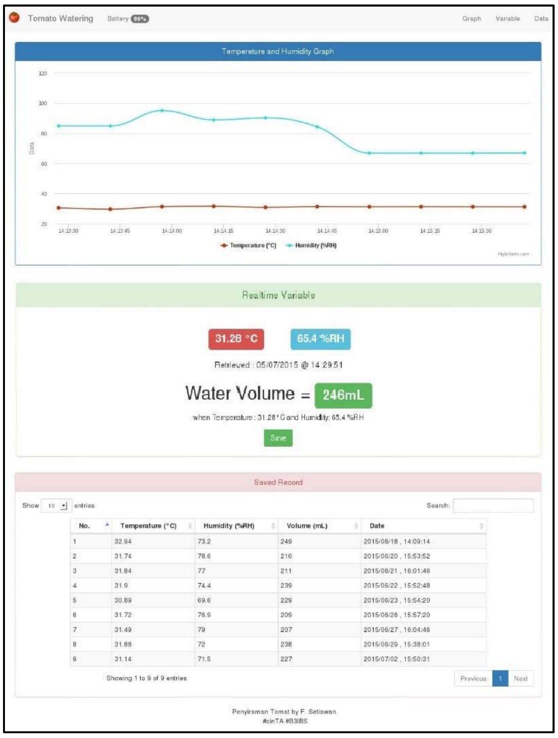

Figure 9. User Interface

From the figure 9 above, we can see some panels and menu. The first is the navigation bar, the navigation bar show the battery level and has button shortcut to the panels. The "Grafik" button is shortcut to chart panel, "Variabel" button is real-time variable panel, and "Data" is the shortcut to saved data panel. Here is the description of each panel:

1). "Temperature and Humidity Graph" Panel.

In this panel, we can see the graph of the value of temperature and humidity from the environment. We can switch the graph to see temperature value graph, humidity value graph, or both temperature and humidity value graph as we need.

2). "Realtime Variable" Panel.

This panel shows 4 things, the first is red label with the temperature value, the second is blue label with the humidity value, the third is the date and time when the data retrieved from the sensor node, and the last thing is the green label which is the water volume for the tomato plant watering. Beside these 4 things, this panel contain a green button which is the save button. The save button will save the temperature and humidity value, date and time, and the water volume.

3). Saved Record" Panel

This last panel will show a table which is contains the previous saved data from the database. In this table we can sort the data by the variable and we can search data as needed.

III. Performance Evaluation

In this performance evaluation section, we implemented the agriculture sensor node in the real tomato environment. The sensor node get data from the environment and then send it to the gateway in the server computer as shown in figure 10.

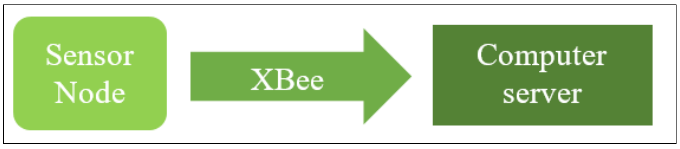

Figure 10. XBee Connection

A. Preparation

Before we test the sensor in application, we have to make sure that the sensor works fine. We test the sensor with serial monitor in Waspmote API. Figure 11 below is the result of the sensor readings with serial monitor. As we can see, the gateway receive data from the sensor node in frame.

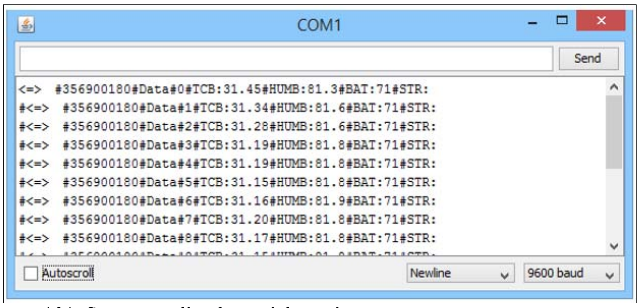

Figure 101. Sensor reading by serial monitor

After we make sure that the sensor node and the gateway works fine, we test the sensor with the application. Figure 12 below shows the sensor reading result from the application.

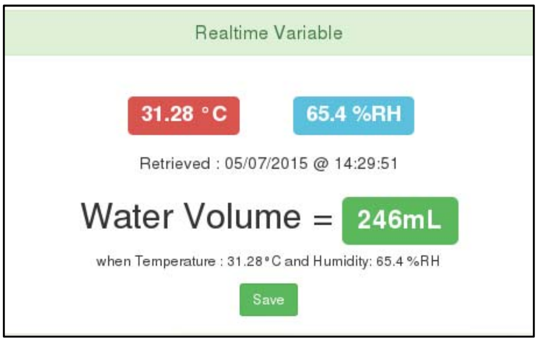

Figure 12. Sensor reading by application

From figure 12 above, we can see some informations. First is the value from the sensor and it also shows the date and time when is the data received by gateway from the sensor node. The last is water volume for watering in that condition. This panel has a "save" button, the button is used to save the sensor reading data, date and time, and also the water volume to the database.

B. The Environment

We didn't test the system in a big farm or environment. Our system is used for specific environment like a greenhouse. In our implementation, we used it in a small greenhouse. Here is the specification of the greenhouse:

- The dimension is 70cm x 90cm x 110.

- For the wall we used a plastic.
- The greenhouse frame is made from wood.

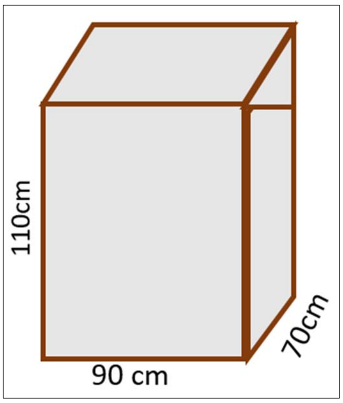

Figure 13. Greenhouse illustration

Seeding process to the process of planting is done inside this greenhouse. This greenhouse is placed in the shade and rather closed so that the air humidity around the plant is not easily influenced by external circumstances.

C. *Testing Flow*

We implemented the system on an environment with some conditions. Which are:

- The implementation is for a greenhouse with specifications stated before.
- Test is done only on one kind of environment.
- The testing are done in tomato's watering time. Which is between 3 – 4 p.m.

The testing in implementation phase has some steps. Here is the testing steps:

1. Place the sensor in the environment.
2. Run the application.
3. Record the humidity value before the watering.
4. Get the watering volume.
5. Spray water with amount as stated in application around the plant's leave.
6. Get and record the humidity value 30 minutes after the watering process.
7. Compare the humidity value before and after the watering process.

These are the environment conditions and testing steps for this system's implementation.

D. *Implementation result*

After doing several testing, we obtained the data as shown in table 2.

Table 2. Testing's result

No	Date	Humidity Before (%RH)	Humidity After (%RH)	Difference
1	28 June	73.2	89.8	16.6
2	29 June	78.6	90.7	12.1
3	30 June	77	90.3	13.3
4	1 July	74.4	89.6	15.2
5	2 July	69.6	89.2	19.6
6	3 July	76.9	91.8	14.9
7	4 July	79	96.5	17.5
8	5 July	72	90.8	18.8
9	6 July	71.5	81.2	9.7
10	7 July	78.6	92.1	15.5
Average		75.08	90.2	15.32

From the Table 2, we can see from the "Humidity Before" column that the humidity is too low for tomato at each watering time. After the watering is done, humidity raised above the 80 level. Also we can see that the humidity value always raised above 9 level. The most significant raise is on 2nd July which is 19.6 level. And the least raise is 9.7 level on 6th July. The average value of humidity before the watering process is 75.08 %RH, it means that humidity is always too low for the tomato. But the average of humidity value after the watering process is high, which is 90.2 %RH. The average humidity value raise is 15.32 level.

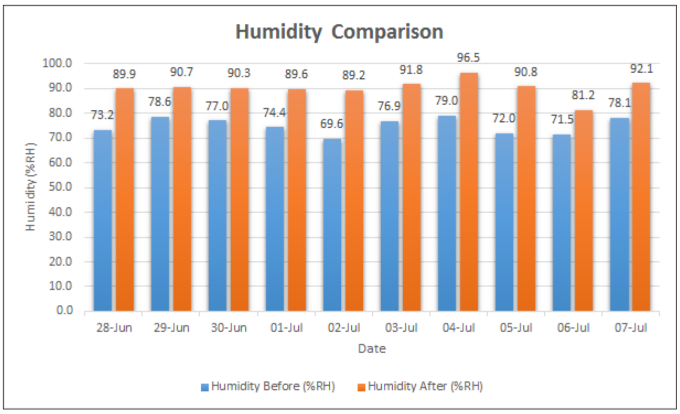

Figure 14. Implementation result on chart

Figure 14 is a chart of the humidity value before and after the watering process. We can see that before the watering process, the humidity is too low for tomato. After the watering process, the humidity raised until above the 80%RH. The humidity values after the watering process are almost similar, it is between 89%RH and 91%RH. Only on 27th June, the humidity value is very high, which is 96.5%RH. From thus experiment, we can say that the system can help human raise the humidity value in environment to suit the tomato's need.

Besides the watering process implementation, we also do another implementation with the aim of monitoring the state of temperature and humidity in the greenhouse from morning until afternoon, ie 8am to 4 pm. Implementation is done by putting sensor node in a greenhouse and then monitor the state of environment through a server/client and record the values at certain hours. Here are the results of the monitoring implementation.

Table 3. Monitoring result

No	Date	Time					
		8am		12am		4pm	
		Temp	Hum	Temp	Hum	Temp	Hum
1	8 July	26,27	90,6	31,34	84,3	28,47	89,3
2	9 July	27,33	89,4	31,95	82,9	27,36	90,5
3	10 July	28,76	89,8	33,34	82,7	29,65	88,2
4	11 July	27,86	93,3	30,58	85,9	28,33	93,3
5	12 July	27,74	91,3	31,74	84,8	28,34	91,5
Average		27,59	90,88	31,79	84.12	28,43	90,56

Table 3 is a table containing data from monitoring implementation. We did this implementation 5 times in the greenhouse. In the table, it can be seen that the recording of the values of temperature and humidity is done 3 times a day, ie at 8am, 12am, and 4pm. Can be seen in the 8am that the temperature and humidity are still suitable for tomato plants. Then at 12am, the humidity is low and the temperature is high due to the sun's heat during the day, but the humidity is still suitable for tomatoes since the humidity is still above 80%RH. At 4pm, the temperature and humidity become normal again because of the watering process.

In the table 3, it can be seen that the average temperature in the morning was 27.59°C and the average humidity is 90.88% RH. Then at noon, the average temperature was 31.79°C and the average humidity is 84.12% RH. In the afternoon, the average temperature in the greenhouse is 28.43°C while the average of humidity values is 90.56% RH. And the last, Table 4 shows the comparison of this paper to other related works.

IV. Conclusion

This paper explains the implementation of temperature and humidity sensor for agricultural environment which is tomato's plant area, and process the data to get the information about the watering volume to get the ideal humidity for tomato. We test the system on a greenhouse for several days. The experiments and analysis results show that this system is able to monitor environment's temperature and humidity values and it can help human to raise the humidity around the tomato's plant on a level which tomato needed. For further research, we plan to add more sensor to give additional variable for the fuzzy process in order to get more accurate water volume amount and add more sensor node so it can be applied to a larger environment.

References

[1] A.L. Diedrichs, G. Tabacchi, G. Grunwaldt, M. Pecchia, G. Mercado, F. G. Antivilo, "Low-Power Wireless Sensor Network for Frost Monitoring in Agriculture Research", IEEE Biennial Congress of Argentina, 11-13 June 2014.

[2] "Agroklimat Tomat," [Online]. Available: http://blog.faedahjaya.com/kabar-tani/agroklimat-tomat. [Accessed 31 June 2016].

[3] M.U.H. Al Rasyid, I.U. Nadhori, A. Sudarsono, Y.T. Alnovinda, "Pollution monitoring system using gas sensor based on wireless sensor network", International Journal of Engineering and Technology Innovation (IJETI), 2016.

[4] M.U.H. Al Rasyid, I.U. Nadhori, Y. Alnovinda, "CO and CO2 Pollution Monitoring Based on Wireless Sensor Network", IEEE International Conference on Aerospace Electronics and Remote Sensing Technology (ICARES), 3-5 Desember 2015.

[5] S-m. Xiong, L-m. Wang, X-q. Qu,Y-z. Zhan, "Application Research of WSN in Precise Agriculture Irrigation", International Conference on Environmental Science and Information Application Technology (ESIAT), 4-5 July 2009.

[6] G.H.E.L. de Lima, L.C. e Silva, P.F.R. Neto, "WSN as a Tool for Supporting Agriculture in the Precision Irrigation", International Conference on Networking and Services (ICNS), 7-13 March 2010.

[7] G. V. Satyanarayana, S.D. Mazaruddin, "Wireless Sensor Based Remote Monitoring System for Agriculture Using ZigBee and GPS", Conference on Advances in Communication and Control Systems (CAC2S), 2013.

[8] P. Patil, U. Kulkarni, B.L. Desai, V.I. Benagi, V.B. Naragund, "Fuzzy Logic Based Irrigation Control System Using Wireless Sensor Network for Precision Agriculture", Agro-Informatics and Precision Agriculture (AIPA), 2012.

[9] D.D.Chaudhary, S.P.Nayse, L.M.Waghmare, "Application of Wireless Sensor Networks for Greenhouse Parameter Control in Precision Agriculture", International Journal of Wireless & Mobile Networ (IJWMN), Vol. 3, No. 1, February 2011.

[10] R. Hussain, J.L. Sahgal, P. Mishra, B. Sharma, "Application of WSN in Rural Development, Agriculture Water Management", International Journal of Soft Computing and Engineering (IJSCE), November 2012.

[11] F. Khan, F. Shabbir, Z. Tahir, "A Fuzzy Approach for Water Security in Irrigation System Using Wireless Sensor Network", Sci.Int., 26(3), pp. 1065-1070, 2014.

[12] B. A. Handoko, Susanto and N. Wakhidah, "Automatic Irrigation Using Microcontroller ATMEGA 8 Based on Soil Moisture and Temperature with Fuzzy Inference System Method".

[13] Y. Tsukamoto, "An approach to fuzzy reasoning method," in Advances in fuzzy set theory and applications, M. M. Gupta, R. K. Ragade and R. R. Yager, Eds., Amsterdam, North-Holland, 1979, pp. 137-149.

Table 4. Comparison of this project to others related works.

No	Research	Type	Platform	Hardware	Methods	Input	Output
1	Ref. [6]	Monitoring System	Desktop	GPS, Sensors, Zigbee, GPRS, Solar panel	-	Sensor values	Display agricultural values
2	Ref. [7]	Simulation, Decision Support System	Desktop [MATLAB]	MEMSIC eKo Pro Series, ES1100 sensor, ES1201 sensor, Leaf Wetness sensor from	Fuzzy	Soil moisture, Leaf wetness, Temperature, Humidity	Maximum soil water deficit (time until next irrigation)

				Decagon			
3	Ref. [8]	Decision Support System	Hardware based	Zigbee, CY3271 PSoC First Touch Starter Kit	-	Temperature, CO_2, Light, Air and soil Moisture, pH value	System control acuter like pump, valve, fans, etc.
4	Ref. [9]	Idea, Decision Support System	-	Sensors	Sensor Clustering	Water level, Climatic change, Pest, Soil moisture	Water requirements
5	Ref. [10]	Simulation, Decision Support System	Desktop [MATLAB]	ES1100 sensor	Fuzzy	Soil moisture, Air temperature	System opens water's control valve
6	This Project	Decision Support System	Web base	Waspmote Agriculture 2.0, Waspmote Starter Kit	Fuzzy Tsukamoto	Air humidity and temperature	Water Volume for watering