A Fuzzy Logic Based Internet of Things (IoT) for Smart Water Bottle

1st Angga Edwin Wijanarko
School of Computing
Telkom Univrsity
Bandung, Indonesia
anggaedwin@alumni.telkomuniversity.ac.id

2nd Maman Abdurohman
School of Computing
Telkom University
Bandung, Indonesia
abdurohman@telkomuniversity.ac.id

3rd Aji Gautama Putrada
School of Computing
Telkom University
Bandung, Indonesia
ajigps@telkomuniversity.ac.id

***Abstract*— This paper proposes the smart water bottle system based on Internet of Things (IoT) using Fuzzy Logic method. This system has input data from water level and temperature levels. Various water levels and room temperatures are used to calculate the level of water consumption. The Fuzzy Inference System provides three classes, i.e. Low, Medium and High, which indicates user drinking requirements. Fuzzy results are selected according to the input given by the sensor for predicting water consumption, after generating the output directly sent to the server to be converted into a drink reminder notification. By using the fuzzy logic method, the prediction of the consumption of drinking water needed for daily activity is quite accurate and it can also be observed that the prediction model by fuzzy produces the appropriate output. This model is tested with a 3-hour notification period for one day and is able to predict water consumption. The result shows the effectiveness of smart water bottle system on predicting water consumption.**

Keywords—Smart water bottle, Fuzzy logic, Internet of Things, Fuzzy Inference System

I. INTRODUCTION

The benefits of drinking water are not as trivial as many people think [1]. The benefits of drinking water can prevent dehydration of the body. However, each person has their own way to meet the needs of body fluids, whether by consuming water or coffee, tea, soda, juice, soft drinks, energy drinks, even though the drinks mentioned earlier are classified as having high sugar and calories [2]. Calorie-free water and sugar are the healthiest choice to keep the body still having enough fluids, to overcome thirst.

Based on the problems that occur, the solution proposed in overcoming these problems is in form of a microcontroller-based prediction tool for calculating the water consumption needed by the body and then remind the user to drink, it can be called a smart water bottle. To predict the level of water consumption, we need to study the value of the input temperature and input level of the water level. Fuzzy logic algorithm is an appropriate way to map an input space into the output space. The workings of fuzzy algorithms is to make fuzzification, reasoning or input values to determine the output value as a form of decision making, making rule based on fuzzy logic control is a form of "If-Then" relation rule, input defuzzyfication is a fuzzy set obtained from the rule composition - fuzzy rules while the resulting fuzzy output is a number in the fuzzy set domain, so if given a fuzzy set in a certain range, a certain crisp value must be retrieved [3]. That is why the fuzzy algorithm was chosen in this paper.

An automatic drinking reminder, before this research, has already been conducted [4]. The research is conducted on elderlies in the age range of 50 to 60 years where sensitivity in feeling thirst is not so felt again, hence the requirement of the tool [5] [6]. High productivity can also cause the change of focus plus activity in an air-conditioned room is one that causes the body not to feel thirsty and experience lack of fluids [7].

To measure the success rate of the tool a series of tests will be conducted. Temperature sensor indicators and water level elevations in the bottle serve as measuring parameters in testing. The use of the Blynk application aims to be able to monitor thirst in realtime. Besides being able to send to Blynk, the smart water bottle tool can send a notification when it has obtained the fuzzy calculation result. The command is a reminder message that contains the level of water consumption that needs to be drunk.

The formulation of the problem in this paper is how to design, implement and test fuzzy logic on the system for water level indicators, room temperature sensors and how to test the success rate of the drinking reminder system.

The limitation in this paper is that the output produced by the indicator is that you need to drink a little, enough and a lot, the age and weight factors are not included in the testing factor, the contents of water in the bottle are people's needs that day the size used is ± 1.5 liters, fuzzy input parameters in this paper focus on room temperature and water level height in the bottle, to measure room temperature using LM35 sensor, to measure water level height using ultrasonic sensors (HCR-SR04), microcontroller communication using ESP8266 -12E NodeMCU wifi module, communication testing parameters are delay and packet lost, the IoT platform used is Blynk, overall system performance is measured in system notification accuracy.

The contribution of this paper is the smart water bottle system using fuzzy logic method based on IoT. This system aimed to prevent dehydrated.

II. RELATED WORKS

Previous research has raised a lot of topics about smart bottle models of hydration reminders to remind humans of adequate water intake in the body at the right time so that the body remains stable. The design of making a tool using sensors that have been connected to the microcontroller and GSM. From the results of the study, the sensor can be installed in a water bottle to measure water levels as low and high, the measurement results obtained will be sent to the microcontroller and then processed and forwarded to the GSM modem using the SIM card and will arrive at the smartphone [8]. Another research on Smart Water Bottle that can estimate and control the amount of liquid poured out of the bottle using a random injection and accelerometer [9]. Rapid measurement of the amount of liquid inside the bottle uses touch and photoplethysmographic sensors, from the results of studies evaluating the use of inertial sensors on bottles and smart-watches from use to detect activity patterns by identifying users [10].

In addition to research on the regulation of smart water bottles, there is research on the importance of water intake for health because it helps build respiratory resilience, especially among parents, even research has been conducted that older people around the age of 50 - 60 years rarely feel thirsty [11] [12] . There is also a research on the calculation of the decision maker for fluid deficiency using the fuzzy logic method wherein the study predicts the level of water consumption by using a function of individual weight, activity and weather which is one of the reasons why the authors chose the fuzzy logic method in their research [13] .

To find out the value of output from the smart water bottle, a monitoring tool is needed that can work in real-time. In this paper, Blynk was used. Blynk is an IoT platform that is used to monitor connected IoT devices [14]. Data storage can be done in real time as long as the device can connect to the internet network to upload data. Blynk can also accommodate a lot of data to store in different file formats.

III. System Built

In this section discusses the development of the system which will be contained in several sub-chapters including the overall modeling flow and system design.

A. Tool Specification

The specifications of a smart water bottle tool consist of 4 components, namely: ESP8266-12E NodeMCU, Arduino Uno, LM35 sensor and HC-SR04 (Ultrasonic) sensor. The LM35 sensor is a temperature sensor that is used to capture the temperature in the room while an ultrasonic sensor is used to capture the water level inside the bottle. Arduino Uno contains everything needed to support the microcontroller, but in this paper the author uses Arduino only as a 5v voltage provider for the needs of ultrasonic sensors [15]. NodeMCU is an ESP8266 type microcontroller which has a wifi module so that no additional modules are needed to connect with the internet or network [16]. This is the reason for choosing the tool to use. This microcontroller sends the captured value from the LM35 sensor and ultrasonic sensor to be sent to Blynk.

B. Room Spesification

The room used for data retrieval is a room measuring ± 10 x 3 meters or a boardroom area. The room used for testing is only one, data collection activities include: water level data collection and room temperature as well as testing data on the smart bottle. Each activity involving data collection was carried out in one room used during this research activity

C. Tool Design

Fig.1 provides an illustration of the Smart Bottle design. This illustration uses the real prototype of the system. The cap of the bottle is shown facing forward. So readers can get a better look at the design of the Ultrasonic Sensor, the sensor in charge of detecting the water level of the Bottle.

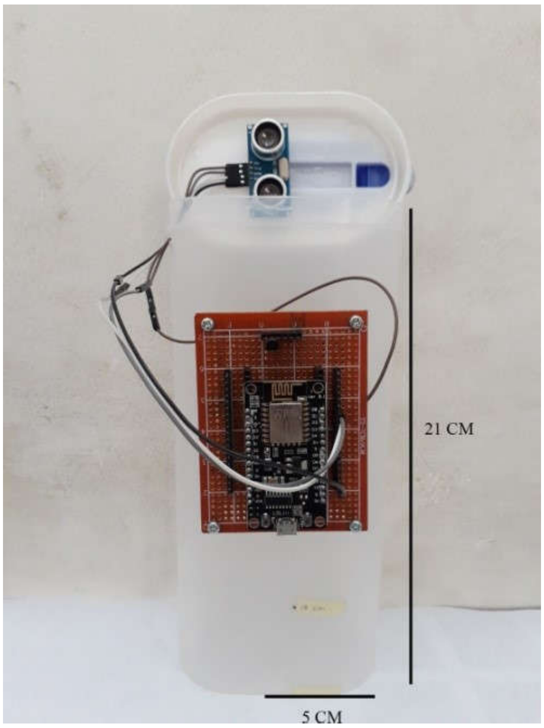

Fig. 1. Prototype of Smart Bottle.

The bottle used in this paper has a diameter of 10 cm and a height of 21 cm. The ultrasonic sensor is attached while the temperature sensor detects the bottle body along with the NodeMCU and Arduino microcontrollers.

This is only a prototype. So, aesthetic is not considered into the design. The design focuses on functionality. Functionalities to be considered are such as: designing how the cable of the ultrasonic sensor inside can connect to the microcontroller outside, without the bottle spilling any water when being tilt.

D. Flow Diagram

Fig. 2 contains the modeling flowcharts as it can be seen in the picture. The system starts by sensing the Temperature and the Water Level of the bottle. After, the Microcontroller runs the Fuzzy Logic, resulting into three possible inferences: Low, Medium, or High. This result is sent by the Microcontroller, with Wi-Fi capabilities, to the Blynk Server. The Blynk Server forwards the data to the smartphone, along with all the data history needed to be shown to the user.

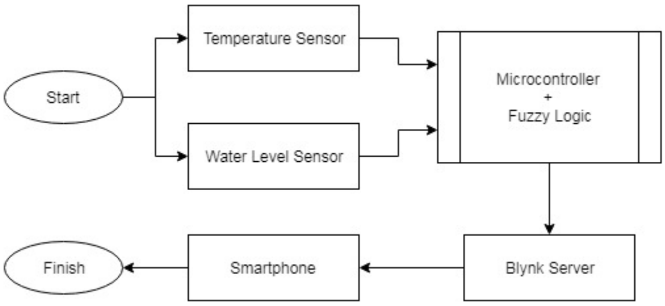

Fig. 2. Flow Diagram.

E. System Design

The overall system design can be seen in the fig. 3. The room temperature sensor used is the LM35 sensor, which is then tasked with capturing the room temperature while the water level sensor used is an ultrasonic sensor which is tasked to capture the height of the water level inside the bottle, then the results of the two sensors will be processed on the microcontroller using the fuzzy logic method. After the sensor data that has been received has been processed, the microcontroller will send a notification message to the Blynk server first then proceed to the Smartphone. The message tells the level of consumption of water that needs to be drunk.

IV. Evaluation

A. Test Scenario

Tests are carried out with the following preparation: data collection of room temperature and water level in the bottle. Retrieving test data and uploading data to Blynk and testing test data using fuzzy logic.

Retrieving data on room temperature and water level is both done by installing an LM35 temperature sensor and an ultrasonic sensor in the bottle. This data collection aims to be processed in fuzzy logic so as to produce 3 types of output, namely low, medium, and high.

B. Analysis

Analysis is carried out to determine the level of success of the built system. There are three analysis taken part in this paper: a. Fuzzy logic analysis, b. Defuzzyfication monitoring chart, and c. Fuzzy testing results. Fuzzy testing results is carried out to test all the fuzzy rules implemented

a. Fuzzy Logic Analysis

Fig. 4 contains a running flow diagram of the fuzzy logic system. It explains the workflow of fuzzy logic where the first step is making fuzzy rules, then the next step is fuzzyfication to determine the crisp value, proceed to the next stage, namely fuzzy inference to find the smallest and largest values generated before the process of fuzzyfication, step last defuzzyfication to produce data output. Here's the fuzzy process that runs on the system.

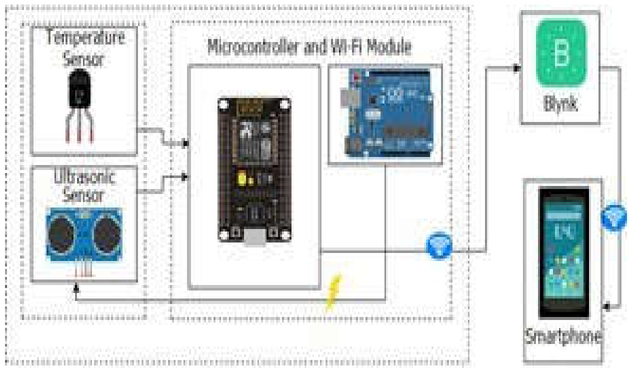

Fig. 3. System Design.

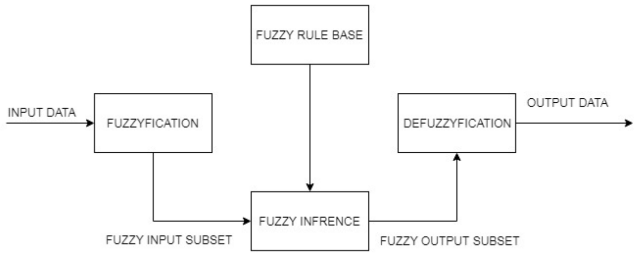

Fig. 4. Fuzzy Logic System.

- Fuzzyfication

To find the crisp value where the input comes from the ultrasonic sensor (x) and the LM35 (y) sensor. For example, input from the ultrasonic sensor and LM35 sensor as shown in Fig. 5, the process of finding the crisp value is as follows :

Crisp Value for Water Level :

$$\mu\text{Medium} = -(x-b)/(b-a), a < x \leq b = j \quad (1)$$

$$\mu\text{Near} = (x-a)/(b-a), a < x < b = j \quad (2)$$

Crisp Value for Room Temperature:

$$\mu\text{Warm} = -(y-f)/(f-e), e < x \leq f = i \quad (3)$$

$$\mu\text{Normal} = (y-e)/(f-e), e < x < f = i \quad (4)$$

So, the fuzzyfication process produces four fuzzy inputs: Water Level = Medium (x) and Near (x), and Room Temperature = Warm (y) and Normal (y).

- Inference

Fuzzy inference designed is divided into 3, namely: low, medium, and high. Fig. 6 shows the defuzzyfication graphic containing the three results.

The rule base is designed as follows:

1. If the Water Level is near and the Room Temperature is normal, then it is included in the Medium category.
2. If the Water Level is near and the Temperature of the Room is warm, then it falls into the High category.
3. If the Water Level is near and the Temperature of the Room is hot, then it falls into the High category.
4. If the Water Level is medium and the Room Temperature is normal, then it falls into the Low category.
5. If the water level is medium and the room temperature is warm, then it falls into the Medium category.

6. If the water level is medium and the room temperature is hot, then it is in the High category.

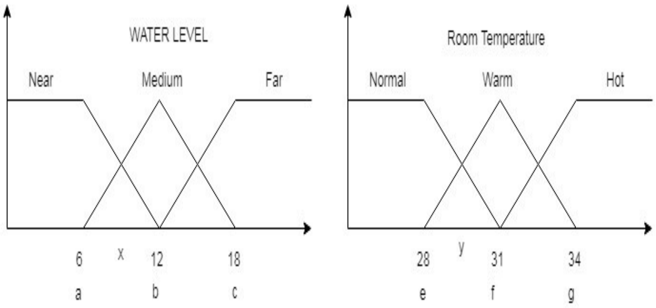

Fig. 5. Fuzzyfication.

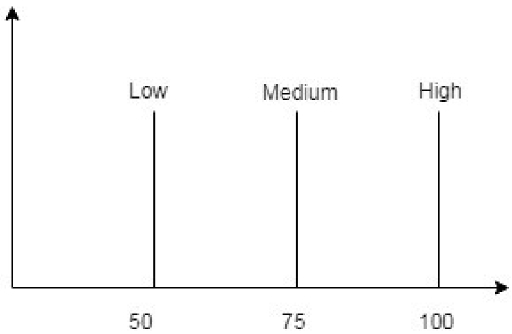

Fig. 6. Inference.

7. If the Water Level is far and the Room Temperature is normal, then it falls into the Low category.
8. If the water level is far and the room temperature is warm, then it falls into the Low category.
9. If the water level is far and the room temperature is hot, then it falls into the Low category.

Table 1 is a rule base that will be programmed in the NodeMCU microcontroller. From these parameters, there are 3 sets of output membership functions, namely low, medium, high.

With the definition of fuzzy rules in Table 1 then use conjunction rules by selecting the minimum membership degree from the linguistic value associated:

• IF Water Level Medium (j) AND Room Temperature Normal (i) THEN Botol is Low (i / j) takes the smallest value

TABLE I. FUZZY LOGIC RULES

Water Level	Temperature		
	Normal	***Warm***	***Hot***
Near	Medium	High	High
Medium	Low	Medium	High
Far	Low	Low	Low

• IF Water Level Far (j) AND Room Temperature Warm (i) THEN Botol is Low (i / j) takes the smallest value

Use the disjunction rule by selecting the maximum membership level from the linguistic values associated:

• Bottle is Low (i / j) (v) Bottle is Low (i / j)

- Defuzzyfication using Sugeno model

Defuzzyfication process produces fuzzy set, Bottle is low (i / j). If using the height method for the defuzzification process, refer to the previous equation:

Defuzzyfication = (α rule [0][0] x medium)+ (α rule [0][1] x low)+ (α rule [0][2] x Low)+ (α rule [1][0] x High)+ (α rule [1][1] x medium)+ (α rule [1][2] x medium)+ (α rule [2][0] x high)+ (α rule [2][1] x high)+ (α rule [2][2] x medium) / rule[j][i] (5)

b. Defuzzyfication Monitoring Chart

Based on the results of the second reasoning the sensors can be seen in the graph above. The way the fuzzy logic test works is by reading the data that has entered. Every 1 record of data that has been entered and processed in fuzzyfication including mapping values according to the degree of membership that has been made, after the stage of fuzzyfication then enter the fuzzy rule or inference to find out the results obtained from the fuzzyfication entered in this inference knowing where the rule is, the last step taken is the process defuzzyfication. Fig. 7 Provides explanation of the relationship between the Fuzzy inputs and the Defuzzyfication result.

c. Fuzzy Testing Results

Table II. shows the results of testing using fuzzy. In the Table it can be seen that all possible inputs are tested. The test results are fluctuating, this is indicated by the results of defuzzyfication obtained during different tests where the values of the two parameters namely water level and room temperature are very influential to determine the defuzzyfication value.

TABLE II. FUZZY LOGIC RULE RESULT

Water Level	***Tempaertaur Sensor***	***Defuzztfication***	***Bottol is***
21.17 Cm	26.1 ^{0}C	50	Low
20.76 Cm	26.1 ^{0}C	50	Low
20.31 Cm	27.39 ^{0}C	50	Low
20.31 Cm	26.43 ^{0}C	50	Low
19.86 Cm	27.39 ^{0}C	50	Low
17.11 Cm	28.36 ^{0}C	51.8	Medium
17.08 Cm	28.36 ^{0}C	51.8	Medium
17.08 Cm	28.36 ^{0}C	51.8	Medium
10.27 Cm	29.97 ^{0}C	74.12	Medium
10.27 Cm	30.29 ^{0}C	75	Medium
10.27 Cm	30.94 ^{0}C	81.4	High
9.86 Cm	30.29 ^{0}C	77.05	High
9.86 Cm	30.94 ^{0}C	83.05	High
3.95 Cm	28.68 ^{0}C	68.18	High
3.06 Cm	28.36 ^{0}C	65.49	High

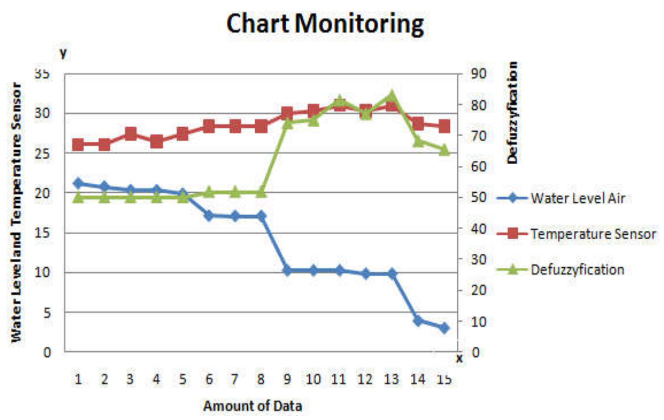

Fig. 7. Fuzzy Logic Chart.

C. Sensor Data Uploaded to Blynk

The Blynk application is an IoT platform which has several features, one of which is monitoring, so that data from the LM35 sensor and ultrasonic sensor can be directly seen in the Blynk application, along with the results. Fig. 8 shows the display shown in the IoT user application

The data uploaded to the Blynk application uses a NodeMCU microcontroller device so that it can be connected correctly and in accordance with the data in the Arduino IDE serial monitor. This data will later be processed in fuzzy logic to calculate its value whether it is in the low, medium and high categories.

On the Blynk graph shows the temperature sensor gets a consistent number which is around 31 ° C while the ultrasonic sensor value is inconsistent because it is adjusted to the condition of the water that will continue to decrease, in the picture above shows the ultrasonic sensor at number 17 Cm. After that the next step is processing the 2 sensor input data in fuzzy logic so that it can produce a value which will then be sent back to Blynk as a notification that can remind the user to drink.

Fig. 8 shows an example of one notification of a total of 3 notifications that will be used in this paper, namely (a). You need to drink a lot of water is a condition where the results of processing fuzzy algorithms are high (b) the second notification is You need to drink enough water where the condition explains when the fuzzy algorithm produced is in the medium value (c) the resulting notification is You need to drink a little bit this condition explains the fuzzy algorithm produced is low. Meanwhile, Fig. 9 shows all type of notifications.

D. Analysis of Data Testing Results

Testing is an activity to measure the level of success in a system that has been built with the aim of knowing whether the system works correctly or not. The data taken is based on the latest test in the Blynk application. In testing that has been done with the fuzzy algorithm, the results are obtained according to the rules that have been made, namely low, medium, and high.

Fig. 8. Blynk Application Display.

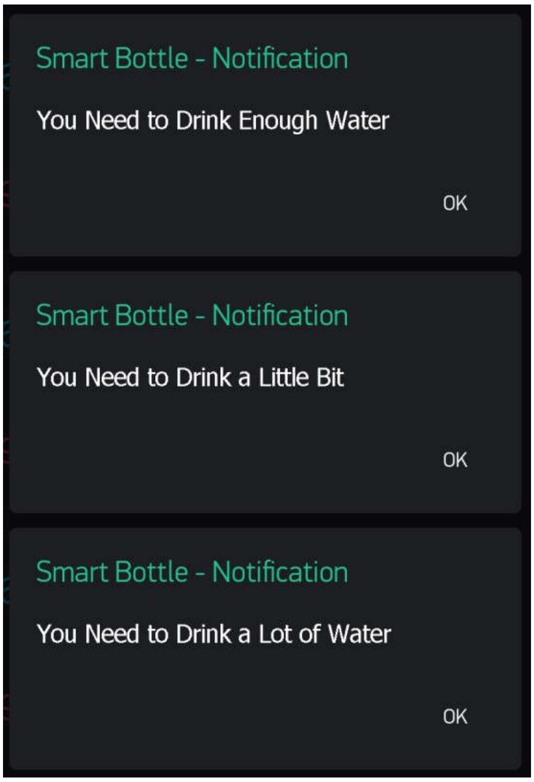

Fig. 9. Notifications.

The results of the tests are then adjusted to the appropriate notification, where if the results of the fuzzy algorithm produce a low value which means that the prediction of the level of consumption of water that must be drunk is a little with notification on the smartphone “You need to drink a little bit”, while for medium values the level of consumption of water that must be drunk is sufficient, the notification issued is “You need to drink enough water” and the last condition is high indicates a prediction of the level of consumption of water that must be drunk is a lot then the notification generated to the application Blynk is “You need to drink a lot of water”. With the results obtained in the test, the results of this test are appropriate.

V. Conclusion and Future Work

Smart water bottle system has been implemented using a microcontroller and two sensors. The device can capture the room temperature and measure water level. The smart water bottle system has been integrated with the IoT Blynk platform so that the value of the sensor can be monitored clearly. The results provided are also in accordance with the rules that have been made, namely low, medium and high. The purpose of the low itself is the prediction of the level of consumption of water that must be drunk is small, while the prediction medium level of consumption of water to drink is sufficient, and the last high indicates predictions of the level of consumption of water to drink is a lot. Based on the experiment results, it can be concluded that the use of fuzzy logic algorithm is appropriate in this paper. The results that have been obtained will be inserted into a push notification sent to the user from the Blynk application that has been previously integrated with a smart water bottle tool.

Based on the testing in the previous chapter and the above conclusions, there are still shortcomings that must be corrected. The fuzzy algorithm used in this study is indeed as expected, but it is possible that other algorithms can also be applied in this study. Using the IOT platform that is used is less responsive or still has a long enough delay, and can display more accurate measurements. In addition, the use of Arduino Uno can be replaced by using a power shield to reduce the costs incurred in the study. Can be added to the prediction parameters of dehydration to complete the functionality of the smart water bottle tool. It is expected that further research can develop both in terms of functionality or algorithms that are more suitable so that better results are obtained.

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References

[1] dr. Allert Noya," Don't underestimate the benefits of drinking water," Alodokter, [Online]. Available : https://www.alodokter.com/jangan-remehkan-manfaat-air-putih.[Accessed 20 November 2018].

[2] Jennifer Alexis Tanjung," This is what will happen if you rarely drink water!," POPBELA, 30 Agustus 2018. [Online]. Available: https://www.popbela.com/beauty/health/jennifer-a-tanjung/efek-jarang-minum-air-putih/full.[Accessed 20 November 2018]

[3] Suyanto, S.T.,MSC, Artificial Intelligence, Bandung: Informatika, 2011

[4] Dr.P.B. Pankajavalli, Mr. R. Saikumar and Mr.R.Maheswaran,"Hydration Reminding Smart Bottle : IoT Experimentation," *Internastional Confrence on Inovation in Power and Advanced Computing Technologies (i-PACT)*, 2017.

[5] Nam Eui Lee, Tae Hwa Lee, Seo Dong Heui, Sung Yeon Kim , "A Smart Water Bottle for New Seniors: Internet of Things (IoT) and Health Care Services," *International Journal of Bio-Science and Bio-Technology ,* vol. 7, pp. 305-314, 2015.

[6] Nam Eui Lee, Tae Hwa Lee, Seo Dong Heui, Sung Yeon Kim , "Healthcare Services and a Smart Water Bottle for Early Seniors: A Design Concept Based on a GoalDirected Design Process," *Advanced Science and Technology Letters,* vol. 88, pp. 200-203, 2015.

[7] Kompasiana," Beware, the AC Room is Prone to Cause Dehydration! ," Kompasiana, 26 Juni 2015. [Online]. Available : https://www.kompasiana.com/ronnyfauzi/550077caa33311e07251106b/awas-ruang-ber-ac-pun-rawan-sebabkan-dehidrasi. [Accessed 20 November 2018].

[8] Dr.P.B. Pankajavalli, Mr. R. Saikumar and Mr.R.Maheswaran,"Hydration Reminding Smart Bottle : IoT Experimentation," *Internastional Confrence on Inovation in Power and Advanced Computing Technologies (i-PACT)*, 2017.

[9] Arinobu Niijima, Takahiro Kusabuka, Soiciro Uchida and Tomoki Watanabe,"Smart Bottle Cap: Controlling Liquid Flow from a Bottle with a Smartphone," *International Confrence on the Internet of Things*, 2015.

[10] Emil Jovanov, Vindhya R. Nallathimmareddygari and Jonathan E. Pryor,"SmartStuff : A Case Study of a Smart Water Bottle,"2016.

[11] Nam Eui Lee, Tae Hwa Lee, Seo Dong Heui, Sung Yeon Kim , "Healthcare Services and a Smart Water Bottle for Early Seniors: A Design Concept Based on a GoalDirected Design Process," *Advanced Science and Technology Letters,* vol. 88, pp. 200-203, 2015.

[12] Nam Eui Lee, Tae Hwa Lee, Seo Dong Heui, Sung Yeon Kim , "A Smart Water Bottle for New Seniors: Internet of Things (IoT) and Health Care Services," *International Journal of Bio-Science and Bio-Technology ,* vol. 7, pp. 305-314, 2015.

[13] Zekai Sen, Abdusselam Altunkaynak,"Fuzzy System Modelling of Drinking Water Consumption Prediction," Expert Systems with Application 36 (2009)11745-11752

[14] Secure Instrument," Using the Blynk Application on ESP8266," Secure Instrument, 5 Mei 2017. [Online]. Available : http://secureinstruments.blogspot.com/2017/05/menggunakan-aplikasi-blynk-pada-esp8266.html.[Accessed 29 November 2018].

[15] Muhammad Ichwan, Milda Gustiana Husada, M.Iqbal Ar Rasyid," Construction of a prototype of an electrical equipment control system on the Android platform," *Jurnal Informatika*, vol. 4, Januari-April 2013.

[16] H. Yuliansyah," Wireless Data Sending Performance Test Using ESP8266 Module Based on Rest Architectur,"vol. 10, 2016.