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A Study of Embedded Fuzzy Logic to Determine Artificial Stingless Bee Hive Condition and Honey Volume

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ABSTRACT

Stingless Bee is particularly nutrient-dense in his honey. Therefore, numerous beekeepers for the Stingless Bee have begun this agricultural enterprise, particularly in Malaysia. However, beekeepers encounter challenges when caring for an excessively large stingless bee colony. Due to the risk of causing colony disruption, the beekeeper cannot always access the hives to monitor honey volume and hive condition. Consequently, the purpose of this paper is to aid beekeepers and prevent disruption to bee colonies by determining the condition of the hive and the quantity of honey using an embedded fuzzy logic system. Artificial hives have been created in order to easily measure the weight of a hive of stingless bees and to divide the honey compartment from the brood compartment in order to calculate the honey volume. Since the stingless bee designs its colony with honey on top and larvae on the bottom, honey volume can be determined by weighing the honey compartment using load cell and internal humidity using dht22. DHT22 is used for measuring the internal temperature and humidity, as previous papers have stated that the hive condition can be determined using the internal temperature and humidity. Morever, FLDa (Fuzzy Logic Designer app) by MATLAB was subsequently utilised to construct membership function, rules, fuzzification, and defuzzification. Then, the same input, membership function, and rules that used in FLDa will be implemented on the Nodemcu ESP8266 using eFLL (Embedded Fuzzy Logic Library). A comparison between the crisp output from FLDa and the crisp output from eFLL was conducted to determine whether eFLL is suitable for use in the NodeMCU ESP8266. As a consequence, the standard deviationand averaged percentage error of differences for hive condition, which is 0.22 and 0.17%, isless than the honey volume, which is 0.49 and 0.66%, because hive condition has a strict correlation with temperature. The hive condition will be rated bad (0% when the temperature is cold or hot state), but it will be rated good (100% when the temperature is normal state). As for honey volume, the majority of results correspond to the percentage of honey compartment weight, unless the humidity is dry state, which will cause the value to be cut in half. Finally, the fuzzy logic system is effectively implemented into an embedded system, making it easier for the beekeeper to monitor the hive condition and honey volume without interfering with the activity of stingless bees.

Keywords: Embedded Fuzzy, Stingless Bee Hive, Artificial Hive

1. INTRODUCTION

Meliponini is the family that contains stingless bees, and within this family are the subfamilies Melipona, Trigona, and Heterotrigona Itama [1]. The Heterotrigona Itama bee is more commonly known as the Lebah kelulut bee in Malaysia. Honey produced by stingless bees is renowned for its exceptional quality and serves as a source of essential nutrients for both humans and other animals [2]. They continue to sell a large quantity of honey, which is in high demand. Multiple conditions, such as diabetes, high blood pressure, and eye infections, have been shown to be treatable with honey [3], [4]. Compared to stinging bees, stingless bees are significantly less common and pose no threat to humans. Since it does not have a sting, it can be grown in almost any environment.

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Stingless bees are sensitive to changes in the environment, particularly in terms of temperature, humidity, and surrounding honey availability [5]–[9]. Therefore, observing the condition of the colony's hive and its honey production are two major concerns of the researchers. Traditionally, monitoring stingless bee activity relied frequently on manual inspection [10], [11]. However, using manual methods to monitor the behavior of honey bees was found to have numerous drawbacks. For instance, the development of a colony of stingless bees will be halted if frequent inspections are conducted to determine honey volume and hive condition.

Several previous publications have used weight, temperature, and humidity to construct fuzzy logic systems. The correlation between temperature and humidity, according to Wardhany et al. [12], is used to determine the condition of the hive. Meanwhile, Kviesis et al. [13] state that temperature data is sufficient for detecting a number of significant honey bee colony states. Checchi et al. [14] proposed using temperature and fuzzy logic to identify colony state. In addition, the study demonstrates that the time variation of weight may indicate the colony's productivity as well as its health and well-being. However, these studies are conducted on honey bees due to the lack of studies on fuzzy logic's application to stingless bees. In addition, research on honey volume has not yet been found due to the complication of measuring only honey within the hive. To determine the honey volume and the condition of the hive, an embedded fuzzy logic system is devised in this study. The embedded fuzzy logic system will initially be created using the FLDa (Fuzzy Logic Designer app) by MATLAB. After constructing inputs, outputs, membership functions, and rules with this app, the Fuzzy System will be implemented on the Nodemcu ESP8266 using the same inputs, outputs, membership functions, and rules. Artifical hive have been constructed to readily measure the weight of the stingless bee hive and to separate the honey compartment from the brood compartment in order to determine the honey volume. Luckily, the stingless bee designs its colony with honey on top and brood on the bottom. Inorder to measure the weight of the honey compartment, the weight sensor is positioned above the brood compartment and below the honey compartment. Furthermore, load cells and DHT22 sensors are used to measure the honey compartment's weight and internal temperature and humidity, respectively.

2. METHODOLOGY

Using FLDa, the fuzzy logic system is constructed as the first step in this study's methodology. The method describes the entire transformation of crisp input into crisp output. The same parameters and linguistic variables are then applied to the development of embedded fuzzy logic. The embedded fuzzy logic system was developed using the eFLL (Embdedded Fuzzy Logic Library) on NodeMCU ESP8266. Using equations (1) through (4), it is possible to calculate the eligibility of the eFFL on NodeMCU EP8266 by comparing the results obtained using DFLa and eFFL.

$$Difference, \Delta = Reference\ Value, u_{Rf} - Reading\ Value\ u_{Rd} \tag{1}$$

$$Average, \bar{X} = \frac{\sum Sample\ value, X}{No.of\ Sample, n} \tag{2}$$

$$Percentage\ Error, \delta = \left| \frac{u_{Rf} - u_{Rd}}{u_{Rf}} \right| . 100\% \tag{3}$$

$$Standard\ Deviation, S = \sqrt{\frac{\sum (X_i - \bar{X})^2}{Sample, n - 1}} \tag{4}$$

2.1 Fuzzy Logic

To facilitate the design and evaluation of fuzzy sets and membership functions, FLDa is used for the initial development. Figure 1 depicts the Type-1 Mamdani fuzzy inference system used in this study. This step enables us to obtain valuable insight into the relationships between inputs and outputs, thereby making the subsequent implementation on NodeMCU ESP8266 more effective and efficient. Fuzzification, Rule Evaluation, and Defuzzification are the three steps necessary to create a Fuzzy Logic System [15].
The Overview Block Diagram for the constructed Fuzzy Logic System is depicted in Figure 2 for a comprehensive understanding of the system. The fuzzy logic system is comprised of three primary processes: fuzzification, fuzzy inteference, and defuzzification. Fuzzification involves transforming cript input data into a fuzzy set based on a membership function (determined based on the range of input data and linguistic terms). Regarding fuzzy inteference, the fuzzy rule will be utilised to transform an input fuzzy set into an output fuzzy set. Defuzzification concludes with the transformation of the output fuzzy set based on the membership function (which has been determined based on the output data range and linguistic terms).

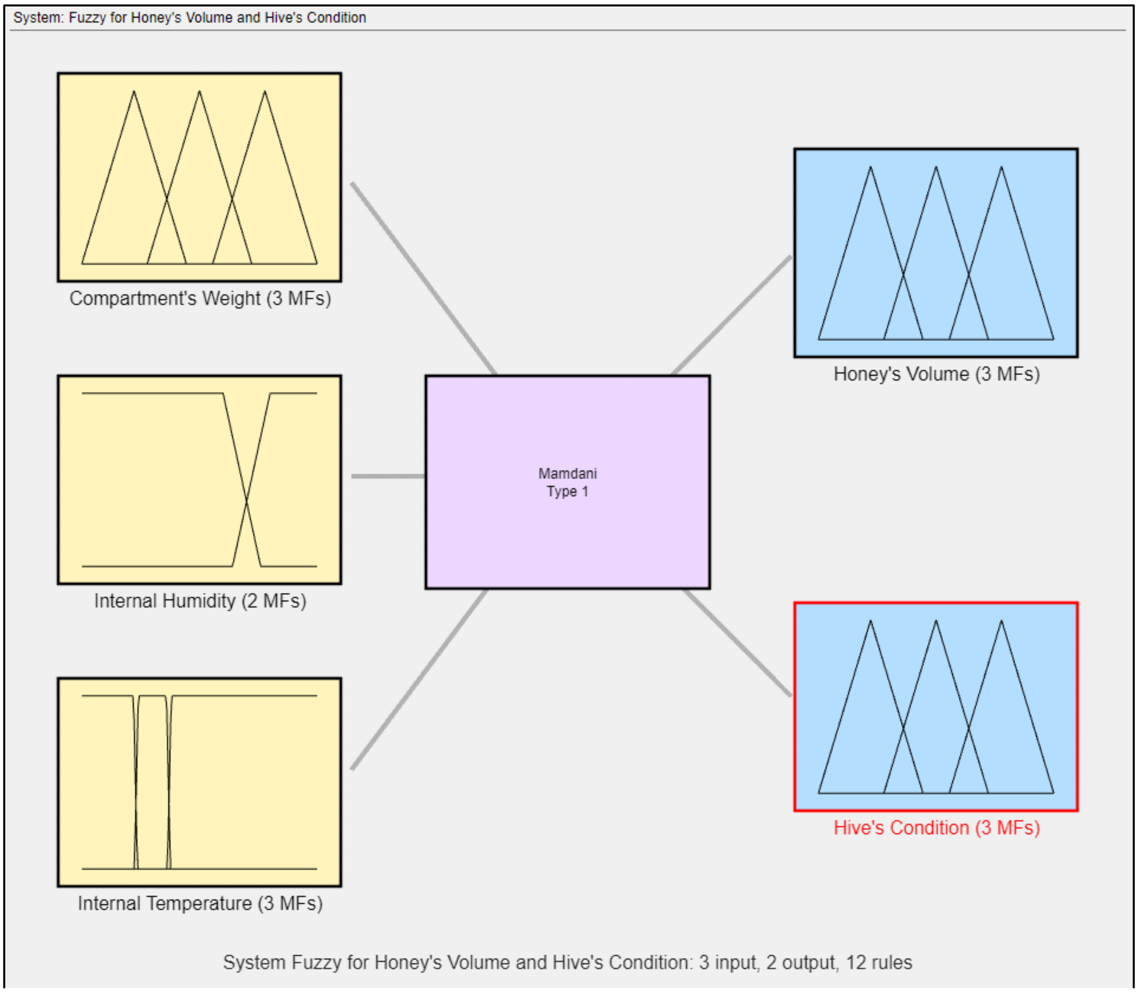

Figure 1. System Fuzzy for Honey Volume and Hive Condition

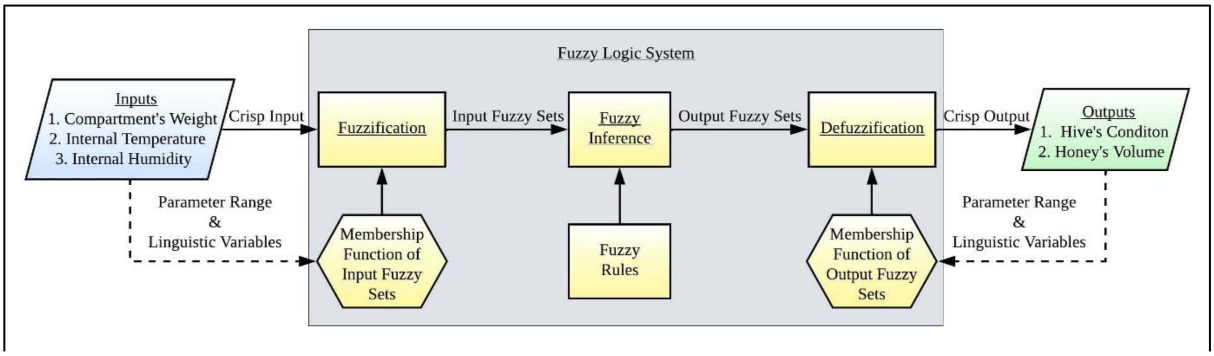

Figure 2. Block Diagram for Fuzzy Logic System

2.1.1 Variables and Range

In general, this experiment employs five base variables, of which three are inputs and two are outputs, as shown in Table 1. The compartment's weight, internal temperature, and humidity are the three input variables. Meanwhile, two output variables are the condition of the hive and the volume of honey. There are three linguistic variables for the weight of a compartment: light, average, and heavy. Cold, normal, and hot are the three linguistic variables for internal temperature. Dry and moist are the two linguistic variables for internal humidity. There are three linguistic variables for the condition of the hive: bad, moderate, and good. Lastly, there arethree linguistic variables pertaining to honey volume: low, medium, and high.
The three inputs are Honey Compartment Weight, Internal Temperature, and Internal Humidity. Moreover, two outputs consist of Condition of Hive and Honey Volume in Honey Compartment. There are several explanations why the maximum and minimum ranges for each variable are determined. For Weight's Compartment, Range 0 to 800 grammes is utilised due to the honeycomb derived from an already 800-gram compartment, as depicted in Figure 3. The Honey Compartment of the Artificial Hive is initially loaded with honey and propolis weighing a total of 1000 grammes. The honey discovered on the honey pot of the stingless bee is then harvested, leaving only the propolis. After approximately five compartments are extracted, the honey weighs approximately 800 grammes. Only about 200 grammes of waste, including propolis and others, will be reduced to tare. Due to this, the weight of the compartment after it has been set on the colony is attributed to honey, as propolis and other substances have already been calculated as 0 grammes.

As for Internal Temperature, Vollet-Neto et al. [16] had already conducted a study on the survivability of stingless bees in relation to internal temperature. The study demonstrates that the survival range for stingless bees is between 22 and 38 degrees Celsius. Temperatures above 38 Celsius or below 22 Celsius are lethal to stingless bees and their colonies. If left unchecked, this problem will get worse and may lead to Colony Collapse Disorder [17] – [19]. Therefore, normal internal temperature range is only between 22 and 38 degrees Celsius.
Regarding Internal Humidity, Jiang et al. [20] had previously researched honey bee foraging behaviour. According to the research, the relative humidity inside an active hive fluctuated only between 75% and 95% RH. However, according to numerous previous experiments, 70% RH is just enough for stingless bees (Heterotrigona Itama) to thrive actively within the hive. For this experiment, therefore, the boundary between arid and moist is set at 70% RH. Finally, for Hive Condition and Honey Volume, both the maximum and minimum values are between 0 and 100 percent, as this range accurately represents the condition and volume outputs.

Table 1 Variables and Range for Fuzzy System

Function	Base Variable	Linguistic Variable	Actual Range	Parameter Range
Input	Compartment's Weight, W	Light	0 – 200	[-200 -200 0 320]
		Moist	70 – 100	[64 80 100 100]
Output	Hive Condition, HC (%)	Bad	0 – 25	[-40 0 0 40]
		Moderate	25 – 75	[10 50 50 90]
		Good	75 – 100	[60 100 100 140]
	Honey Volume, HV (%)	Low	0 – 25	[-40 0 0 40]
		Medium	25 – 75	[10 50 50 90]
		High	75 – 100	[60 100 100 140]

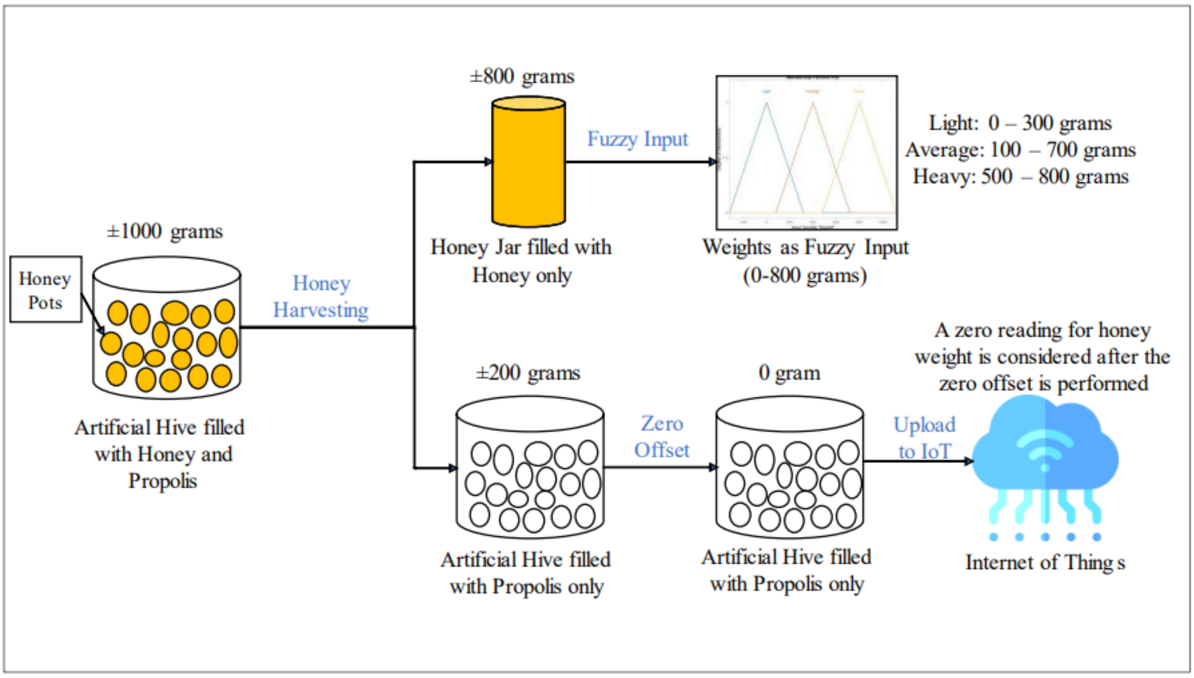

Figure 3. Honey Volume Range Determination

2.1.2 Membership Function

A membership function represents a fuzzy set graphically. It illustrates how 0 to 1 value are mapped to inputs and outputs. Membership function is essential for both Fuzzification and Defuzzification in order to transform crisp input into input fuzzy set and output fuzzy set into crisp output, respectively. After defining the linguistic variables, it is necessary to construct the membership function. In this phase, a graphical representation of the fuzzy set is provided. The x-axis represents the inputs, while the y-axis represents the degrees of membership. Figure 4 depicts an example of a membership function for Compartment Weight. Simply enter the number of linguistic variables, type of line graph, and parameter for each linguistic variable to use this membership function. The membership function for the remaining variables is then determined based on Table 1.

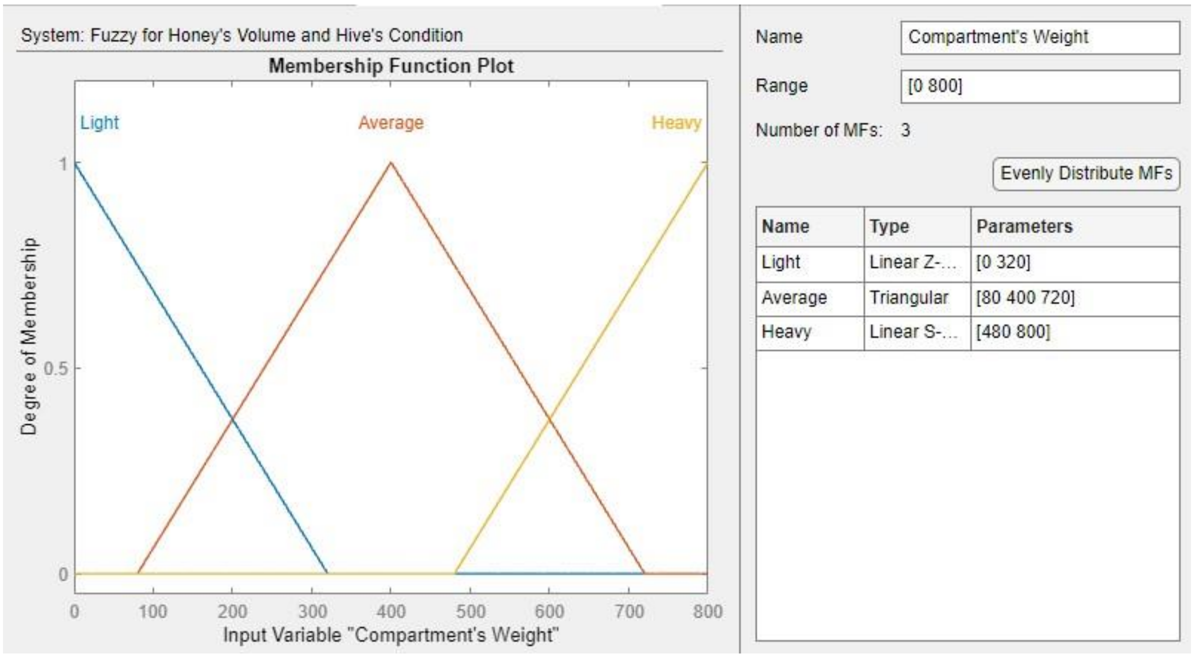

Figure 4. Membership Function for Compartment's Weight

2.1.3 Fuzzy Inference and Rules

This section comprises the fuzzy logic system's decision-making regulations or controls. It also includes the IF-THEN conditions utilised for conditional programming and system control. This instrument determines the optimal principles for a specific input. The algorithm then applies these principles to the input data to produce a fuzzy output. Table 2 displays the list of fuzzy rules for this system which are 12 rules in total.

The quantity of honey in the hive is determined by the hive weight and relative humidity. The weight of the colony is an indicator of the volume of honey contained within it. On the other hand, humidity levels are crucial for determining whether honey is present in the hive. While the weight of the hive can accurately determine the total volume of all components, including propolis, honey, and even bees, the humidity of the hive specifically indicates the presence of honey. Consequently, by combining these two parameters, it can effectively estimate the honey volume and confirm its presence within the hive. In this experiment, there will be three inputs and two outputs.

According to Wardhany et al. [12], the relationship between temperature and humidity is used to determine the condition of the hive. This is due to the fact that bees cannot tolerate high temperatures and humidity. If these bees are exposed to extreme temperatures and humidity, they can cause injury to the hive, the colony, the bees, the honey, and the propolis, among other things.

Table 2 Fuzzy Rules

Rule	Compartment's Weight	Internal Temperature	Internal Humidity	Hive Condition	Honey Volume
1.	Light	-	Dry	-	Low
2.	Average	-	Dry	-	Low
3.	Heavy	-	Dry	-	Medium
4.	Light	-	Moist	-	Low
5.	Average	-	Moist	-	Medium
6.	Heavy	-	Moist	-	High
7.	-	Cold	Dry	Bad	-
8.	-	Normal	Dry	Moderate	-
9.	-	Hot	Dry	Bad	-
10.	-	Cold	Moist	Bad	-
11.	-	Normal	Moist	Good	-
12.	-	Hot	Moist	Bad	-

2.1.4 Embedded Fuzzy Logic

For the development of Embedded Fuzzy Logic, the eFLL (Embedded Fuzzy Logic Library) for the Mamdani inference fuzzy logic model by AJ Alves [21] will be utilised in the Arduino IDE software. Coding will then be uploaded to NodeMCU ESP8266 for entirely automated operation. Internal Temperature and Humidity are measured by a DHT22 sensor, while the weight of a compartment is measured by load cells.

3. RESULTS AND DISCUSSION

Comparing the results of FLDa and eFLL in this section. Then, the ThingSpeak interface containing input data and eFLL data will be demonstrated in this section as evidence of improving to let beekeeper monitoring via online.

Table 3 displays 20 random samples used to compare LFDa and eFLL results. The random number for the compartment's weight ranges from 0 to 800. The Internal Temperature is determined by a random number between 20 and 40. For Internal Humidity, the random number is between 50 and 100.Table 3 uses all four equations: (1) for differences, (2) for average, (3) for percentage error, and (4) for standard deviation.In this case, the result from FLDa serves as the reference value, while the result from eFLL serves as the reading value. This is because the comparison is used to determine if the eFLL is compatible with NodeMCU ESP8266.

Observationally, the average percentage error for hive condition is 0.17 percent, which is marginally less than the average percentage error for honey volume, which is 0.66 percent. In addition, honey volume is more dispersed than hive condition, as the standard deviation for honey volume, 0.49, is greater than the standard deviation for hive condition, 0.22. This occurs because the difference value for hive condition has a greater proportion of 0 values than honey volume. This is due to the high sensitivity of the hive condition to temperature, which has been set so that temperatures below 22°C and above 38°C are marginally detrimental to hive condition. Nonetheless, there are a few instances in which the result for hive condition is approximately halved (±50%) when the humidity inside the hive is low, as it is also dependent on humidity. This makes ideal sense because hive conditions decline when the temperature is cold or hot andthe humidity is dry, whereas they better when the temperature is normal, and the humidity is high. As for honey volume, as long as the internal humidity is moist, the results from honey volume and compartment weight correspond closely. However, if the humidity is insufficient, half of the compartment's weight will be comprised of honey.

Table 3 Comparison between FLDa and eFFL

Sample	Compartment's Weight, W (m)	Internal Temperature, T (°C)	Internal Humidity, H (%)	Hive Condition for FLDa, (%)	Honey Volume for FLDa, (%)	Hive Condition for eFLL, (%)	Honey Volume for eFLL, (%)	Difference of Hive Condition	Difference of Honey Volume	Hive Condition Error, (%)	Honey Volume Error, (%)
1.	164.37	38.19	68.21	0	18.5	0	18.48	0	-0.02	0	0
2.	373.32	25.80	78.59	100	50	100	50	0	0	0	0
3.	124.86	29.06	61.17	50	0	50	0	0	-0.01	0	0
4.	134.10	26.24	54.31	50	0	50	0	0	-0.01	0	0
5.	390.23	30.24	85.85	100	50	100	50	0	0	0	0
6.	141.91	34.18	81.98	100	14.2	100	14.30	0	0.1	0	0.70
7.	656.32	23.10	88.70	56.40	85.50	56.45	85.37	0.05	-0.13	0.09	0.15
8.	459.30	35.55	87.00	100	50	100	50	0	0	0	0.00
9.	529.64	25.86	75.99	99.9	61.6	100	61.19	0.1	-0.41	0.10	0.67
10.	456.65	38.33	89.36	0	50	0	50.00	0	0	0	0.00
11.	176.95	38.33	84.06	0	20.8	0	20.81	0.	0.01	0	0.05
12.	255.75	23.50	83.14	88.20	35.40	88.17	35.26	-0.03	-0.14	0.03	0.40
13.	533.67	37.55	97.59	6.24	62.50	6.26	62.71	0.02	0.21	0.32	0.34
14.	716.47	34.64	53.54	50	49.1	50	47.70	0	-1.4	0	2.85
15.	525.88	21.47	75.18	0	56.5	0	56.24	0	-0.26	0	0.46
16.	370.41	21.52	74.77	0	43.9	0	43.12	0	-0.78	0	1.78
17.	15.09	36.40	85.87	100	0	100	0.00	0	-0.01	0	0.00
18.	84.54	36.50	58.55	44.9	0	44.09	0.00	-0.81	-0.01	1.80	0.00
19.	12.42	24.64	85.30	100	0	100.00	0.00	0	-0.01	0	0.00
20.	310.27	24.59	82.43	100	47.5	100.00	46.31	0	-1.19	0	2.51
Average, $\bar{X}$								**-0.05**	**-0.29**	**0.17**	**0.66**
Standard Deviation, S								**0.22**	**0.49**		

4. CONCLUSION

Embedded Fuzzy Logic has been effectively implemented in NodeMCU ESP8266 by utilising the Embedded Fuzzy Logic Library. This will not occur if the fuzzy system is not first tested using the MATLAB app Fuzzy Logic Designer.By utilising a fuzzy logic system, beekeepers will be able to observe the hive condition and honey volume without disturbing the activity of stingless bees. This will increase honey production by stingless bees because they will not be distracted during production. As a consequence, the standard deviation for both hive condition and honey volume is less than 0.5, indicating that the difference is not evenly distributed across the mean. Moreover, the averaged percentage error of differences between hive condition and honeyvolume is less than 1%, which is very low and indicates that there are few gaps. Overall, this willmake eFFL compatible with NodeMCU ESP8266, as there are not many differences between it and FLDa.

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