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Development and Implementation of Fuzzy-Like Temperature Controller for a Rice Cooker

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ABSTRACT
This paper presents an evaluation of performances of rice cooking system using Intelligent Controller that is Fuzzy Logic Controller (FLC) to meet the special requirements and some limitations of the rice cooking system. A new inference scheme is given to estimate the amount of rice and water to be used, and the temperature will be controlled according to the amount of rice and the time while cooking. The FLC system is designed by using MATLAB Fuzzy Logic Toolbox. The results obtained from the simulation software is given in this paper. This study proposes an automatic rice cooker temperature controller, which uses the difference between the amount of time and quantity of rice inside the cooker to determine the required temperature. The difference is assumed to affect the heating element in order to achieve the desired set point. The operating voltage is also taken into account. The research involves finding the mathematical model of a rice cooking system, designing a controller and performing a simulation to analyze the performance of the designed controller using Matlab/Simulink. The controller is based on adaptive fuzzy to control the temperature. The result shows that the controller is able to follow the input reference and the output response of adaptive fuzzy control and has better tracking performance. The developed system is hoped to address the issue of high cost of electricity, time wastage and over cooked or half cooked food.
KEYWORDS: Fuzzy Logic, Rice Controller, MATLAB,

I. INTRODUCTION

Usually the conventional digital cooking appliances, depends on the fixed temperature setting and is not automatically adjusted for optimal result. In the field of temperature control in cooking appliances, excellent real-time, high reliability, and good intelligence are proposed by many researchers. The traditional PID algorithm is, in fact, still playing a main role in the control process. The temperature conditioning system has becoming a field to be researched to improve the user convenience by applying intelligent system such as Adaptive Fuzzy controller.

While the enhanced control system is being designed, the consideration of the type of control system must be included in a modeling design. In particular the controller must be able to avoid the inefficiency of having the cooker operate all the time. Several control options were considered as timing circuit, which would turn the cooker off, if the food inside are ready and a temperature sensor input, which would change the operation of the cooker depending on the temperature (Mohd Shahrieel et al, 2019). Based on the observation of using the present conventional application, it always working all the time without a systematic control. Therefore, the control of the rice cooker is adjusted through a feedback control system, which monitors and maintains a constant temperature based on the data input from the sensor.

II. LITERATURE REVIEW

The reason for using fuzzy logic in control applications stems from the idea of modeling uncertainties in the knowledge of a system's behavior through fuzzy sets and rules that are vaguely or ambiguously specified. By defining a system's variables as linguistic variables such that the values they can take are also linguistic terms (modeled as fuzzy sets), and by establishing the rules based on said variables, a general method can be devised to control these systems: Fuzzy Control (Babuška, 1998; Chen, 2009). Fuzzy control is a class of control methodology that utilizes fuzzy set theory (Pedrycz, 1993). The advantages of fuzzy control are twofold. First, fuzzy control offers a novel mechanism for implementing control laws that are often based on knowledge or on linguistic descriptions. Second, fuzzy control provides an alternative methodology for facilitating the design of non-linear controllers for plants that rely on generally uncertain control that is very difficult to relate to the conventional theory of non-linear control (Li & Tong, 2003; A. Sala et al., 2005).

Every day we mindlessly perform complex tasks: parking, driving, recognizing faces, packing the groceries at the supermarket, moving delicate objects, etc. To solve these tasks (overcome an obstacle), we gather all the information necessary for the situation (topology of the terrain, characteristics of the obstacle such as speed, size, etc). With this information and by relying on our experience, we can carry out a series of control actions to provide feedback present between the system under control and our bodies to achieve the desired goal. The controller receives the performance indices (reference) and the system output. To replace the human in a control process, a controller must be added. The controller is a mathematical element, and as such all of the tasks that it is able to perform must be perfectly defined. This control link is studied in Control Theory and is based on two principles:

1. The system to be controlled must be known so that its response to a given input can be predicted. This prediction task requires having a complete model of the system. This identification phase is essential to the performance of the control algorithm.

2. The objective of the control must be specified in terms of concise mathematical formulas directly related to the system's variables (performance index).

Meanwhile, when a system's complexity increases, mathematics cannot be used to define the aforementioned points. The model cannot be defined due to non-linearity to its non-stationary nature, to the lack of information regarding the model, and so on. We are, however, living in rapidly evolving times where the main goal is to break the limitations that exist in our use of machines in an effort to increase productivity. The use and advances in intelligent machines will fundamentally change the way we work and live. To this end, we are building autonomous control systems that are designed to work properly for long periods of time under given uncertainties in the system and the environment. These systems must be capable of compensating for faults in the system without any outside intervention. Intelligent autonomous control systems use techniques from the field of Artificial Intelligence (AI) to achieve autonomy. These control systems consist of conventional control systems that have been augmented using intelligent components, meaning their development requires interdisciplinary research (Jang et al., 1997). The emergence and development of Artificial Intelligence is of great importance. AI can be defined as that part of computer science that is charged with the design of intelligent computers, meaning systems that exhibit those characteristics that we associate with intelligent human behavior, such as understanding, learning, reasoning, problem solving, etc. Fuzzy Control is one of the new techniques in Intelligent Control, one that aims to imitate the procedure we humans use when dealing with systems (Cai, 1997).

Another important consideration is that the control can be expressed as a set of rules of the type: "For certain conditions with some variables, do these actions in others". In this structure, the conditions are called antecedents and the actions consequents. We may conclude that human reasoning in these situations involves applying logic to uncertain magnitudes. If we want to implement this control artificially, the most convenient course of action is to use a tool that models uncertain magnitudes, this being Fuzzy Set Theory, and apply a logic to these magnitudes, this being Fuzzy Logic (Klir & Yuan, 1995). Both elements belong to a new field in the symbolic branch of Artificial Intelligence that has found in Fuzzy Control one of its main applications, even above other, more formal applications such as expert systems. The fact that it mirrors the process of human reasoning justifies the success of this new method, due to its ease of use and understanding. In a few years AI has blossomed and experienced great commercial success, eclipsing even that of
expert systems.

III. PRINCIPLE OF THERMAL GENERATION

Magnetic energy is generated and transferred to the cooking vessel using the principle of electromagnetic induction and is transformed into thermal energy at the cooking vessel. This principle involves rectifying the relatively low frequency ac line input voltage using an uncontrolled switching device such as a diode. Switching the rectified voltage at a frequency between 20 kHz to 35 kHz produces a high frequency magnetic flux. The cooking vessel acts as a lossy magnetic core which converts the magnetic field into heat.

The main components used to generate and transfer this heat energy are the pan or cooking vessel, an inductor, a resonant capacitor. The geometry of the inductor winding is important in generating the magnetic field required to generate and transfer the heat. The inductor windings are spiral in shape. The wires are wound around each other in a horizontal plane. This geometrical arrangement increases the surface area of the magnetic flux. The concentration of these magnetic flux lines around the pan is further enhanced by using rectangular-shaped ferrite magnet bars, placed at equal intervals around the inductor windings.

IV. FUZZY LOGIC CONTROL (FLC)

Fuzzy Logic Controller (FLC) is the one of the most powerful controller which can control non-linear system because of it non-linearity characteristic behaviour. Fuzzy Logic Control (FLC) is one of the intelligent control systems that are a successful solution to many control problems. The fuzzy models can represent the highly nonlinear processes and can smoothly integrate a priori knowledge with information obtained from process data (T.J. Ross, 2004)**.** Many control solution need the mathematical model of the system to be controlled, but the FLC only need the measurement of input and output signals of the system to be controlled (J. Harris, 2006).

This controller consists of fuzzy membership function, fuzzy rules and Defuzzyfication. Fuzzy membership rules are used to set the input and output range in several level such as low, medium and high. The fuzzy rules are used to relate and combine the input and output of FLC. Commonly, the relation of input and output are using “OR” and “AND” logic. Defuzzyfication is used to convert the rules output to appropriate value which is to be used by the system. This controller is widely used in temperature control.

Fuzzy Logic Controller have three successive blocks through which the control signal is generated (Fig. 1).The first block is fuzzification which fuzzifies the input sent through an inference block where decisions are made by firing certain rules. The fuzzy control system is based on the theory of fuzzy sets and fuzzy logic. Previously a large number of fuzzy inference systems and Defuzzyfication techniques were reported. The output of the inference engine is a set of fuzzification knowledge which is converted to a crisp control signal through a technique of Defuzzyfication.

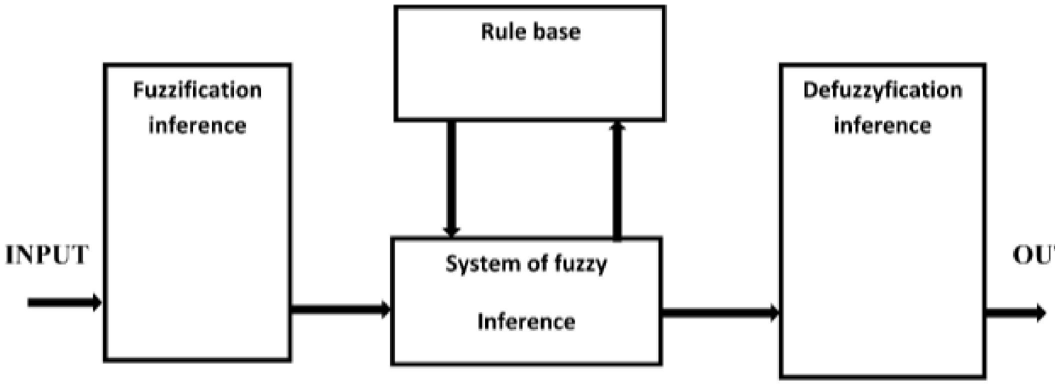

Figure 1: Block diagram of Fuzzy Logic System

This implies that the process of converting a crisp input value to a value is called fuzzification. The fuzzification block thus matches the input data with the conditions of the rules to determine how well the condition of each rule matched that particular input instance. Defuzzification other hands takes the output of the rules and generates a crisp numeric value used as the control input to the temperature regulation process.

V. RICE COOKER SYSTEM

The principle of rice cooker is the three major components which are rice bowl, heater and thermostat. A spring pushes thermostat against the bottom bowl, for good thermal contact to ensure accurate temperature measurement. At the end of cooking, some of the water added will have been absorbed by the rice and the rest is boiled off. Once the heating continues past the boiling point, the thermostat then trips, switching the rice cooker to low power “warming” mode.

From the basic principle of rice cooker as mention earlier, a fuzzy controller can be designed so that more robust and sophisticated rice cooker system can be produced. The fuzzy controller design need a well define inputs variables and also the yielding of outputs variables

a. Simulation of fuzzy temperature control

Normally, before proceeding with the implementation of the controller, a simulation is performed to evaluate its performance. The results of the simulation can aid in improving the design of the fuzzy controller and in verifying that it will work correctly when it is implemented. Such a simulation is shown below, implemented using Matlab (Sivanandam et al., 2007), specifically Simulink to simulate the control loop and fuzzy toolbox to implement the fuzzy controller. The controller designed earlier is defined using the fuzzy toolbox in Matlab, yielding the fuzzy system shown in Figure 7. The fuzzy partition of the inputs and output is shown in Figure 8. As for the output surface, it is shown in Figure 9.

With this tool, we can see how the inference process is carried out. The next step is to carry out a simulation with the temperature system to check the control system’s performance. To do this, we will use the simulation tool Simulink, which allows us to implement the control loop in blocks and to use the fuzzy system made with the fuzzy toolbox as the controller. The temperature controller is an instrument used to control temperature by taking an input from temperature sensor and has an output that is connected to a control element such as heater.

b. Fuzzy Logic Temperature Controller

The problem is to design a temperature controller which will keep the controlled temperature at a set value at 70°C within a range of 40-100°C. Temperature values are assumed to be integers. The universe of discourse that is the range of temperature is 40°C to 100°C. The temperature difference is

$\Theta i - \Theta r = TEMP$

Where:

Θi = input temperature

Θr = relative temperature

TEMP = temperature error

As Θi varies from 40°C to 100°C TEMP varies from - 30°C to +30°C. Thus, range is normalized into a derived universe of discourse (UOV) having a range within [-1, +1] and the temperature error TEMP is changed to TERR. The UOV is divided into the following regions LN, SN, ZE, SP, and LP depending on the deviation of the set value of temperature with actual input values.

Where,

LN=large negative, SN=small negative, ZE=zero,

SP=small positive, LP=large positive

In addition to TERR, time Amount of Rice (AMT) is used as another input to the controller having the same UOV. The output HOUT stands for controller output having same UOV which controls a heater. The membership functions are all triangular and approximately 50%overlapped between successive membership function is maintained.

VI. RULE TABLE

The connectivity between the inputs is always logical AND or logical OR. Here we use only logical AND. The Rule Table for the above problem from general experience is constructed as follows. For example,

If (TERR is SN) AND (AMT is SN) then the output of the heater i.e. HOUT should be such that the variables trying to deviate the desired output should work against. Therefore, HOUT should be LP.

This explains the following rule table (Table 1):

Table 1: Rule Table

AMT / TERR	LN	SN	ZE	SP	LP
LN	LP	SP	LP	SP	ZE
SN	LP	LP	SP	ZE	SN
ZE	LP	SP	ZE	SN	LN
SP	SP	ZE	SN	LN	LN
LP	ZE	SN	LN	LN	LN

The output of a process can be logical union of two or more membership functions defined on the universe of discourse the output value. Max membership function principle used for defuzzification process. The output variable is converted to crisp value by the process of defuzzification. The defuzzified output is the fed to the further circuit to obtain the control signal.

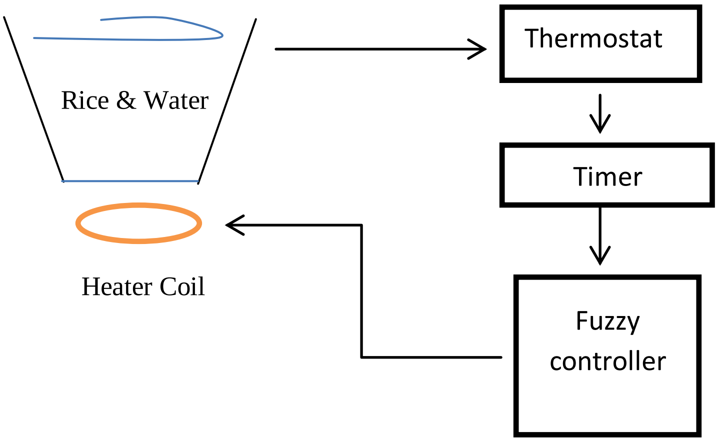

Figure 2: Operation of Rice Cooker

VII. SYSTEM ANALYSIS

Considering the model design simulation (Fig. 3) using the MATLAB; the fuzzy logic controller has 2 inputs which are time and amount of rice with temperature as the output (Fig. *3)*. The 2 inputs are used for accessing the current conditions of the process such that the necessary action can be taken by providing the correct control signal for output. The Table 1 shows the amount of rice and the time needed to cook for conventional rice cooker.

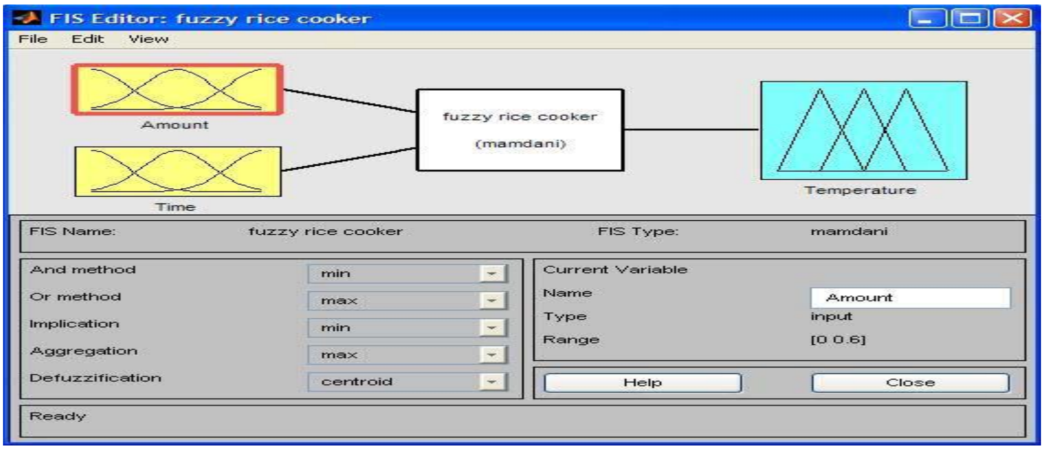

Figure 3: Fuzzy Inference System in MATLAB

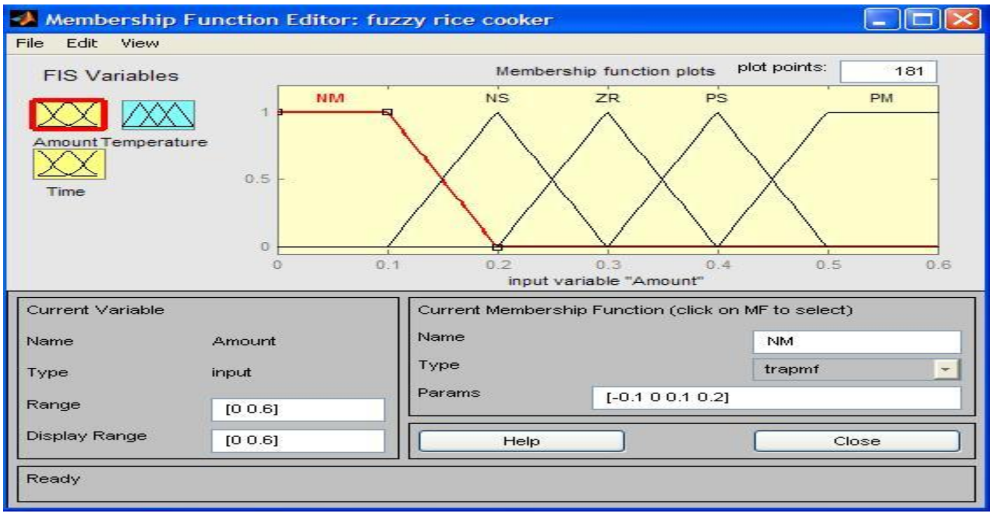

Figure 4: Membership function of amount in MATLAB

Fig. 4 shows the membership function of the amount of rice. The range is set at 0.0 to 0.6 which mean 0 cup to 6 cups in real quantity, the ratio for normalization is 1:0.1.

The fuzzy set of amount is quantizing (partition) the inputs such that each has 5 fuzzy sets which included Negative Medium (NM), Negative Small (NS), Zero (ZR), Positive Small (PS) and Positive Medium (PM). For the 2 input variables, use triangular waveforms for the middle fuzzy sets and trapezoidal functions on the sides. The fuzzy partitions for both the input variables (error and error-variation) and for the output variable (increase-energy-supplied) will consist of seven diffuse groups uniformly distributed in a normalized universe of discourse with range [-1,1].

The membership functions for the controller's input variables, at the edge of the universe of discourse, are saturated. This means that at a given point, the expert regards all values above a given value as capable of being grouped under the same linguistic description of "large-positive" or "large-negative". The membership function of the controller's output variable, however, cannot be saturated at the edge if the controller is to function properly. The basic reason is that the controller cannot tell the actuator that any value above a given value is valid; instead, a specific value must always be specified. Moreover, from a practical stand point, we could not carry out a defuzzification process that considers the area of conclusion of the rule if, as an output, we have membership functions with an infinite area.

Table 2:Membership Function Range

Membership Function	Angle	Range	Range
Negative medium	'trapmf'	[-0.1 0 0.1 0.2]	[0—2] Cups of Rice
Negative small	'trimf'	[0.1 0.2 0.3]	[1—3] Cups of Rice
Zero	'trimf	[0.2 0.3 0.4]	[2—4] Cups of Rice
Positive Small	'trimf	[0.3 0.4 0.5]	[3—5] Cups of Rice
Positive medium	trapmf'	[0.4 0.5 0.6 0.7]	[4—7] Cups of Rice

Where:
NM = Negative Medium;
NS = Negative Small;
ZR = Zero,
PS = Positive Small
PM =Positive Medium.

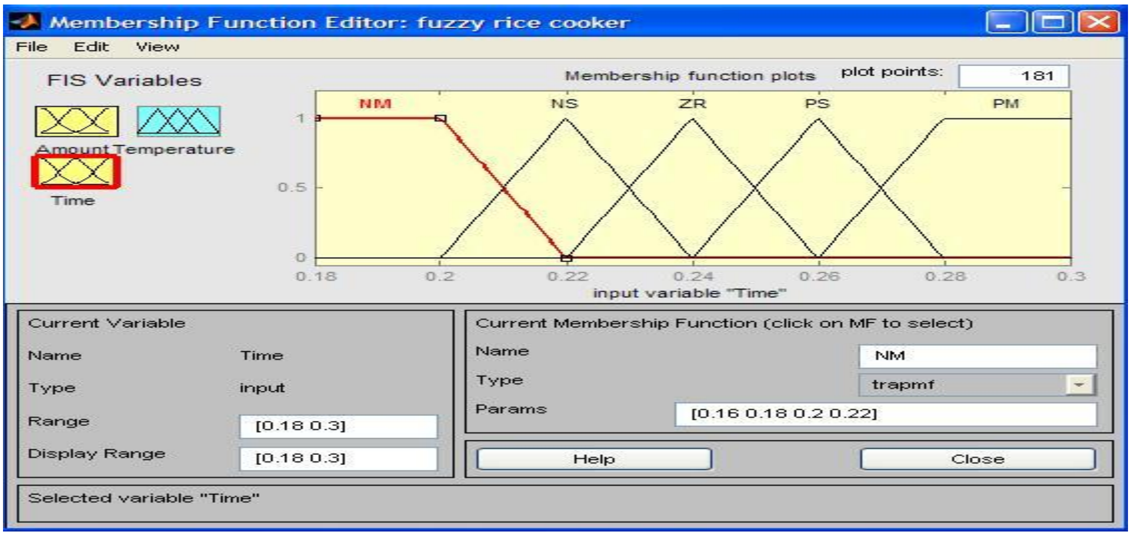

Figure 5: Membership function of time in MATLAB

Figure 5 shows the membership function of time elapse for cooking the rice. The range is set at 0.18 to 0.30 which means 18 minutes to 30 minutes in real time, the ratio for normalization is 10:0.1. The fuzzy set of time contains 5 membership functions (Table 3) which included NM, NS, ZR, PS and PM.

Table 3: Membership Relationship

Membership function	Angle	Range
'Negative Medium'	'trapmf'	[0.16 0.18 0.2 0.22]
'Negative Small'	' trimf'	[0.2 0.22 0.24]
Zero	' trimf'	[0.22 0.24 0.26]
Positive Small	' trimf'	[0.24 0.26 0.28]
Positive Medium	trapmf'	[0.26 0.28 0.3 0.32]

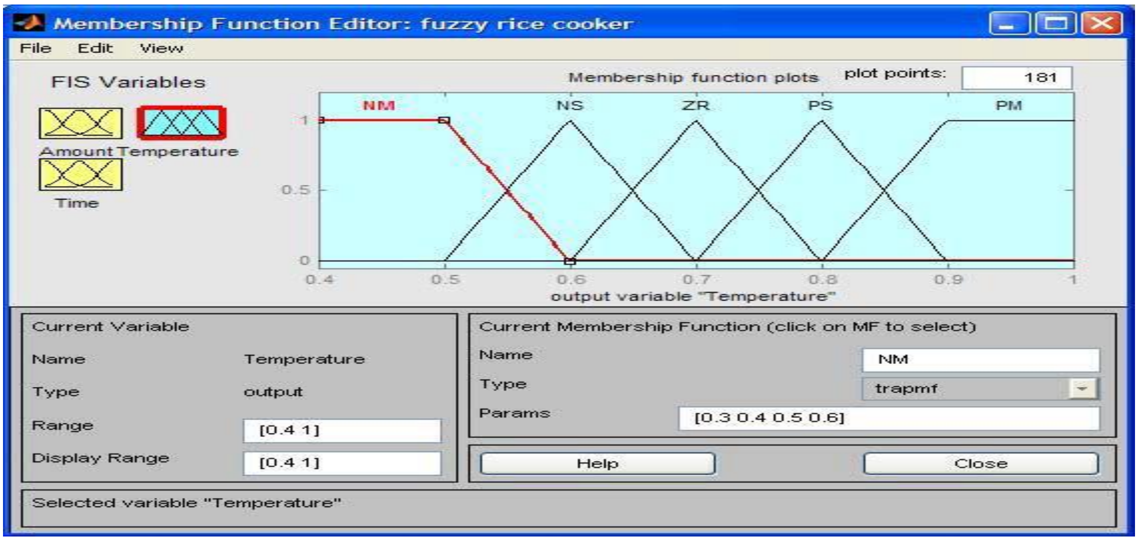

Figure 6: Membership function of temperature in MATLAB

Figure 6 shows the membership function of temperature controlled according to the amount of rice and time elapse for cooking the rice. The range is set at 0.4 to 1.0 (Table 4) which means 40°C to 100°C in real temperature, the ratio for normalization is 100:1. The fuzzy set of time contains 5 membership functions which included NM, NS, ZR, PS and PM.

Table 4:Membership Temperature Range

Membership Function	Angle	Range	Temp. ^{0}C	Temp Range
'Negative Medium'	'trapmf'	[0.3 0.4 0.5 0.6]	[30—60]	(very Small) Warm
'Negative Small'	'trimf'	[0.5 0.6 0.7]	[50—70]	(Small)
Zero	'trimf'	[0.6 0.7 0.8]	[60—80]	(medium)
Positive Small	'trimf'	[0.7 0.8 0.9]	[70—90]	(High)
Positive Medium	'trapmf'	[0.8 0.9 1 1.1]	[80—110]	(very High)

VIII. FUZZY CONTROL RULES

The Fuzzy control rules are set as shown in Table 2. The concept to design the rules is based on to the inputs which are amount of rice and time elapse. For example, when 2 cups rice (about NS in amount) is cooked until 20 minutes (about NM in time) the output temperature is PS (about 70°C-90°C), when the time cooking until 22 minutes (about NS in time), the output temperature will be ZR (60°C-80°C) and then keep reducing the temperature until the time ZR (about 22 minutes-26 minutes) or later, the temperature will be kept in NM (about 40°C-60°C) which is called as ‘warm’ condition.

Therefore, the Fuzzy rules for the controller as stated below:

1. IF (Amount) is “NM” and (Time) is “NM” then (Temperature) is “ZR” (1).
2. IF (Amount) is “NS” and (Time) is “NM” then (Temperature) is “PS” (1).
3. IF (Amount) is “ZR” and (Time) is “NM” then (Temperature) is “PM” (1).
4. IF (Amount) is “PS” and (Time) is “NM” then (Temperature) is “PM” (1).
5. IF (Amount) is “PM” and (Time) is “NM” then (Temperature) is “PM” (1).
6. IF (Amount) is “NM” and (Time) is “NS” then (Temperature) is “NS” (1).
7. IF (Amount) is “NS” and (Time) is “NS” then (Temperature) is “ZR” (1).
8. IF (Amount) is “ZR” and (Time) is “NS” then (Temperature) is “PS” (1).
9. IF (Amount) is “PS” and (Time) is “NS” then (Temperature) is “PM” (1).
10. IF (Amount) is “PM” and (Time) is “NS” then (Temperature) is “PM” (1).
11. IF (Amount) is “NM” and (Time) is “ZR” then (Temperature) is “NM” (1).
12. IF (Amount) is “NS” and (Time) is “ZR” then (Temperature) is “NS” (1).
13. IF (Amount) is “ZR” and (Time) is “ZR” the (Temperature) is “ZR” (1).
14. IF (Amount) is “PS” and (Time) is “ZR” then (Temperature) is “PS” (1).
15. IF (Amount) is “PM” and (Time) is “ZR” then (Temperature) is “PM” (1).
16. IF (Amount) is “NM” and (Time) is “PS” then (Temperature) is “NM” (1).
17. IF (Amount) is “NS” and (Time) is “PS” then (Temperature) is “NS” (1).
18. IF (Amount) is “ZR” and (Time) is “PS” then (Temperature) is “NS” (1).
19. IF (Amount) is “PS” and (Time) is “PS” then (Temperature) is “ZR” (1).
20. IF (Amount) is “PM” and (Time) is “PS” then (Temperature) is “PS” (1).
21. IF (Amount) is “NM” and (Time) is “PM” then (Temperature) is “NM” (1).
22. IF (Amount) is “NS” and (Time) is “PM” then (Temperature) is “NM” (1).
23. IF (Amount) is “ZR” and (Time) is “PM” then (Temperature) is “NM” (1).
24. IF (Amount) is PS” and (Time) is “PM” then (Temperature) is “NS” (1).
25. IF (Amount) is “PM” and (Time) is “PM” then (Temperature) “ZR” (1).

IX. RESULTS & DISCUSSION

The simulation results of fuzzy logic temperature controller for rice cooker in respect to the Amount, Time and Temperature using MATLAB is shown below (Fig. 7):

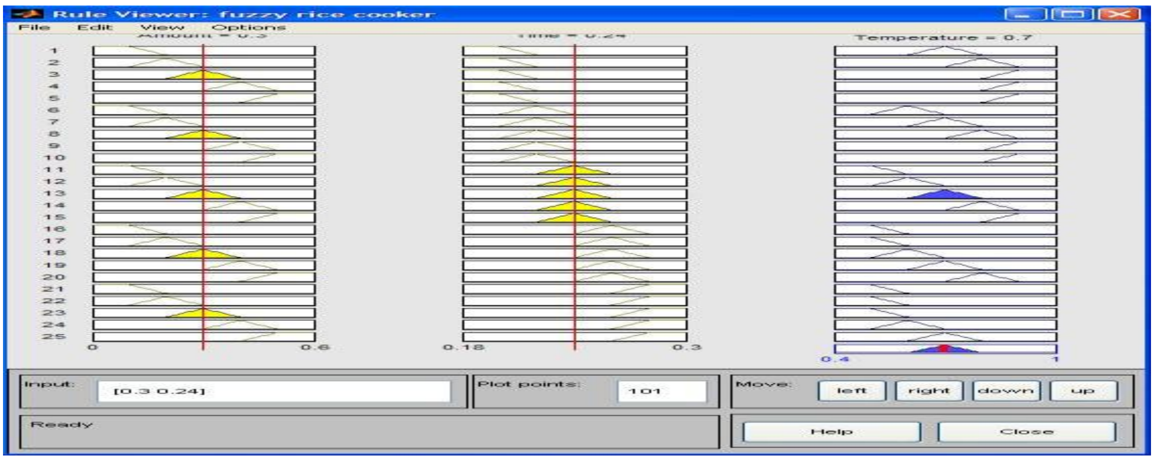

Figure 7: ***Simulation results based on 3 indices***

The simulation results obtained from MATLAB which fix the amount of rice equal to 3 cups and vary the time between 18 minutes to 30 minutes is shown below (Fig. 8).

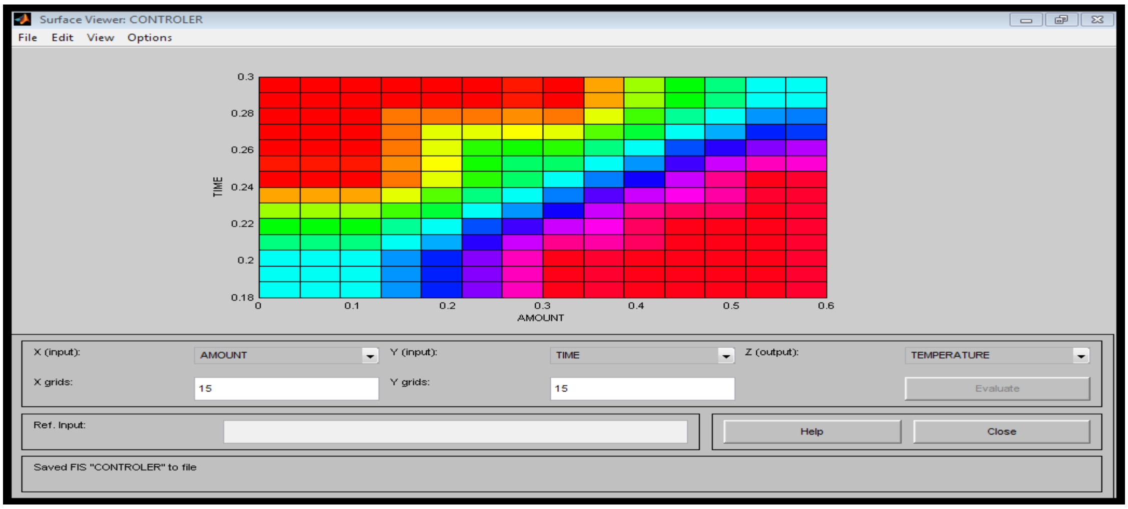

Figure 8: The surface view of Time with respect to the amount of Rice.

Meanwhile, the MATLAB simulation results obtained which fix the amount of rice equal to 3 cups in terms of temperature variation is shown below (Fig. 9).

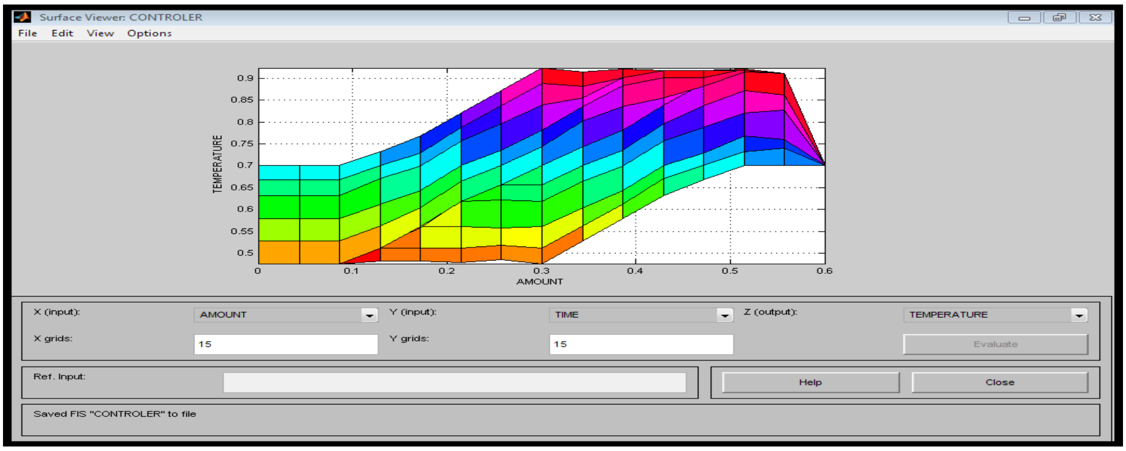

Fig 9: Surface View of Temperature with respect to the Amount of Rice

Equating the amount of rice to 3 cups, the rice is cooked once the start button is ON until 20th minutes which the temperature is 92.4°C in MATLAB. Then the heat is reduced from 28th minutes to 22nd minute but still maintains the temperature in 'warm' condition with the temperature of 47.6°C as shown in MATLAB (Fig. 10).

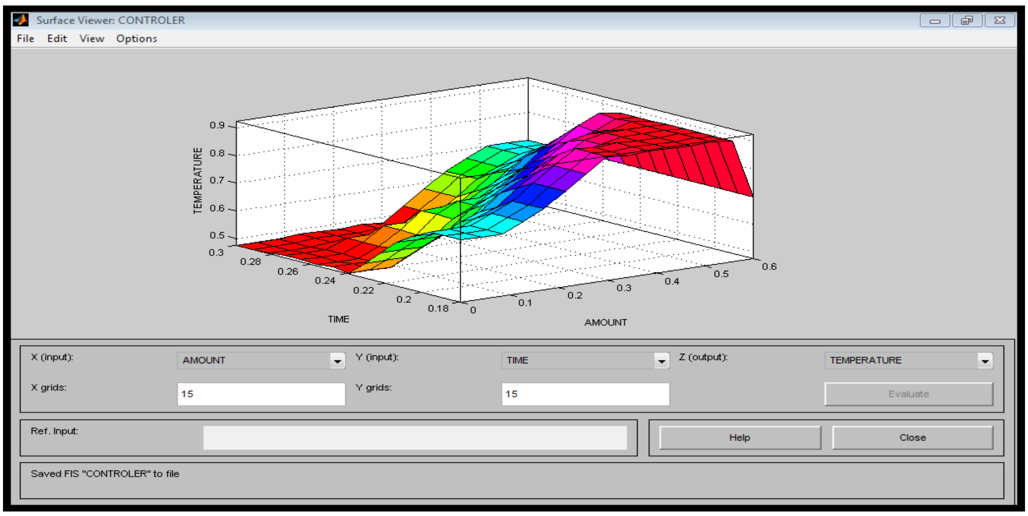

Figure 10: Time with Amount & Temperature variation

The energy efficiency comparison between FLC and conventional PID is represented below.
Using:
P= IV

***Where* I** =15amps, **V**=220volts.
P= 220*15= 3300watts.
TIME= x/60mins. **ENERGY**=Power*Time.

TABLE 5: Energy Consumption rate

AMOUNT	TIME	ENERGY CONSUMPTION	VALUE {Watt.Hr}
1 CUPS	20 MINS	3300*0.3333	1100
2 CUPS	22 MINS	3300*0.3667	1210
3 CUPS	24 MINS	3300*0.4000	1320
4 CUPS	26 MINS	3300*0.4333	1430
5 CUPS	28 MINS	3300*0.4667	1540
6 CUPS	30 MINS	3300*0.5000	1650

This implies that the fuzzy rice cooker will finish cooking as the time mentioned according to the amount of rice (Table 5), then the rice cooker will keep the rice in warm temperature which is 47.6°C.

X. CONCLUSION

The fuzzy rice cooker system had been designed to control the temperature while the rice is cooked by regarding to the amount of rice and the time elapse. Every input (amount of rice and time elapse) and output (temperature controlled) consists of five (5) membership functions which includes NM, NS, ZR, PS and PM. The type of membership function for NM and PM are trapezoidal while the type of membership function for the others is triangular. The fuzzy control system consists of 25 rules. The simulation had been done by using MATLAB FIS Toolbox. The response of FLC is free from these dangerous oscillations in the transient period. Hence the proposed FLC is better than the PD and PID controller. ***From the above tables*** we can observe the differences in the amount of energy used to cook the same quantity of rice. From the time difference obtained for both fuzzy logic controlled rice cooker and that of the conventional cooker, we can see that FLC 'REDUSES' energy wastages and hence lower power bills.

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