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Extended Fuzzy Rule Suram for Coffee Drying System

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Keywords

*Fuzzy, Membership Function,
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ABSTRACT

Extended fuzzy rule Suram is an algorithm developed to control a drying system using diesel as an energy source by modifying the value of the fuzzy membership function {0.5,1}. For a coffee drying room control system with solar energy, the bleak rule is based on fuzzy logic with the weather, air condition and wind speed variables. This algorithm is applied to the coffee drying process. The state variable membership function is represented in error values and changes in error with a typical triangular and trapezoidal map for weather variables, air conditions, while wind speed is expressed in terms of wind speed. The results of the analysis of experiments with 16 fuzzy rules to control system output according to weather conditions obtained optimization of the use of solar energy by minimizing the use of electrical energy by heating. This algorithm also adjusts the coffee drying schedule by controlling the chamber, namely through temperature and humidity control. The results of the application of this algorithm show that the efficiency of electrical energy reaches 40,86%.

INTRODUCTION

The Fuzzy Rule Suram Algorithm has been implemented in a solar wood drying system using weather and environmental variables.(Dion, Pranco, Tri, and Horwood, 1991). But for the extended Fuzzy Rule Suram algorithm, the two variables are added by paying attention to wind speed. Some of the reasons for the need for this speed variable is that the wind speed greatly affects the percentage of the amount of energy captured by the collector. The drying rate increases with the increase in temperature and air velocity because the volume of air molecules expands at high temperatures so that the air capacity to absorb water vapor increases, The drying rate becomes saturated at a constant temperature and air velocity when the water content in the object is low, Process conditions The most effective drying on the dryer made is at a temperature of 128°C and wind speed of 2.8 m/s with a drying rate of 25 gr/hour on objects with a thickness of 2 cm and 45 gr/hour on objects with a thickness of 4 cm, and effect on the drying process at high air velocity conditions ($v=2.8m/s$) (Haque, 2002).

When the drying process begins, the wind speed at a certain level of drying of the material with high moisture content requires a high wind speed as well. Thus, a large number of water molecules have only a short distance to travel (diffusion) to reach the surface. Water is basically waiting for the air to transfer energy to the coffee (to evaporate the water) and then carry the moisture away. When the coffee has a low water content, the amount of water on the surface is much less and the water molecules in the core have to travel further to reach the surface. The diffusion of water to the surface is slow if there is no wind flow. (Haque, 2002)

The coffee drying process uses a drying schedule that is very dependent on the moisture content of the coffee, by

conditioning the kiln at room temperature and humidity. The control algorithm used to control the actuator is the heater, damper, and sprayer. Each running drying process aims to optimize processing time and available energy, under conditions of process stability. The main energy source is solar energy from the collector and an alternative energy source is electric heating. (Zakarias, 2016)

The maximum utilization of solar energy in the coffee drying process is the goal of this control algorithm and depends on the amount of solar energy and changes in ambient temperature and wind speed. response to changes in solar energy in environmental temperature and humidity variables is a control system variable. The coffee drying process begins by determining the set point value for the drying room temperature and humidity. The temperature and humidity conditions in the drying room are adjusted to the moisture content of the coffee. (Zakarias, 2016)

This air-drying method of coffee is known as natural or unwashed coffee and is a traditional and ancient method. After the coffee is harvested, the coffee cherries are separated from the dirt by winnowing, and then placed on the flat surface of the dryer. If without a dryer, the drying process lasts 2-3 weeks, where the cherries are rotated 3 times a day, but with this dryer, 1 week is enough. and after that do the stripping until the remaining coffee beans only. (Zakarias, 2016)

The fuzzy rule suram algorithm is implemented for the drying scheduling of Arabia coffee by modifying the triangular and trapezoidal membership functions in the range [0.5, 1]. The wind speed is based on the input of solar energy collected by the collector. This process is fully controlled automatically and continuously so that the coffee drying process can be done quickly by maximizing solar energy. (Zakarias, Retantyo, Sri, and Istiyanto, Jazi, 2009a).

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Prototype of Coffee Dry Kiln

The control parameters of this solar coffee drying system are the amount of load, duration, operating temperature and usually fixed airflow, although this can vary according to the moisture content of the coffee. Many mechanical drying systems, particularly horizontal designs, only dry efficiently when fully charged, while others are more flexible. For this tool, the coffee is placed in layers according to the airflow on a flat plate. Depending on input moisture content, technology, and operating temperature, typical drying times are from 12 to 24 hours. If the duration is insufficient, the coffee product will not be stable and if it is too long, the producer loses

money due to loss of quality and weight. The uniformity of drying is an aspect that has received little attention but there is no reason to believe that rapid drying will result in a uniform population of dry particles because the migration of water through the seed and fruit tissues is quite slow. Air temperature is usually controlled at the inlet and is very important because temperatures in the grain above 45°C can damage the quality of the coffee and some of the immature beans will turn black and thus lose much of their commercial value. But at the beginning of the process, the temperature can reach 60°C with coffee water content above 32%. The prototype of coffee dry kiln in show at figure 1.

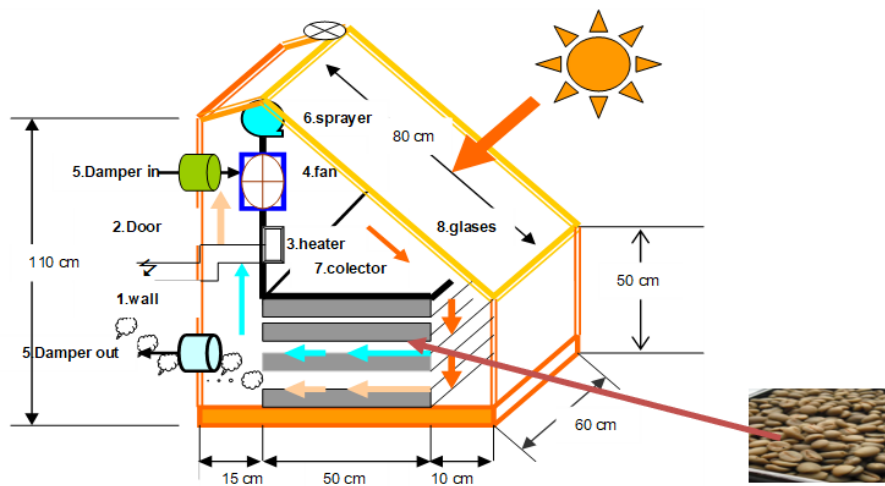


Figure 1: Detail of design the prototyping of coffee drying kiln

Measurement of solar energy by Piranometer type MS-801 Chino, it has maximum voltage +50 mVDC, which to have a data from Agency of meteorology and geophysics Medan Indonesia. The most important part of this solar dryer is the heat circulation pump. The air in the kiln passes through the coffee load and absorbs moisture from the coffee. Part of that air circulates through a fan where the moisture is condensed and removed from the drying chamber. Thus the heated dry air returns to the kiln chamber. Energy consumption is minimal, as there is almost no air exchange in/out. The air circulation in the kiln is very

slow to lift the water content of the coffee. The solar coffee dryer control system considers that:

- i. coffee does not need to be weeded every day but needs to be stirred daily;
- ii. Also protected from contamination of the product by pets;
- iii. protected from rain during the day;
- iv. Maintain different lot separations;
- v. Humidity monitoring is well controlled.

The type of collector used is a flat plate collector and the collector is oriented in such a way as to receive maximum solar energy, and functions as the roof of the coffee dryer.

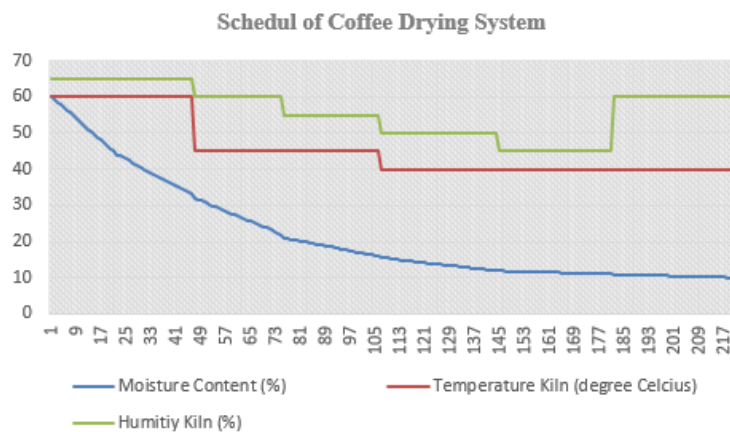


Figure 2: Schedule of coffee drying system

The coffee drying schedule is a set of instructions for operating the kiln during the drying period presented in tabular form showing the temperatures and humidity to be used at various stages of the process. This schedule varies greatly depending on the solar energy collected by the collector. Similarly, the captured solar energy is highly dependent on wind speed, which is represented by air temperature and humidity. This coffee drying schedule is shown in Figure 2.

Process Drying of Coffee

The coffee drying process begins with filling the coffee holder plate from the prototype so that it reaches 100 kg which is divided into 5 levels. According to experience with daily coffee drying, the drying schedule in Figure 2 is set according to the temperature and humidity in the kiln. The solar energy captured by the collector is flowed

throughout the room through the coffee pile using a fan slowly. The dry air that flows in heats the coffee so that the water vapor in the coffee will be carried away by the hot air and flowed into the exhaust air.

In order to minimize energy consumption, the damper is opened once in a while when the air is saturated, where the drying kiln has almost no internal/external air exchange (Zakarias, 2016)

The amount of solar energy collected by the collector is converted by the parameters of ambient temperature and ambient humidity according to the prevailing wind speed, as shown in tables 1 and 2. The amount of solar energy needed, for $MC \geq 22\%$ according to equation 1, and the amount of solar energy needed, for $MC < 22\%$ according to equation 2.

$$I_0 = 617 + 9.7(Td_0 - 45) \text{ (watt/m}^2\text{)} \quad (1)$$

$$I_0 = 535 + 16.5(Td_0 - 40) \text{ (watt/m}^2\text{)} \quad (2)$$

Table 1: Convert solar radiation to variable temp. ambient and humidity ambient with wind speed $\geq 2,8$ m/s(high)

No.	Set Point Td_0 (°C)	Set Point Hd_0 (%)	MC (%)	Solar Radiation I_0 (Watt/m ²)	Temp. Ambient Ta (°C)			Hum. Ambient Ha (°C)		
					Min	Rate	Max	Min	Rate	Max
1	2	3	4	6	7	8	9	10	11	12
1	60	65	45 - 60	763.0	30.5	31.5	32.5	54	62	70
2	60	65	33 - 45							
3	45	60	22 - 33	652.0	29.7	30.7	31.7	52	60	68
4	45	55	16 - 22	617.5	29.4	30.4	31.4	50	58	66
5	45	45	12 - 16	561.0	29.1	30.1	31.1	46	54	62
6	40	60	10 - 12	535.0	28.9	29.9	30.9	52	60	68

Table 2: Convert solar radiation to variable temp. ambient and humidity ambient with wind speed $\geq 2,8$ m/s(high)

No.	Set Point Td_0 (°C)	Set Point Hd_0 (%)	MC (%)	Solar Radiation I_0 (Watt/m ²)	Temp. Ambient Ta (°C)			Hum. Ambient Ha (°C)		
					Rate	Max	Min	Rate	Max	
1	2	3	4	6	7	8	9	10	11	12
1	60	65	45 - 60	663.0	30.5	31.5	32.5	54	62	70
2	60	65	33 - 45							
3	45	60	22 - 33	552.0	29.7	30.7	31.7	52	60	68
4	45	55	16 - 22	517.5	29.4	30.4	31.4	50	58	66
5	45	45	12 - 16	461.0	29.1	30.1	31.1	46	54	62
6	40	60	10 - 12	435.0	28.9	29.9	30.9	52	60	68

The amount of solar energy needed, for $MC < 22\%$ according to equation 3, and the amount solar energy needed, for $MC < 22\%$ according to equation 4.

$$I_0 = 517 + 9.0(Td_0 - 45) \text{ (watt/m}^2\text{)} \quad (3)$$

$$I_0 = 435 + 16.0(Td_0 - 40) \text{ (watt/m}^2\text{)} \quad (4)$$

The design of membership functions for the parameters in fuzzy logic is implemented in a triangular and trapezoidal membership function model according to the coffee drying schedule as shown in Figure 2. and Table 1. [Klir and Yuan, 1995]. For this reason, it is necessary to apply a coffee-drying furnace control system. The process of

fuzzification of membership functions in the range [0,5, 1], and for the weather, which is presented at ambient temperature Ta and changes in ambient temperature CTa with a set point value of drying temperature $Td_0 = 60^\circ\text{C}$ and drying humidity $Rd_0 = 65\%$ is presented in Figure 3. with variable M : over - cloudy ; B : cloudy; CB : clear clouds ; C: clear; SC : clearest most obvious and for changes in ambient temperature used -H = - High, -M = -Medium, -S = - Small, Z = Zero, S = Small, M = Medium, H = High.

The computational process of changing ambient

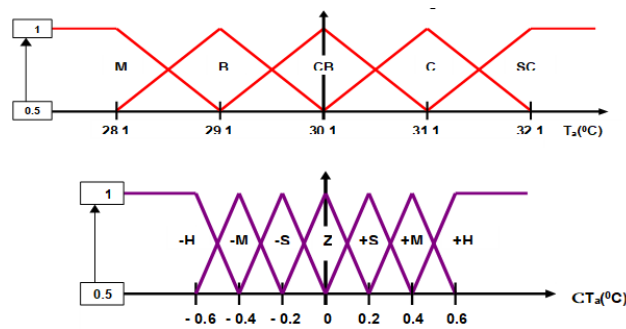


Figure 3: Membership function of temperature ambient and change temperature ambient for $Td_0 = 600C$ and $Rd_0 = 65\%$ temperature parameters is expressed by equation.5. with $n = 0$ s/d ∞

$$CTa [(n+1)T] = Ta[(n+1)T] - Ta[nT] \quad (5)$$

Weather representation is also expressed in the environmental temperature variable and its changes, and is used to maximize and calculate the value of the membership function, with reference to table 2. Fuzzyfication of the membership function in the range [0,5, 1] air conditions (ambient Ha humidity and changes in ambient humidity CHa for set point drying temperature ($Td_0 = 60oC$) and drying humidity ($Rd_0 = 65\%$) are presented in Figure 4. with variables: P : Hot; AP : Slightly

Hot; H : Flock; S: Fresh; D : Cold, and for change in ament humidity used -H = - High, -M = -Medium, -S = - Small, Z = Zero, S = Small, M = Medium, H = High Computation process of variable change of humidity ambient are given eq.6. with $n > 0$ to ~

$$CHa [(n+1)T] = Ha[(n+1)T] - Ha[nT] \quad (6)$$

Representing air conditions in ambient humidity parameters and their changes used for the maximum membership function, with the appropriate rules in the look-up table schema, are shown in table 3. The next step is to adjust to table 1. and adjust to the drying schedule in figure 2

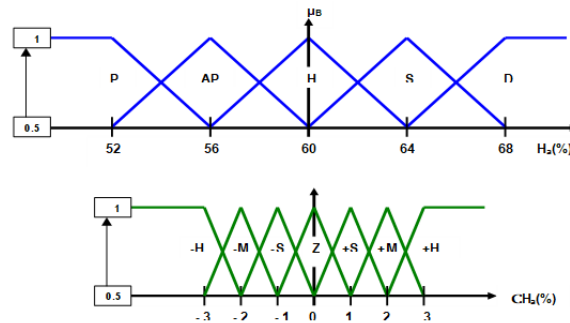


Figure 4: Membership function of temperature ambient and change temperature ambient for $Td_0 = 600C$ and $Rd_0 = 65\%$

Table 3: Look-up table for membership Function for temperature of ambient

Ta\CTa	Over-cloudy (M)	Cloudy (B)	Bright-Cloud (CB)	Clear (C)	Clearest (SC)
-H	Over-cloudy	Over-cloudy	Cloudy	Bright-Cloud	Clear
-M	Over-cloudy	Cloudy	Bright-Cloud	Clear	Clearest
-S	Over-cloudy	Cloudy	Bright-Cloud	Clear	Clearest
Z	Over-cloudy	Cloudy	Bright-Cloud	Clear	Clearest
+S	Over-cloudy	Cloudy	Bright-Cloud	Clear	Clearest
+M	Over-cloudy	Cloudy	Bright-Cloud	Clear	Clearest
+H	Cloudy	Bright-Cloud	Clear	Clearest	Clearest

Table 4: Look-up table for membership Function for humidity of ambient

Ha\CHa	Hot	Rather-Hots	Swarm	Fresh	Cold
-H	Hot	Hot	Rather-Hot	Swarm	Sejuk
-M	Hot	Rather-Hot	Swarm	Fresh	Cold
-S	Hot	Rather-Hot	Swarm	Fresh	Cold
Z	Hot	Rather-Hot	Swarm	Fresh	Cold
+S	Hot	Rather-Hot	Swarm	Fresh	Cold
+M	Hot	Rather-Hot	Swarm	Fresh	Cold
+H	Rather-Hot	Swarm	Fresh	Cold	Cold

Implementation of Algorithm

The algorithm of the extended Fuzzy Rule Suram is designed in such a way that the automatic control unit has a built-in program for coffee drying. The drying process control system takes place automatically, so the operator's presence is not required during drying. The greater energy consumption is generally only on the first day during the heating stage when the electric heater is turned on until the working temperature is reached. (Patrick and Spooner, 1995). The input variable ambient temperature measurement as an input parameter is carried out by the

SHT11 sensor as shown in Figure 5. The flowchart of the fuzzy rule algorithm is illustrated in Figure 6. In table 4 it is explained that the input of the drying chamber is adjusted to the schedule. That way the kiln becomes integrated with an automatic system using electric heating. This option is also suitable for large-capacity furnaces and in cases where the power supply is unstable (large voltage or current oscillations or frequent power outages during the winter period). Drying in this case is done conventionally when during the day the electrical energy is only used for the flow fan. (Wengert and Oliveira, 2007).

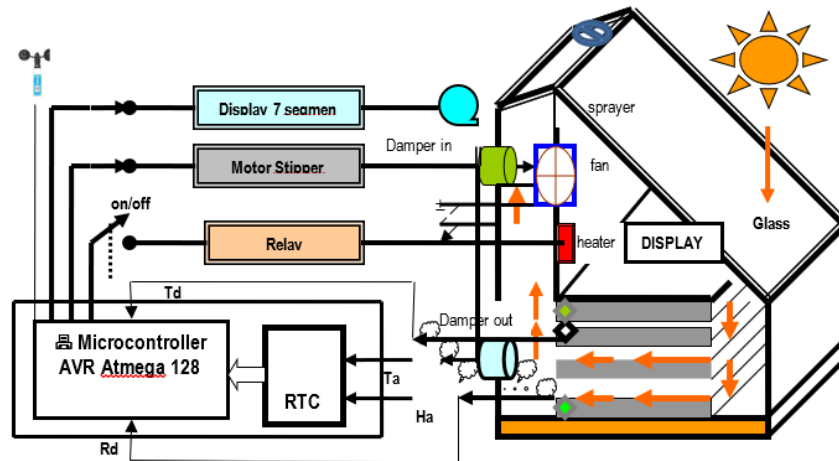


Figure 5: Automatic control system for coffee drying kiln prototype (Source: Skuratov, 2003)

Microcontroller AVR Atmega 128 has a capacity a big amount 128k flash, 53 pin I/O, 6 channel PWM and 8 channel 10-bit ADC; then to be used for application system control complex.

Microcontroller AVR Atmega 128 is a microcontroller AVR Atmel 8 bit family, with specifications are

- 128 Kb Flash PEROM
- 4Kb EEPROM
- 4Kb SRAM
- On-chip Analog Comparator
- 8 Channel 10 bit ADC

- 2 8 bit PWM
- 6 PWM with programmable resolution (2-16 bit)
- Dual Programmable UART
- SPI Interface
- Programmable Watchdog with On Chip Oscillator
- Adjustable VREF ADC
- 53 bit I/O
- Power On Reset and Programmable Brown out detection
- Internal Calibrated RC Oscillator
- The pocket included the ISP cable, CD and RS232 cable

Anemometer The input parameters used for the fuzzy

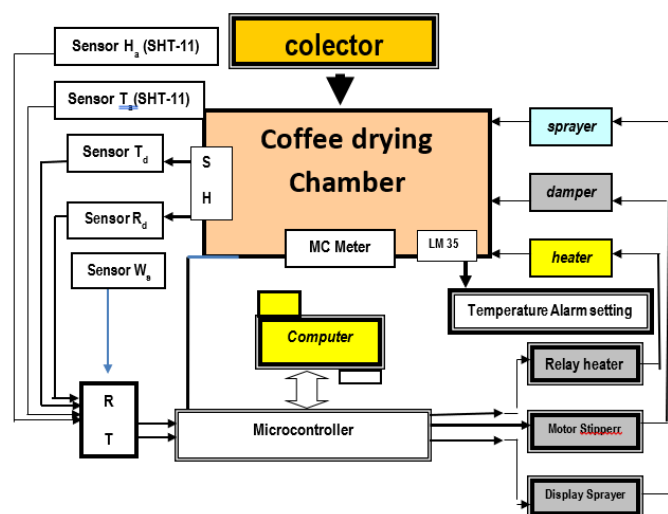


Figure 6: Schematic of the control system for the application of the fuzzy rule algorithm (Source: Wang, Liu, Gu, Sun, and de Silva, 2001)

rule gloomy are shown in table 5 . There are 5 parameters used, namely: drying temperature Td, drying chamber humidity Rd, ambient temperature Ta, ambient humidity Ha, and wind speed v.

In particular, wind speed is a special consideration because it has 2 alternatives, namely above 2.8 m/s and below, thus adjusting for the use of the 16 output parameters according to table 6 and table 7.

Table 5: Parameter Input

No.	Variable	Range	Describe
1.	Temperature Drying Td	0 – 150 °C	
2.	Temperature Ambient Ta	0 – 150 °C	Weather
3.	Humidity Drying Rd	0 – 100 %	
4.	Humidity Ambient Ha	0 – 100 %	Conditions of air
5.	Wind speed Wd	0 – 10 m/s	

The higher the wind speed, the more energy is lost, and vice versa. So that the rules obtained will be different at high wind speeds and low wind speeds. This of course will affect the length of time the actuator works, where in terms of heating time the greater but the active damper time will be smaller, but for the sprayer it will remain.

The effect of this wind speed can be seen in table 1 and table 2, how significant is the energy conversion required to increase the temperature of the drying chamber when the wind speed is high compared to the low wind speed. Each stage of the coffee drying schedule, the difference in solar radiation needs reaches 100 watt/m2.

Table 6: Parameter output at implemented the fuzzy rule suram algorithm for wind speed low

No.	Rule	Actuator			Conditions
		Heater	Damper	Sprayer	
1.	SUR-AM – 1	off	off	S	Lowering Drying Temperature Td and suddenly increasing Drying Chamber Humidity Rd [Heating Process]
2.	SUR-AM – 2	H	off	off	Increase Drying Temperature suddenly and decrease Drying Chamber Humidity Rd.
3.	SUR-AM – 3	H	D ₃	off	To increase the temperature of the Drying Chamber Td and to hold the Humidity of the Drying Chamber Rd.
4.	SUR-AM – 4	H	D ₂	S	Increasing Drying Temperature and Lowering Humidity Dryer Chamber Rd.
5.	SUR-AM – 5	H ₁	D ₃	off	To lower Drying Temperature Td and to maintain Drying Chamber Humidity Rd
6.	SUR-AM – 6	H ₂	off	S	To lower the Drying Temperature Td and to lower the Drying Chamber Humidity Rd
7.	SUR-AM – 7	off	off	off	To maintain Drying Temperature Td and Drying Chamber Humidity Rd
8.	SUR-AM – 8	H	D1	off	To maintain Drying Temperature Td and Adjust Drying Chamber Humidity Rd with Ambien Humidity Ha [Equalizing Process]

Note:

D1 : Damper ON : 3 minute

D2 : Damper ON : 2 minute

D3 : Damper ON : 1 minute

S : Sprayer ON : 1 minute

H: Heater ON : 15 minute

H1: Heater ON : 10 minute

H2: Heater ON : 5 minute

Table 7: Parameter output at implemented the fuzzy rule suram algorithm for wind speed high.

No.	Rule	Actuator			Conditions
		Heater	Damper	Sprayer	
1.	SUR-AM – 1	off	off	2S	Lowering Drying Temperature Td and suddenly increasing Drying Chamber Humidity Rd [Heating Process]
2.	SUR-AM – 2	2H	off	off	Increase Drying Temperature suddenly and decrease Drying Chamber Humidity Rd.
3.	SUR-AM – 3	2H	0.5D ₃	off	To increase the temperature of the Drying Chamber Td and to hold the Humidity of the Drying Chamber Rd.

4.	SUR-AM – 4	2H	0.5D ₂	2S	Increasing Drying Temperature and Lowering Humidity Dryer Chamber Rd.
5.	SUR-AM – 5	2H ₁	0.5D ₃	off	To lower Drying Temperature Td and to maintain Drying Chamber Humidity Rd
6.	SUR-AM – 6	2H ₂	off	2S	To lower the Drying Temperature Td and to lower the Drying Chamber Humidity Rd
7.	SUR-AM – 7	off	off	off	To maintain Drying Temperature Td and Drying Chamber Humidity Rd
8.	SUR-AM – 8	2H	0.5D ₁	off	To maintain Drying Temperature Td and Adjust Drying Chamber Humidity Rd with Ambien Humidity Ha [Equalizing Process]

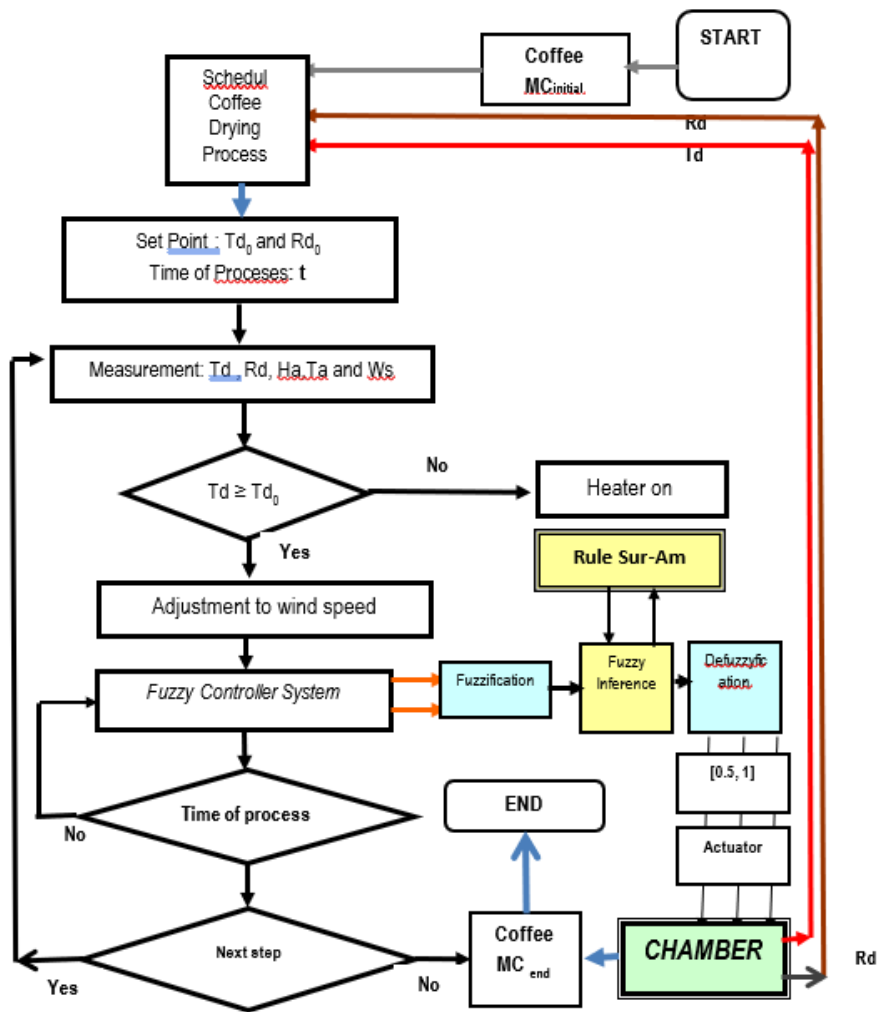


Figure 7: Flowchart Algorithm of Fuzzy Rule Suram for coffee drying

Flowchart Algorithm of Fuzzy Rule Gloomy for coffee drying is presented in Figure 7, starting with inputting the water content of the coffee curry to be dried. With this water content value, it is adjusted to the drying schedule to get the initial value of the temperature of the Tdo coffee drying room and the initial humidity of the Rdo drying room. The sensor reads the required parameters including Drying Room Temperature Td, Drying Room Humidity Rd, Ambien Temperature Ta, Ambien Humidity Ha, and wind speed at that time.

If the drying chamber temperature Td is smaller than Tdo, the heater is in the ON position, and if Td is greater than or equal to Tdo, then the wind speed is high or low. Furthermore, it is adjusted to the appropriate rules for treating the drying chamber, through a fuzzy computational process. The process continues if the processing time has not been reached and the process steps are carried out according to the drying schedule. The process will stop when the moisture content of the coffee is reached, or the drying step is complete.

Computation of Fuzzy Rule Suram

This Fuzzy Rule Suram is a fuzzy logic-based rule containing weather conditions and air conditions which are implemented in the coffee drying process. Obtained 16 output control rules by utilizing fuzzy logic operators implemented in a solar coffee dryer, the performance of this fuzzy controller will optimize the use of solar energy, to minimize the consumption of electrical energy by the heater, according to wind speed. This control rule is needed to maintain a chamber condition according to the coffee drying schedule. To maximize the use of solar energy, it is necessary to have a control system that is responsive to changes in the amount of solar energy and environmental temperature. SURAM's Fuzzy Rule is able to optimize the use of solar energy and is responsive to changes. This process will provide hope for minimal use of electrical energy and the system will quickly respond to changes in environmental conditions.

The advantage of the SUR-AM Rule is that it reduces the time delay of the actuator response, where to activate the actuator it is not necessary to process the influence of solar energy on the temperature and humidity of the drying chamber and/or the effect on changes in moisture content. This is the intelligence of the fuzzy controller system so that the coffee drying process can be maintained at the expected conditions

For computation of the fuzzy rule suram, it begins by

entering the initial value of the water content in MC coffee = 54%. According to the drying schedule, the drying chamber temperature is set at $T_{do} = 60\text{ }^{\circ}\text{C}$ and the humidity in the drying room is $R_{do} = 65\%$ and wind speed = 1.2 m/s. Furthermore, the measurement data showed that the ambient temperature $T_a = 29.2\text{ }^{\circ}\text{C}$, Humidity ambient $H_a = 64\%$. In the next measurement, it was obtained that $T_a(n + 1) = 29,6\text{ }^{\circ}\text{C}$ and $H_a(n + 1) = 64.2\%$, where measurements are carried out every 5 minutes.

From equation (5), it is found that the change in the ambient temperature value is $CT_a(n+1) = T_a(n+1) - T_a = 29.6 - 29.2 = 0.4\text{ }^{\circ}\text{C}$. From Figure 3, it is found that there are two membership values of $T_a = 29.2$, namely cloudy : B and CB: clear clouds, respectively: $\mu_B = 0.9$ and $\mu_{CB} = 0.1$, according to Figure 3. Similarly, the change is $CT_a = 0.8\text{ }^{\circ}\text{C}$ according to Figure 4, $H_a = 64\%$ is at $S = \text{Fresh}$ with a membership value of $\mu_S = 1.0$ and the change in humidity $CH_a = 0.2\%$ is at $\mu_z = 0.8$ and $\mu_s = 0.2$.

From table 3 it is obtained with conditions $B = 0.9$ and $CB = 0.1$ at the position of change + M, then the weather conditions are Claud with membership value = 0.9 and Bright Claud = 0.1. Likewise for the air condition in table 4, stated in the Fresh state with a maximum membership value of 0.8. And the possibilities that occur from each combination of weather conditions and air conditions are stated in table 8, table 9, and table 10.

Table 8: Implementation of Fuzzy Rule SURAM on Condition : $T_d [(n+1)] < T_{d_0}$

N0.	IF	AND	AND weather conditions is	AND air conditions is	THEN		
1	$T_d [(n+1)] < T_{d_0}$	$R_d [(n+1)] > R_{d_0}$	Over-Cloud	Hot	SUR-AM – 2		
2				Rather Hot	SUR-AM – 2		
3				Swam	SUR-AM – 2		
4				Fresh	SUR-AM – 2		
5				Cold	SUR-AM – 2		
6			Cloud			Hot	SUR-AM – 2
7						Rather Hot	SUR-AM – 2
8						Swam	SUR-AM – 2
9						Fresh	SUR-AM – 2
10						Cold	SUR-AM – 2
11			Bright-Cloud			Hot	SUR-AM – 2
12						Rather Hot	SUR-AM – 2
13						Swam	SUR-AM – 2
14						Fresh	SUR-AM – 2
15						Cold	SUR-AM – 2
16			Clear			Hot	SUR-AM – 3
17						Rather Hot	SUR-AM – 2
18						Swam	SUR-AM – 2
19						Fresh	SUR-AM – 2
20						Cold	SUR-AM – 2
21			clearest			Hot	SUR-AM – 3

22				Rather Hot	SUR-AM – 3
23				Swam	SUR-AM – 2
24				Fresh	SUR-AM – 2
25				Cold	SUR-AM – 2
26			Over-Cloud	Hot	SUR-AM – 3
27				Rather Hot	SUR-AM – 3
28				Swam	SUR-AM – 3
29				Fresh	SUR-AM – 3
30				Cold	SUR-AM – 3
31			Cloud	Hot	SUR-AM – 3
32				Rather Hot	SUR-AM – 3
33				Swam	SUR-AM – 3
34				Fresh	SUR-AM – 3
35				Cold	SUR-AM – 3
36			Bright-Cloud	Hot	SUR-AM – 4
37				Rather Hot	SUR-AM – 4
38				Swam	SUR-AM – 3
39				Fresh	SUR-AM – 3
40				Cold	SUR-AM – 3
41			Clear	Hot	SUR-AM – 4
42				Rather Hot	SUR-AM – 4
43				Swam	SUR-AM – 4
44				Fresh	SUR-AM – 3
45				Cold	SUR-AM – 3
46			clearest	Hot	SUR-AM – 4
47				Rather Hot	SUR-AM – 4
48				Swam	SUR-AM – 4
49				Fresh	SUR-AM – 3
50				Cold	SUR-AM – 3

Table 9: Implementation of Fuzzy Rule SURAM on Condition $Td [(n+1)] = Td_0$

N0.	IF	AND	AND weather conditions is	AND air conditions is	THEN OUTPUT is (Table 5 and 6)
N0.	IF	AND	AND Keadaan Cuaca is	AND Kondisi Udara is	THEN OUTPUT is
1	$Td [(n+1)] = Td_0$	$Rd [(n+1)] > Rd_0$	Over-Cloud	Hot	SUR-AM – 2
2				Rather Hot	SUR-AM – 2
3				Swam	SUR-AM – 2
4				Fresh	SUR-AM – 2
5				Cold	SUR-AM – 2
6			Cloud	Hot	SUR-AM – 2
7				Rather Hot	SUR-AM – 2
8				Swam	SUR-AM – 2
9				Fresh	SUR-AM – 2
10			Bright-Cloud	Cold	SUR-AM – 2
11				Hot	SUR-AM – 3
12				Rather Hot	SUR-AM – 3

13				Swam	SUR-AM – 2
14				Fresh	SUR-AM – 2
15				Cold	SUR-AM – 2
16			Clear	Hot	SUR-AM – 3
17				Rather Hot	SUR-AM – 3
18				Swam	SUR-AM – 3
19				Fresh	SUR-AM – 2
20				Cold	SUR-AM – 2
21			clearest	Hot	SUR-AM – 3
22				Rather Hot	SUR-AM – 3
23				Swam	SUR-AM – 3
24				Fresh	SUR-AM – 2
25				Cold	SUR-AM – 2
26			Over-Cloud	Hot	SUR-AM – 3
27				Rather Hot	SUR-AM – 3
28				Swam	SUR-AM – 3
29				Fresh	SUR-AM – 3
30				Cold	SUR-AM – 3
31			Cloud	Hot	SUR-AM – 3
32				Rather Hot	SUR-AM – 3
33				Swam	SUR-AM – 3
34				Fresh	SUR-AM – 3
35				Cold	SUR-AM – 3
36		$Rd [(n+1)] \leq Rd_0$	Bright-Cloud	Hot	SUR-AM – 6
37				Rather Hot	SUR-AM – 6
38				Swam	SUR-AM – 3
39				Fresh	SUR-AM – 3
40				Cold	SUR-AM – 3
41			Clear	Hot	SUR-AM – 6
42				Rather Hot	SUR-AM – 6
43				Swam	SUR-AM – 3
44				Fresh	SUR-AM – 3
45				Cold	SUR-AM – 3
46			clearest	Hot	SUR-AM – 6
47				Rather Hot	SUR-AM – 6
48				Swam	SUR-AM – 6
49				Fresh	SUR-AM – 3
50				Cold	SUR-AM – 3

Table 10: Implementation of Fuzzy Rule SURAM on Condition : $Td [(n+1)] > Td_0$

N0.	IF	AND	AND weather conditions is	AND air conditions is	THEN OUTPUT is (Table 5 and 6)
1			Over-Cloud	Hot	SUR-AM – 2
2				Rather Hot	SUR-AM – 2
3				Swam	SUR-AM – 2
4				Fresh	SUR-AM – 2
5				Cold	SUR-AM – 2

6	Td [(n+1)] = Td ₀	Rd [(n+1)] > Rd ₀	Cloud	Hot	SUR-AM – 2
7				Rather Hot	SUR-AM – 2
8				Swam	SUR-AM – 2
9				Fresh	SUR-AM – 2
10				Cold	SUR-AM – 2
11			Bright-Cloud	Hot	SUR-AM – 5
12				Rather Hot	SUR-AM – 5
13				Swam	SUR-AM – 2
14				Fresh	SUR-AM – 2
15				Cold	SUR-AM – 2
16			Clear	Hot	SUR-AM – 5
17				Rather Hot	SUR-AM – 5
18				Swam	SUR-AM – 5
19				Fresh	SUR-AM – 2
20				Cold	SUR-AM – 2
21			Sangat Cerah	Panas	SUR-AM – 5
22				Agak Panas	SUR-AM – 5
23				Hangat	SUR-AM – 5
24				Sejuk	SUR-AM – 2
25				Dingin	SUR-AM – 2
26			Over-Cloud	Hot	SUR-AM – 3
27				Rather Hot	SUR-AM – 3
28				Swam	SUR-AM – 3
29				Fresh	SUR-AM – 3
30				Cold	SUR-AM – 3
31			Cloud	Hot	SUR-AM – 3
32				Rather Hot	SUR-AM – 3
33				Swam	SUR-AM – 3
34				Fresh	SUR-AM – 3
35				Cold	SUR-AM – 3
36			Bright-Cloud	Hot	SUR-AM – 6
37				Rather Hot	SUR-AM – 6
38				Swam	SUR-AM – 6
39				Fresh	SUR-AM – 7
40				Cold	SUR-AM – 7
41			Clear	Hot	SUR-AM – 6
42				Rather Hot	SUR-AM – 6
43				Swam	SUR-AM – 6
44				Fresh	SUR-AM – 7
45				Cold	SUR-AM – 7
46			Clearest	Hot	SUR-AM – 6
47				Rather Hot	SUR-AM – 6
48				Swam	SUR-AM – 6
49				Fresh	SUR-AM – 7
50				Cold	SUR-AM – 7

From the computational results the output used in the actuator treatment is Rule Suram 2, according to table 7. Furthermore, from table 5 that the Rule Suram 2 is Heater ON, Damper OFF, and Sprayer OFF, the meaning is Increase Drying Temperature suddenly and decrease Drying Chamber Humidity Rd. And From equation 1, the required solar energy is: $I_o = 617 + 9.7(T_{do} - 45)$ (watt/m²) = $617 + 9.7(60 - 45) = 617 + 145.5 = 762.5$ Watt/ m².

Experiment Result

The measurement was carried out in Kampung Salaon-

dolok, Samosir Island, North Sumatra, Indonesia, as a coffee-producing area on Monday, April 12, 2021, at: 10.30 WIB. The prototype was prepared for the drying process of 100 kg of coffee with an average moisture content of 54.75%. Initial conditions: Initial temperature: 29.2 oC and humidity of 64%. The drying process is carried out for 7 full days, so that the drying process is completed on Monday, April 19, 2021 at 7.30 WIB. Parameter measurement results are presented in Figure 8. Coffee Moisture Content, Drying Chamber Temperature, Humidity Chamber, every 5 minutes.

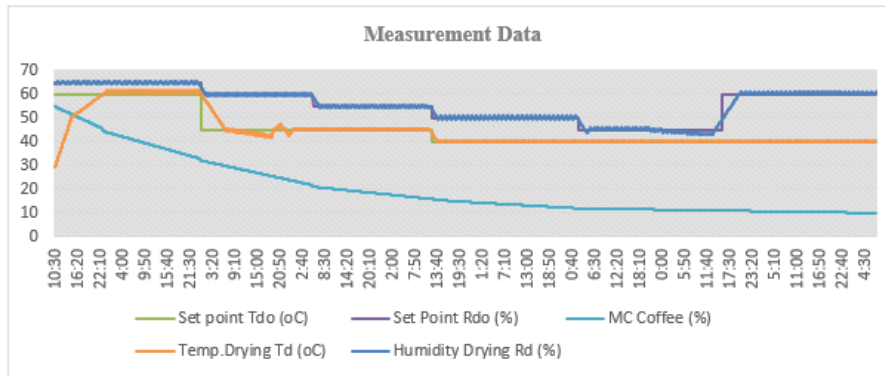


Figure 8: Measurement results: Moisture Content of MC coffee, Temperature Drying, and Humidity Drying on April 12 - 19- 2021

From the measurement results, it is shown that the Fuzzy Rule Suram algorithm is able to follow the coffee drying schedule. It is also shown that the dried coffee reaches the average Moisture content of coffee MC = 10%. The results of measurements of solar energy in the coffee drying process on April 12 - 19 2021 are presented

in Figure 9, showing that the solar energy used is 40, 86% of the total energy requirement. Solar energy is utilized maximally during the day and at night using a heater using electrical energy. For further development, a solar energy storage system is needed, so that it can be utilized at night.

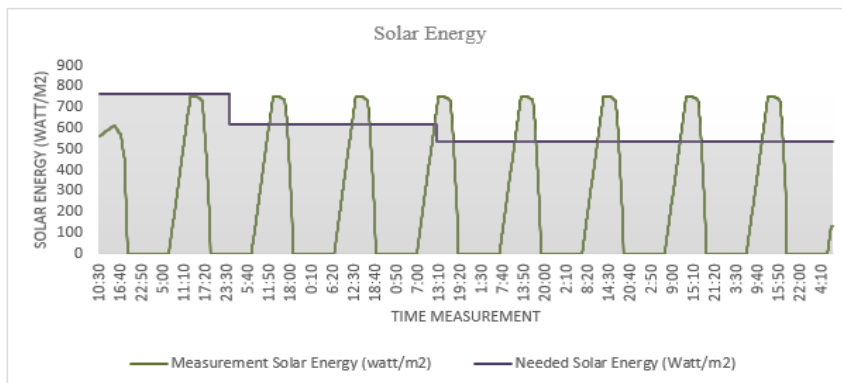


Figure 9: Measurement results of solar energy in the coffee drying process on 12 - 19 April 2021

CONCLUSION

The Fuzzy Rule Suram Algorithm in the coffee drying process is based on fuzzy logic with modified membership functions in the range [0,5, 1] on the parameters of weather conditions and air conditions in the form of ambient temperature and ambient humidity. In the computational process of this algorithm, 16 fuzzy rules to control the output system can be built which consist of 8 rules each for conditions of high wind speed above 2.8 m/s, and low wind speed.

There are 3 x 50 treatments for the heater actuator, damper and sprayer, based on the real humidity conditions of the drying room and the humidity according to the drying schedule.

From the results of the implementation on the prototype of this coffee dryer, the utilization of solar energy is 40.86% of the required energy, this is due to the acceleration of the drying process day and night continuously, but can save processing time from 21 days to 7 days.

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