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APPLICATION OF AIR HEATER AND COOLER USING FUZZY LOGIC CONTROL SYSTEM

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ABSTRACT

This research paper describes the design and implementation of an autonomous room air cooler using fuzzy rule based control system. The rule base receives two crisp input values from temperature and humidity sensors, divides the universe of discourse into regions with each region containing two fuzzy variables, fires and rules, and gives the output singleton values corresponding to each output variable. Three defuzzifiers are used to control the actuators ; cooler fan, water pump and room exhaust fan. The results obtained from the simulation were found correct according to the design model. This research work will increase the capability of fuzzy logic control systems in process automation with potential benefits. MATLAB-simulation is used to achieve the designed goal.

Keywords : Fuzzy logic control, MATLAB simulation.

Introduction:

The control system design, development and implementation need the specification of plants, machines or processes to be controlled. A control system consists of controller and plant, and requires an actuator to interface the plant and controller. The behavior and performance of a control system depend on the interaction of all the elements. The dynamical control systems design, modeling and simulation in local and distributed environment need to express the behavior of quantitative control system of multi-output variables control environment to establish the relation between actions and consequences of the control strategies.

Computational Intelligence(CI) is a field of intelligence processing related with different branches of computer sciences and engineering. The fuzzy systems are

Paradigm of CI. The contemporary technologies in the area of control and autonomous processing are benefitted using fuzzy sets.

The user based processing capability is an important aspect of fuzzy systems taken into accounts in any design consideration of human centric computing system. The human centricity plays a vital role in the areas of intelligent data analysis and system modeling. The elements of fuzzy sets belong to varying degrees of membership or belongingness. Fuzzy sets offer an important and unique feature of information granules. A membership function quantifies different degrees of membership. The higher the degree of membership A (x), the stronger is the level of belongingness of this element to A. Fuzzy sets provide an ultimate mechanism of communication between humans and computing environment.

The fuzzy logic and fuzzy set theory deal with nonprobabilistic uncertainties issues. The fuzzy control system is based on the theory of fuzzy sets and fuzzy logic. Previously a large number of fuzzy inference systems and defuzzification techniques were reported. These systems/ techniques with less computational overhead are useful to obtain crisp output. The crisp output values are based on linguistic rules applied in inference engine and defuzzification techniques.

The efficient industrial control with new techniques of fuzzy algorithm based on active rule selection mechanism to achieve less sampling time ranging from milliseconds in pressure control, and higher sampling time in case of temperature control of larger installations of industrial furnaces has been proposed.

Basic structure of the proposed model:

The basic structure of the proposed model of autonomous water room cooler consist of room air cooler and air heater with fuzzy logic control system. The room cooler mounted in room has heater fan, a cooler fan, a water pump to spread water on its boundary walls of grass roots or wooden shreds. A room exhaust fan, humidity and temperature sensors used to monitor the environment of room are mounted in the room. The sensors with amplification and voltage adjustment unit are connected with the two fuzzifiers of the fuzzy logic control system. Four outputs of defuzzifiers: heater fan speed control, cooler fan speed control, water pump speed control and room exhaust fan speed control are connected through actuators.

Simplified design algorithm of fuzzy logic for room air cooler system:

This simplified design algorithm is used to design the fuzzifier, inference engine, rule base and defuzzifier for the autonomous room air heating and cooling system according to the control strategy of the processing plant to archive the quantity and quality of the desire needs to maintain the room environment.

This design work uses five triangular membership function equally determined over a scale range of 0°C to 40°C for the temperature input and 0% to 100% relative humidity inputs. The five fuzzy membership functions for temperature inputs are termed as: cold 0-10°C, cool to 0-20°C, normal 10-30°C. As for humidity input, the five fuzzy membership functions are: dry 0%-25%,not too dry 0%-50%,moist 25%-75%, not too wet 50%-100%, and wet range 75%-100%. This fuzzy logic model aims to determine the amplitude of the voltage signal 0-5v to be sent to the four actuators for: heater fan speed, cooler fan speed, water pump speed and room exhaust fan speed to maintain a constant and desired environment. Her no time constrain is applied. Four outputs of this proposed system are: heater fan speed, cooler fan speed, water pump speed and room exhaust fan speed. Each output variable consist of five membership functions: Stop 0-5, Low 0-50, Medium 40-60, Fast 50-90, Very fast 90-100.

Fuzzifier:

The set points of fuzzifiers use the data of two input variables, “Temperature” and, “Humidity”. Their occupied region description, membership functions and range are given in TABLE 1 and TABLE 2.

Table 1

Membership Functions And Ranges Of Input Variable Temperature

Membership Function (Mf)	Ranges	Region Occupied
Cold	0-10	1
Cool	0-20	1-2

Normal	10-30	2-3
Warm	20-40	3-4
Hot	30-40	4

Table 2

Membership Functions And Ranges Of Input B Variable Humidity

Membership Function (MF)	Ranges	Region occupied
Dry	0-25	1
Not too Dry	0-50	1-2
Moist	25-75	2-3
Not too Wet	50-100	3-4
Wet	75-100	4

For each input variable, five membership functions are used

The five membership functions , "Cold", "Cool", "Normal", "Warm", "Hot" are used to show the various ranges of input fuzzy variables "TEMPERATURE" in a plot consisting of four regions.

The five membership functions, "Dry", "Not too Dry", "Moist", "Not too Wet" , "Wet" are used to show the various ranges of input fuzzy variable "HUMIDITY" in a plot also consisting of four regions.

The linguistic values are the mapping values of the fuzzy input variables with the membership functions occupied in the regions. As we are using two variables, therefore four linguistic values. The mapping of input fuzzy variables with the functions in four regions is listed in TABLE 3.

Table 3

Linguistic Values of Fuzzifiers Outputs In All Regions

Input Variables	Linguistic Fuzzifiers Outputs	Region 1	Region 2	Region 3	Region 4

Temperature	f_1	f_1 [1]	f_1 [2]	f_1 [3]	f_1 [4]
	f_2	f_1 [2]	f_1 [3]	f_1 [4]	f_1 [5]
Humidity	f_3	f_2 [1]	f_2 [2]	f_2 [3]	f_2 [4]
	f_4	f_2 [4]	f_2 [3]	f_2 [4]	f_2 [5]

Table 4

Rule Mapping For Regions Occupied

Case No.	**Regions Occupied**		**Rules**
	Temperature Input variable 1	**Humidity Input variable 2**	**f_n [m]= Membership value, where n=No. of input variable, m=No of membership func-**
1	1	1	$R_1=f_1$^f_3 = f_1[1]^f_2[1] $R_2=f_1$^f_4 = f_1[1]^f_2[2] $R_3=f_2$^f_3 = f_1[2]^f_2[1] $R_4=f_2$^f_4 = f_1[2]^f_2[1]
2	1	2	$R_1=f_1$^f_3 = f_1[1]^f_2[2] $R_2=f_1$^f_4 = f_1[1]^f_2[3] $R_3=f_2$^f_3 = f_1[2]^f_2[2] $R_4=f_2$^f_4 = f_1[2]^f_2[3]
3	1	3	$R_1=f_1$^f_3 = f_1[1]^f_2[3] $R_2=f_1$^f_4 = f_1[1]^f_2[4] $R_3=f_2$^f_3 = f_1[2]^f_2[3] $R_4=f_2$^f_4 = f_1[2]^f_2[4]
4	1	4	$R_1=f_1$^f_3 = f_1[1]^f_2[4] $R_2=f_1$^f_4 = f_1[1]^f_2[5] $R_3=f_2$^f_3 = f_1[2]^f_2[4] $R_4=f_2$^f_4 = f_1[2]^f_2[5]
5	2	1	$R_1=f_1$^f_3 = f_1[2]^f_2[1] $R_2=f_1$^f_4 = f_1[2]^f_2[2] $R_3=f_2$^f_3 = f_1[3]^f_2[1] $R_4=f_2$^f_4 = f_1[3]^f_2[2]

6	2	2	$R_1=f_1$^f_3 = $f_1[2]$^$f_2[2]$ $R_2=f_1$^f_4 = $f_1[2]$^$f_2[3]$ $R_3=f_2$^f_3 = $f_1[3]$^$f_2[2]$ $R_4=f_2$^f_4 = $f_1[3]$^$f_2[3]$
7	2	3	$R_1=f_1$^f_3 = $f_1[2]$^$f_2[3]$ $R_2=f_1$^f_4 = $f_1[2]$^$f_2[4]$ $R_3=f_2$^f_3 = $f_1[3]$^$f_2[3]$ $R_4=f_2$^f_4 = $f_1[3]$^$f_2[4]$
8	2	4	$R_1=f_1$^f_3 = $f_1[2]$^$f_2[4]$ $R_2=f_1$^f_4 = $f_1[2]$^$f_2[5]$ $R_3=f_2$^f_3 = $f_1[3]$^$f_2[4]$ $R_4=f_2$^f_4 = $f_1[3]$^$f_2[5]$
9	3	1	$R_1=f_1$^f_3 = $f_1[3]$^$f_2[1]$ $R_2=f_1$^f_4 = $f_1[3]$^$f_2[2]$ $R_3=f_2$^f_3 = $f_1[4]$^$f_2[1]$ $R_4=f_2$^f_4 = $f_1[4]$^$f_2[2]$
10	3	2	$R_1=f_1$^f_3 = $f_1[3]$^$f_2[2]$ $R_2=f_1$^f_4 = $f_1[3]$^$f_2[3]$ $R_3=f_2$^f_3 = $f_1[4]$^$f_2[2]$ $R_4=f_2$^f_4 = $f_1[4]$^$f_2[3]$
11	3	3	$R_1=f_1$^f_3 = $f_1[3]$^$f_2[3]$ $R_2=f_1$^f_4 = $f_1[3]$^$f_2[4]$ $R_3=f_2$^f_3 = $f_1[4]$^$f_2[3]$ $R_4=f_2$^f_4 = $f_1[4]$^$f_2[4]$
12	3	4	$R_1=f_1$^f_3 = $f_1[3]$^$f_2[4]$ $R_2=f_1$^f_4 = $f_1[3]$^$f_2[5]$ $R_3=f_2$^f_3 = $f_1[4]$^$f_2[4]$ $R_4=f_2$^f_4 = $f_1[4]$^$f_2[5]$
13	4	1	$R_1=f_1$^f_3 = $f_1[4]$^$f_2[1]$ $R_2=f_1$^f_4 = $f_1[4]$^$f_2[2]$ $R_3=f_2$^f_3 = $f_1[5]$^$f_2[1]$ $R_4=f_2$^f_4 = $f_1[5]$^$f_2[2]$
14	4	2	$R_1=f_1$^f_3 = $f_1[4]$^$f_2[2]$ $R_2=f_1$^f_4 = $f_1[4]$^$f_2[3]$ $R_3=f_2$^f_3 = $f_1[5]$^$f_2[2]$ $R_4=f_2$^f_4 = $f_1[5]$^$f_2[3]$

15	4	3	$R_1=f_1$^f_3 = $f_1[4]$^$f_2[3]$ $R_2=f_1$^f_4 = $f_1[4]$^$f_2[4]$ $R_3=f_2$^f_3 = $f_1[5]$^$f_2[3]$ $R_4=f_2$^f_4 = $f_1[5]$^$f_2[4]$
16	4	4	$R_1=f_1$^f_3 = $f_1[4]$^$f_2[4]$ $R_2=f_1$^f_4 = $f_1[4]$^$f_2[5]$ $R_3=f_2$^f_3 = $f_1[5]$^$f_2[4]$ $R_4=f_2$^f_4 = $f_1[5]$^$f_2[5]$

Fuzzifier converts the input crisp value into the linguistic fuzzy values. The output of fuzzifier gives the linguistic values of fuzzy set for the two input variables, two fuzzifiers are used which are shown in Table 5.

Each fuzzifier consist of : a multiplier : which converts the input voltage range 0-5v into the crisp value 0-40 for temperature by multiplying the input with 10,and the crisp value 0-100 for humidity by multiplying the input with 25,comparators ; used to decide the region occupied by input variable, subtractors; used to find the difference of crisp value from the end value of each region, multiplexer; using the address information from the region selection and inputs from the four subtractors, multiplex the four values because the system is designed for the four predefined regions, divider; used to divide the difference value in each selected region by 10 to find the mapping value of membership function with the input variable value of temperature in that region, and to find the mapping value of membership function for input variable value of humidity, divide the difference value in each selected region by 25, a second fuzzy set subtractor; used to find the active value of the second fuzzy set by subtracting the first active fuzzy set value from 1. The general internal hardware structural scheme of a fuzzifier for four regions and the results of fuzzification are shown in TABLE 5 for mathematical analysis.

Table 5

Results of Fuzzification

Input variables	Input voltage(u)	Values	Region selection	Fuzzy set calculation
Temperature	1.9 volts	X=10u=19	10<=x<20 Region -2	f1=(20-19)/10=0.1 f2=1-f1=1-0.1=0.9

Humidity	0.8 volts	X=25u=20	0<=x<25	f3=(30-20)/25=0.4 f4=1-f3=1-0.4=0.6

Inference Engine

The inference engine consists of four AND operators, these are not the logical ANDs but select minimum value input for the output. This inference engine accepts four inputs from fuzzifier and applies the min-max composition to obtain the output R values. The min-max inference method uses min-AND operation between the four inputs. Fig. 7 shows this type of inference process. Number of active rules = m^n**,** where m = maximum number of overlapped fuzzy sets and n = number of inputs. For this design, m = 5 and n = 2, so the total number of active rules are 25. The total number of rules is equal to the product of number of functions accompanied by the input variables in their working range. The two input variables described here consisted of five membership functions. Thus, 5 x 5 = 25 rules were required which are shown in TABLE 6.

Table 6

Total Number of Rules

Temperature (◦C)	Humidity %	Speed of Heater Fan	Speed of Cooler Fan	Speed of Water Pumb	Speed of Room Exhaust Fan
Cold	Dry	High	Stop	Fast	Fast
Cold	Not too dry	Medium	Stop	Medium	Slow
Cold	Moist	Medium	Stop	Medium	Slow
Cold	Not too wet	Low	Stop	Low	Slow
Cold	Wet	Low	Low	Stop	Slow

Cool	**Dry**	**Medium**	**Stop**	**Medium**	**Slow**
Cool	**Not too dry**	**Low**	**Stop**	**Low**	**Stop**
Cool	Moist	Low	Stop	Low	Stop
Cool	Not too wet	Stop	Low	Low	Medium
Cool	Wet	Stop	Low	Stop	Medium
Normal	**Dry**	**Stop**	**Low**	**Medium**	**Slow**
Normal	**Not too dry**	**Stop**	**Low**	**Medium**	**Slow**
Normal	Moist	Stop	Stop	Medium	Stop
Normal	Not too wet	Low	Low	Stop	Slow
Normal	Wet	Low	Low	Stop	Slow
Warm	Dry	Stop	Stop	Low	Stop
Warm	Not too dry	Stop	Stop	Low	Stop
Warm	Moist	Medium	Medium	Stop	Slow
Warm	Not too wet	Low	Low	Medium	Slow
Warm	Wet	Low	Low	Medium	Slow
Hot	Dry	Stop	High	High	Stop
Hot	Not too dry	Stop	High	High	Slow
Hot	Moist	Stop	High	High	Medium
Hot	Not too wet	Stop	High	Medium	Medium
Hot	Wet	Stop	High	Low	Stop

In this case only 4 rules are required for the particular values of the two variable s because each value of two variables in a region corresponds to mapping of two functions. The corresponding mapping values of f_1 [2], f_1[3] , f_2[3], f_2[4] were used to establish the 4rules. Here f_1[3] means the corresponding mapping value of membership function “Cool” of temperature in region – 2 and the similar definitions are for the others.

$R_1 = f_1 \wedge f_3 = f_1[2] \wedge f_2[3] = 0.1 \wedge 0.4 = 0.1$

$R_2 = f_1 \wedge f_4 = f_1[2] \wedge f_2[4] = 0.1 \wedge 0.6 = 0.1$

$R_3 = f_2 \wedge f_3 = f_1[3] \wedge f_2[3] = 0.9 \wedge 0.4 = 0.4$

$R_4 = f_2 \wedge f_4 = f_1[3] \wedge f_2[4] = 0.9 \wedge 0.6 = 0.6$

Rule Selector

The rule selector receives two crisp values of temperature and humidity. It gives singleton values of output functions under algorithm rules applied on design model. For two variables, four rules are needed to find the corresponding singleton values S1, S2, S3 and S4 for each variable according to these rules are listed in Table 7.

Table 7

Illustration of Rules Applied Model

Rule No.	Inputs		Singleton values of outputs				
	Temperature	**Humidity**	**Speed of Heater Fan**	**Speed of cooler Fan**	**Speed of water pump**	**Speed of Room exhaust Fan**	**Singleton Values**
1	**Cool**	Dry	Medium= 0.50	Stop =0.1	Medium= 0.50	Fast =0.70	S1
2	**Cool**	Not too dry	Low= 0.25	Stop= 0.1	Low= 0.25	Medium= 0.50	S2
3	**Normal**	Dry	Stop= 0.1	Low= 0.25	Medium= 0.50	Slow= 0.25	S3
4	**Normal**	Not too dry	Stop= 0.1	Low = 0.25	Medium= 0.50	Slow= 0.25	S4

The rule base accepts two crisp input values, distributes the universe of discourse into regions with each region containing two fuzzy variables, fires the rules, and gives the output singleton values corresponding to each output variable.

Deffuzifier

In this system, three defuzzifiers control the actuators; speed of heater fan, speed of cooler fan, speed of water pump, speed of room exhaust fan. The membership functions of the three output variables, and the detail of each plot is given in TABLE 8.

Table 8

Output Variables Membership Functions

MF_S	Range	Speed of Heater Fan	Speed of Cooler Fan	Speed of Water Pump	Speed of Room Exhaust Fan

MF_1	0-5	High	Stop	Medium	Medium
MF_2	0-50	Low	Low	Low	Slow
MF_3	40-60	Low	Medium	Medium	Medium
MF_4	50-90	Stop	High	High	Fast
MF_5	70-100	Stop	Very high	Very high	Very fast

The defuzzification process provides the crisp value outputs after estimating its inputs. In this system 8 inputs are given to each of three defuzzifiers. Four values of R1, R2, R3, R4 from the outputs of inference engine and four values S1, S2, S3, S4 from the rule selector are shown in Fig. 10. Each defuzzifier estimates the crisp value output according to the center of average (C.O.A) method using the mathematical expression, ∑S i * Ri /∑Ri , where *i* = 1 to 4. Each output variable membership function plot consists of five functions with the same range values for simplification. Fig.12 shows the design arrangement of a defuzzifier. One defuzzifier consists of : one adder for **∑Ri** , four multipliers for the product of Si * Ri , one adder for ∑S **i * Ri** , and one divider for ∑S **i * Ri** /∑**Ri**. Finally a defuzzifier gives the estimated crisp value output.

RESULTS AND DISCUSSION

The designed values for three outputs; cooler fan speed, water pump speed and room exhaust fan **∑Ri** = R1+R2+R3+R4 = 0.1+0.1+0.4+0.6 = 1.2

Table 9

Designed Value For Heater Fan Speed

I	Si	Ri	Si*Ri
1	0.50	0.1	0.05
2	0.25	0.1	0.025
3	0.1	0.4	0.04
4	0.1	0.6	0.06

∑Si * Ri = 0.175 & ∑Ri = 1.2

∑Si * Ri / ∑Ri = 0.175 / 1.2

= 0.1457

= 14.57% of Heater fan speed.

Table 10

Designed Value For Heater Fan Speed

I	Si	Ri	Si*Ri
1	0.1	0.1	0.01
2	0.1	0.1	0.01
3	0.25	0.4	0.1
4	0.25	0.6	0.15

∑Si * Ri = 0.27 & ∑Ri = 1.2

∑Si * Ri / ∑Ri = 0.27 / 1.2

= 0.225

= 22.5% of Cooler fan speed.

Table 11

Designed Value For Water Pump Speed

I	Si	Ri	Si*Ri
1	0.50	0.1	0.05
2	0.25	0.1	0.025
3	0.50	0.4	0.2
4	0.50	0.6	0.3

∑Si * Ri = 0.575 & ∑Ri = 1.2

∑Si * Ri / ∑Ri = 0.575 / 1.2

= 0.4792

= 47.92% of Water pump speed.

Table 12

Designed Value For Exhaust Fan Speed

I	Si	Ri	Si*Ri
1	0.70	0.1	0.07
2	0.50	0.1	0.05
3	0.25	0.4	0.1
4	0.25	0.6	0.15

$\sum Si * Ri = 0.37$ & $\sum Ri = 1.2$

$\sum Si * Ri / \sum Ri = 0.37 / 1.2$

$= 0.3083$

= 30.83% of Exhaust fan speed.

Using mathematical expression $\sum$S **i * Ri / $\sum$Ri** the crisp values for output variables were determined and the results were found according to the MATLAB simulation. These results are compared in TABLE 14 and found correct according to the design model.

MATLAB simulation was adapted according to the arrangement of membership functions for four rules as given in TABLE 12.

Table 13

Arrangement of Membership Functions For Simulation

Rule no	Inputs		Outputs			
	temperature	Humidity	Speed of Heater Fan	Speed of Cooler Fan	Speed of Water Pump	Speed of Room Exhaust Fan
1	Cool	Dry	Medium	Stop	Medium	Fast
2	Cool	Not too dry	Low	Stop	Low	Medium
3	Normal	Dry	Stop	Low	Medium	Slow
4	Normal	Not too dry	Stop	Low	Medium	Slow

In Fig. 13 the same values of input variables, Temperature = 28, and Humidity = 40 are shown. Various values of input and output variables match the dependency scheme of the system design. The simulated values were checked using MATLAB-Rule.

The correctness of results shows the validity of the simplified design work for processing system using fuzzy control system.

Table 14
Comparison of Simulated And Calculated Result

Result	Speed of Heater Fan	Speed of Cooler Fan	Speed of Water Pump	Speed of Room Exhaust Fan
Design values	14.57	22.5	47.92	30.83
MATLAB Simulation	11.9	20.3	49.1	27.8
% error	6.3	4.8	5.6	7.1

Simulation Graphs Discussion

This system was simulated for the given range of input variables. The given value of: Temperature = 19 lies in region 2 of the range 10-20 and Humidity = 20 lies in region 3 of the range 0-25. The four rules were applied for MATLAB simulation according to this range scheme. In this design model, the speed of heater fan and the speed of cooler fan depends upon the selected value of temperature sensor, water pump and exhaust fan speeds depend on the value of humidity. The simulated and calculated results are according to the reliance scheme.

The cooler fan speed is directly proportional to temperature and it does not depend upon the humidity. The water pump speed is inversely proportional to humidity and it does not depend upon the temperature. The exhaust fan speed is directly proportional to humidity.