International Journal of Trend in Scientific Research and Development (IJTSRD)
International Open Access Journal
ISSN No: 2456 - 6470 | www.ijtsrd.com | Volume - 2 | Issue – 5

Color and Height Control of Fluid Mixing System Using Fuzzy Logic

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ABSTRACT
This paper presents a qualitative control of a fluid mixer, which is a non-linear plant. The mixer has as inputs two fluids of the resulting mix. The control system consists of two independent fuzzy controllers which are responsible for maintaining the water level at a given height and for adjusting the color of the fluid in the mixing tank. The main points studied are response when the desired color is changed and when the output flow changes. Simulation results show that approach of using two independent controllers, with simple rule-bases, can give good results. The simulation of fuzzy logic controller for a fluid mixing system using MAT LAB Simulink and MAT LAB Fuzzy Logic Toolbox. The Centroid (MAMDANI) method and center of gravity singleton method for defuzzification will be used in the inference engines.

Key words: *Fluid Mixing Process, Fuzzy Logic Controller, MATLAB simulation, MATLAB Fuzzy Logic Toolbox*

I. INTRODUCTION
Ordinary fuzzy controllers have been successfully applied to a variety of plants since the pioneering works of MANDANI and collaborators. In the case of multivariable processes, the natural method can be to consider as rules experiences all the controller inputs, which raise in number as the number of desired outputs, or reference inputs, develops. This would certainly make the process of designing the control strategy, or rule –base, a more complex one. [1]On the other hand, if independent controllers are used simpler and the control strategy develops potentially more reliable. In this case of robot control through a learning fuzzy controller, it has been presented that the use of independent controllers for each link can provide good results. That is, the controller, by adjusting their set of rules, copes very well with the coupling between variables. In this work, the method of using separate fuzzy controllers is employed, with the purpose of verifying whether this strategy is satisfactory.

II. DESCRIPTION OF THE PLANT
In the fluid mixing process, there are two auxiliary tanks as shown in Figure1.The first auxiliary tank contains colored water C_1, while the second one comprises clear water C_2.Two valves control the input flow q to the mixing tanks which contains mixed liquid C_0 that controlled the output flows $q_1$and q_2 from the auxiliary tanks. [2]

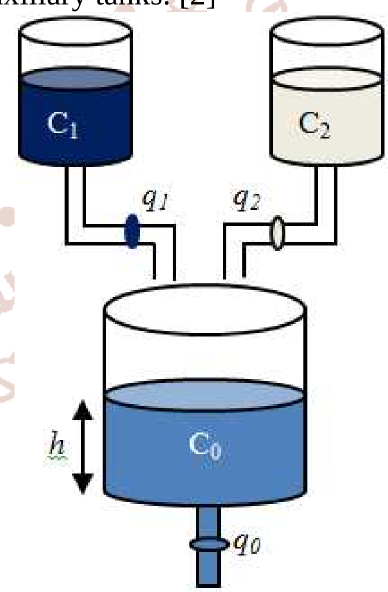

Figure1. A Fluid Mixer

The output flow q_0 is taken as a disturbance, has the coloration c of the resulting mix and is a function of the output pipe cross-section ab, of the liquid level h in the mixing tank and of a constant Cd associated to the shape and material of the output pipe.

In order to make simpler the simulation, it has been supposed that:

- The auxiliary tanks always contain sufficient liquid for the process to keep on running.
- The time required to get a constant mixture is ignored.
- The time delays associated to the fluid flow in the pipes are ignored.
- The dynamics of the input valves are ignored.

The following equations model the plant,

$$q - q_0 = \frac{dV}{dt} = S.\frac{dh}{dt} \quad cm^3s^{-1} \tag{1}$$

$$q = q_1 + q_2 \; cm^3s^{-1} \tag{2}$$

Taking into concern the dynamics of the output valve:

$$q_0 = Cd\ .ab\ .\sqrt{2\,gh} \quad cm^3s^{-1} \tag{3}$$

Where,
g = the gravity acceleration,
V= the volume of liquid and
S = the area of the liquid surface in the mixing tank.

By using (3) in (1):

$$\frac{dh}{dt} = -\frac{Cd\ .ab\ .\sqrt{2\,gh}}{S} + \frac{q}{S} \tag{4}$$

The mixing process is modeled by:

$$\frac{dh}{dt} = \frac{1}{S}(q1 + q_2 - q_0) \tag{5}$$

$$c_1.q_1 - c_0.q_0 = \frac{d\,(c_0.S.h)}{dt} = S.(c_0.\frac{dh}{dt} + h\,\frac{dc_0}{dt}) \tag{6}$$

By combining (5) and (6):

$$\frac{dc_0}{dt} = \frac{1}{Sh}.(c_1.q_1 - c_0(q_1 + q_2)) \tag{7}$$

Equations (4) and (7) designate the system's dynamics; h and c0 are the variables to be used by the controlling system.

The mixing tank properties and values used are as specified in Table 1. [3]

Table1. Mixing process variables and values

Variables	Description	Values
C_0	Colorations(no unit)	Variable
C_1	Colorations(no unit)	1
C_2	Colorations(no unit)	0
q	Input flow(cm^3s^{-1})	Variable
q_1,q_2	Output flows from the mixing tanks(cm^3s^{-1})	Variable
q_0	Output flow from the mixing tank (cm^3s^{-1})	Variable
h	Liquid level in the mixing tank	Variable
h_{ink}	Initial liquid level in the mixing tank (cm)	5
h_{max}	Maximum allowable height of water in tank(cm)	100
ab	Output pipe cross-section (cm^2)	0.1
S	Area of the liquid surface in the mixing tank(cm^2)	3600
C_d	Constant related to the shape and material of the output pipe.	3
g	Gravity acceleration(cms^{-2})	980

III. FUZZY LOGIC CONTROL SYSTEM

In the FLC controller, there are three main parts such as Fuzzification, Fuzzy Logic Rule Base and Defuzzification. Figure 2 shows the block diagram of FLC with a Fluid Mixing Process.

Fuzzification:
Converting the physical values of the current process signal, the error signal.

Rule-Base:
A group of rules may use several variables both in the condition and the conclusion of the rules.

Defuzzification:
Converting all the fuzzy terms created by the rule base of the controller to crisp terms (numerical values)

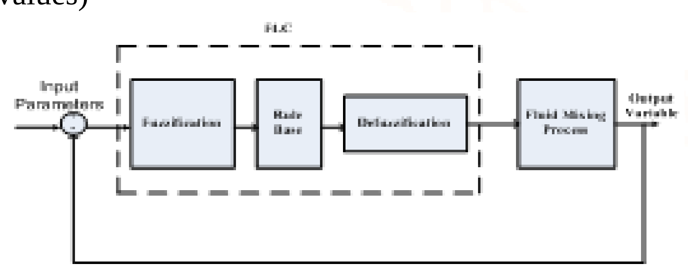

Figure2. Block Diagram of FLC with a Fluid Mixing Process.

For an sample, study a simple system where each rule involves two experiences and one resultant .A fuzzy system with two non-interactive inputs x_1 and x_2(experiences)and a single output y(resultant) are described by a collection n of n linguistic if-then propositions.

$$\text{IF}x1 \text{ is } A_1^{(k)} \text{ and } x_2 \text{ is } A_2^{(k)} \text{ THEN } y^{(k)} \text{ is } B^{(k)}, \quad (8)$$

k=1, 2…, n.

Where $A_1^{(k)}$ and $A_2^{(k)}$are fuzzy sets representing the k^{th} antecedent pairs and $B^{(k)}$ are the fuzzy sets representing the k^{th} resultant. Created on the MAMDANI implication method inference, and for a set of disjunctive rules, the accumulated output for the *n* rules will be given by,

$$\mu_B^{(k)}(y)=\text{Max-Min}[\mu A_1^{(k)}(\text{input}(i),\mu A_2^{(k)}(\text{input}(j))] \quad (9)$$

Since the process needs at its input non-fuzzy values, the controller output fuzzy set must be defuzzified, the result being a value μ. In the fluid mixing process under concern, the FLC controller controls both the output coloration C_0 and the liquid height *h* in the mixing tank at desired set point. The fuzzy controller has three inputs *Ec*, *DEc* and *Eh* and two outputs *q* and *qr*.

A. Coloration Control

The numerical information needed by the control system in order to attain those goal line is set by the coloration error Ec and the change of error DEc and the height error, it is more suitable to choose as output variable the total flow q and the proportion qr of the colored water in the flow, defined as:

$$q_r = \frac{q_1}{q_1 + q_2} \quad (10)$$

In design of color controller, fuzzy sets N, Z, P are assigned to *Ec* and *DEc*as specified in Figure 5 and 6.

Where: N: Negative

Z : Zero

P : Positive

Table2 shows the fuzzy logic rule base for color control for a fluid mixing process. There are three linguistic variables and 9 rules are used for color control. In the coloration controller, fuzzy sets *N,Z,P* are used for Ec and DEc, while fuzzy sets *L, M, H* are used for the controller output qr as specified by their membership functions shown in figure 4,5 and 6 respectively.

B. Height Control

In design of height controller, fuzzy sets *H*, *Z*, *L* are assigned to *Eh* and *N* ,*Z*, *P* are assigned to r as specified in Figure 8 and Figure 9 respectively. The output *q* represents by fuzzy sets *close fast*, *close low*, *no change*, *open low and open fast* illustrated in Figure 10. Where:

H=High N=Negative

Z=Zero Z =Zero

L=Low P =Positive

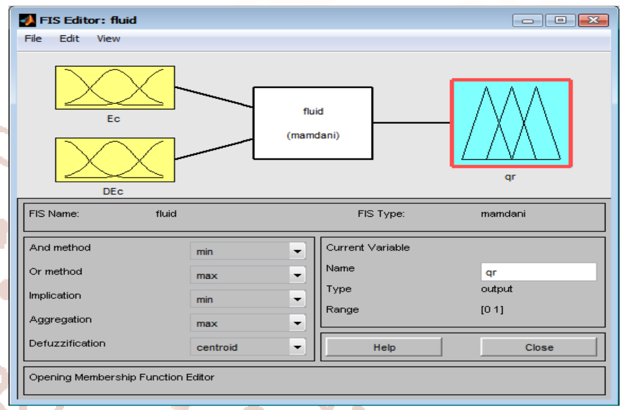

Figure 3.FIS Editor of Fuzzy Logic Controller for color control

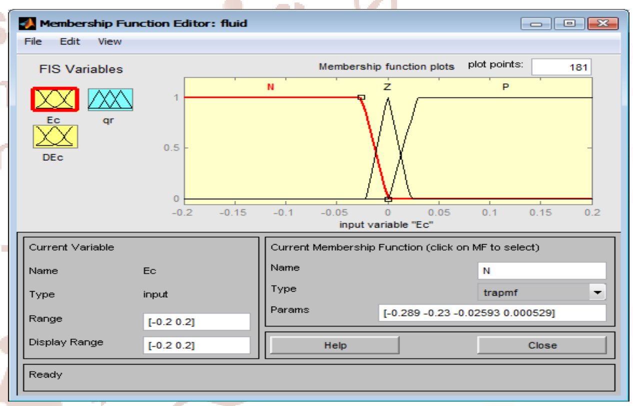

Figure4. Membership function Editor of FLC for Ec

Table3 shows the fuzzy logic rule base for height control for a fluid mixing process.

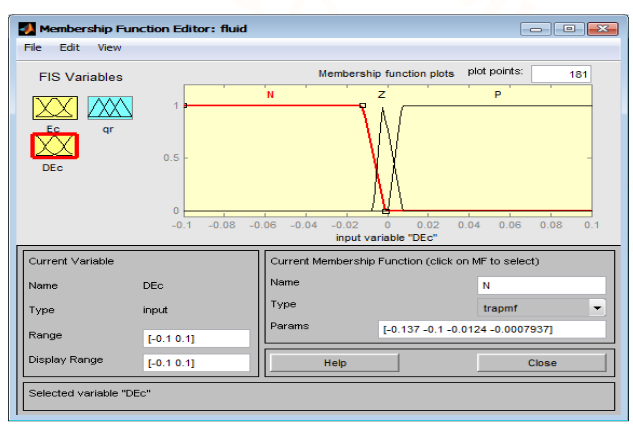

Figure5. Membership function Editor of FLC for DEc

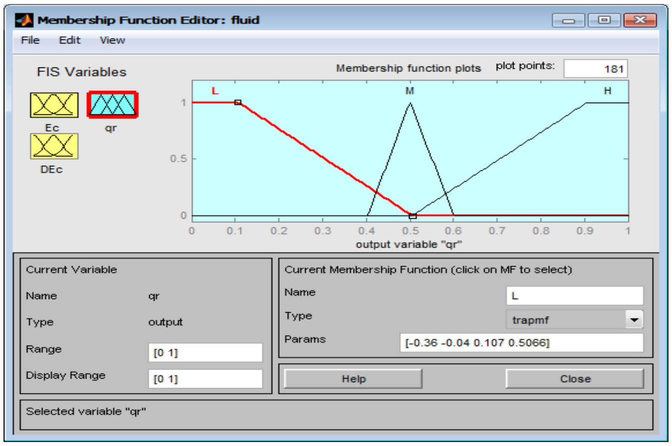

Figure6. Membership function Editor of FLC for qr

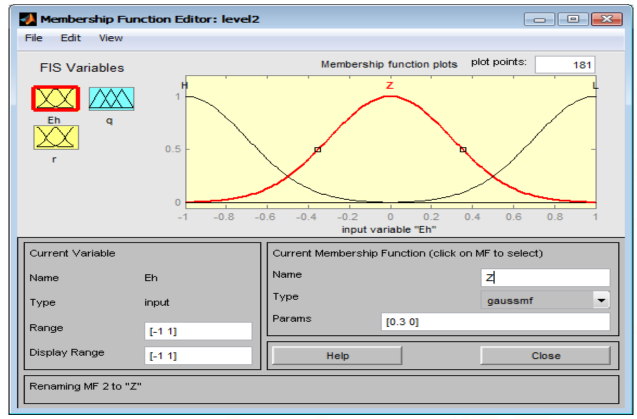

Figure8. Membership function Editor of FLC for Eh

Table 2: Rule Base for Color Control

No.	INPUTS		OUTPUTS
	Ec	DEc	qr
1	N	N	L
2	Z	N	L
3	P	N	M
4	N	Z	L
5	Z	Z	M
6	P	Z	H
7	N	P	M
8	Z	P	H
9	P	P	H

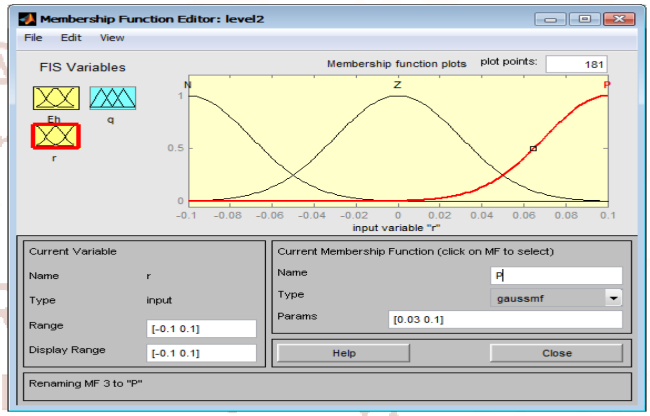

Figure9. Membership function Editor of FLC for r

Table 3: Rule Base for Color Control

No.	INPUTS		OUTPUTS
	Eh	r	q
1	Z	-	no change
2	L	-	open fast
3	H	-	close fast
4	Z	P	close low
5	Z	N	open low

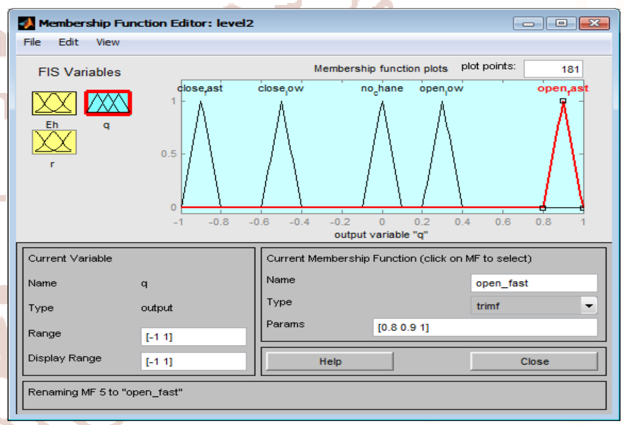

Figure10. Membership function Editor of FLC for q

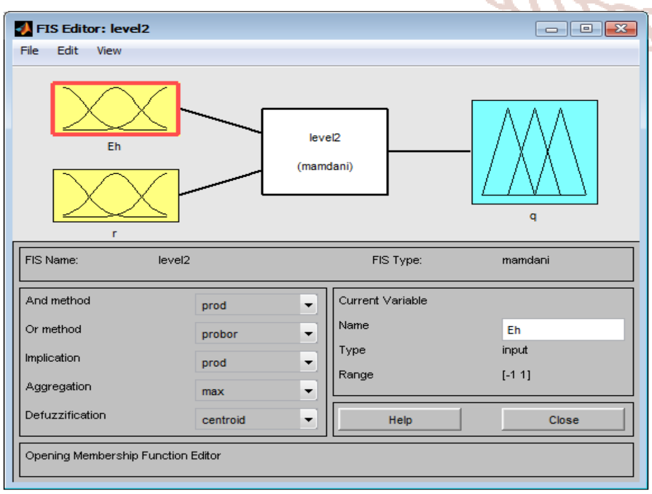

Figure7. FIS Editor of Fuzzy Logic Controller for color control

IV. SIMULATION RESULT OF FUZZY LOGIC CONTROLLER

The result of the simulation of fuzzy logic based of color control for fluid mixing process as shown in Figure 11.The desired color is defined by fuzzy logic between 0 and 1.There are two input and one output controller is used to achieve desired coloration. The two FLC inputs *Ec and DEc* are 0.2*(P)*, 0*(Z)* respectively. The result of the simulation of fuzzy logic based of height control for fluid mixing process as shown in Figure 15.There are two input and one output controller is used to achieve desired height. The two FLC inputs *Eh and r* are 0.2*(Z)*, 0 respectively. The outputs of controllers *qr* and *q* are 0.8199*(H)* and 0.029*(no change)*.Figure 12 and 16 show the checking with MATLAB command box for FLC respectively. The rule viewer of FLC as shown in Figure13 and 17 whereas the surface viewer of FLC for simulation results as shown in Figure14 and 18 respectively. Design system has flexibility to easily adjust the input and output parameters according to the mixture requirement.

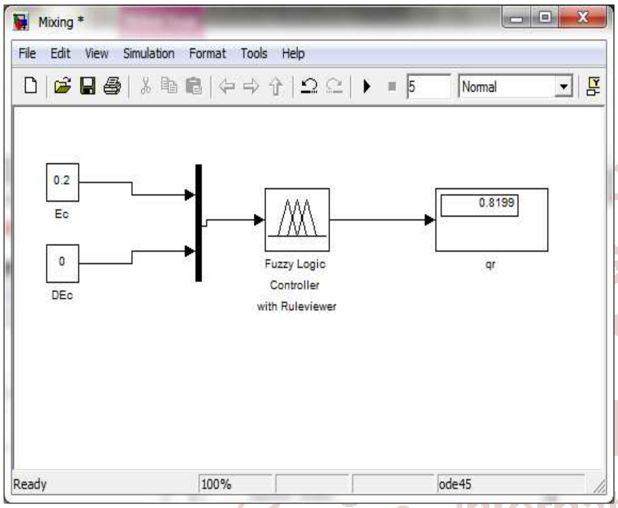

Figure11.Checking with MATLAB SIMULINK for color control

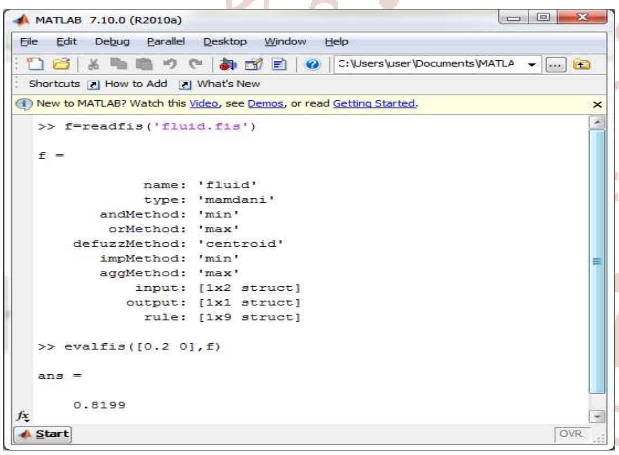

Figure12.Checking with MATLAB Command Box for color control

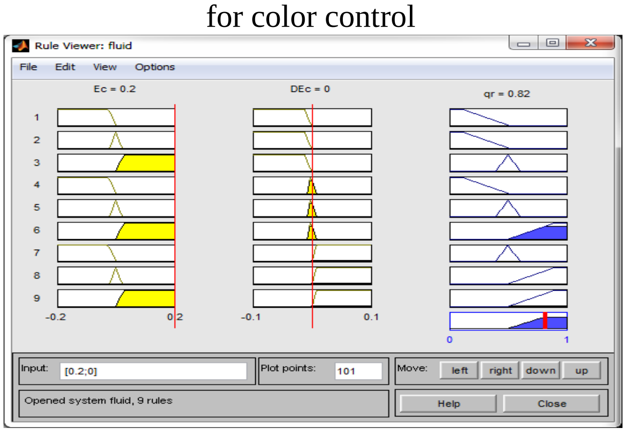

Figure13.Rule Viewer of FLC for color control

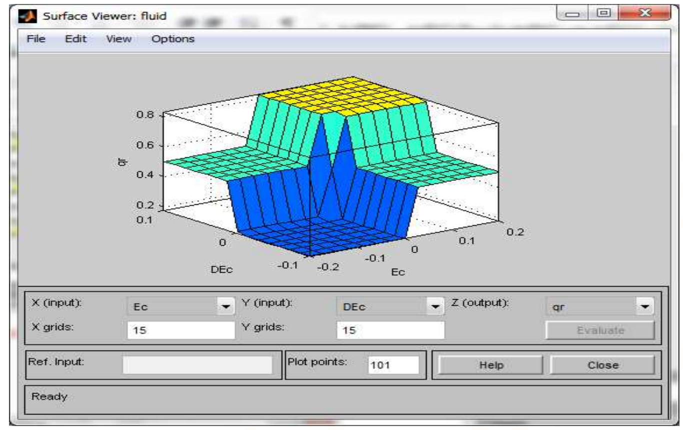

Figure14. Surface viewer of FLC for *Ec*,*DEc*, and *qr*

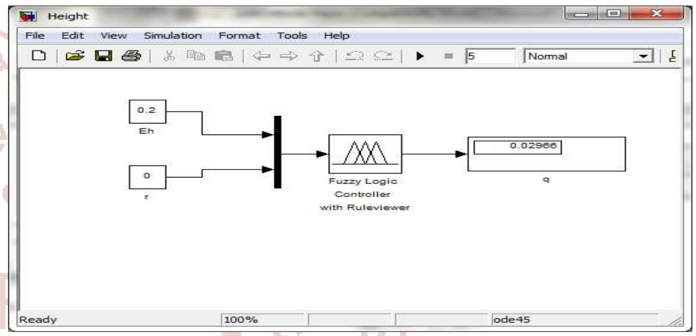

Figure15.Checking with MATLAB SIMULINK for height control

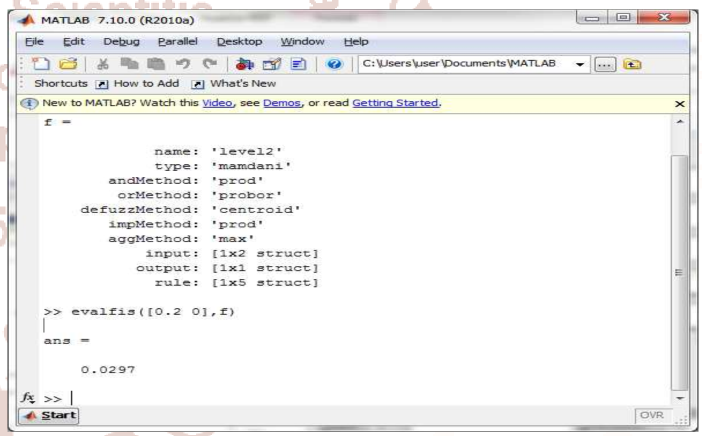

Figure16.Checking with MATLAB Command Box for height control

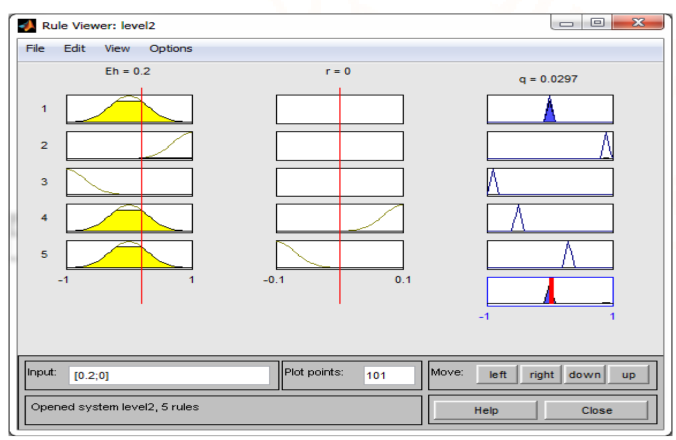

Figure17.Rule Viewer of FLC for height control

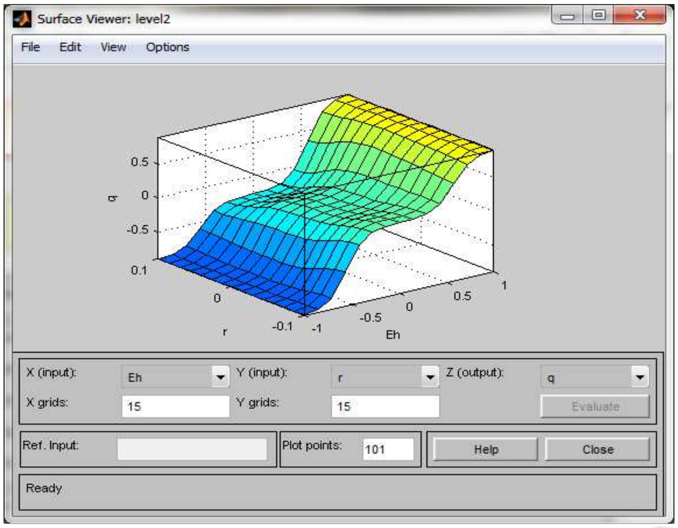

Figure18. Surface viewer of FLC for *Eh*,*r* and *q*

V. CONCLUSION

This design system has elasticity to easily adjust the input and output parameters according to the mixing process. This design is very useful for fluid mixing process and it is widely used in industrial applications. In the case of mixing process, Fuzzy Logic Controller becomes simpler and the control strategy becomes potentially more reliable.

ACKNOWLEDGMENT

I would wish to acknowledge the many colleagues at Mandalay Technological University who have contributed to the passing this research paper.

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