Intelligent Control Systems (0640734)

Lecture (7)

Fuzzy Logic Control

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Conventional Control:

After gaining an intuitive understanding of the plant's dynamics and establishing the design objectives, the control engineer typically solves the control problem by doing the following:

1. Developing a model of the plant to be controlled.
2. Using the mathematical model, or a simplified version of it, to design a controller .
3. Using the mathematical model of the closed-loop system and mathematical or simulation-based analysis to study its performance (possibly leading to redesign).
4. Implementing the controller and evaluating the performance of the closed-loop system (again, possibly leading to redesign).

Conventional Control:

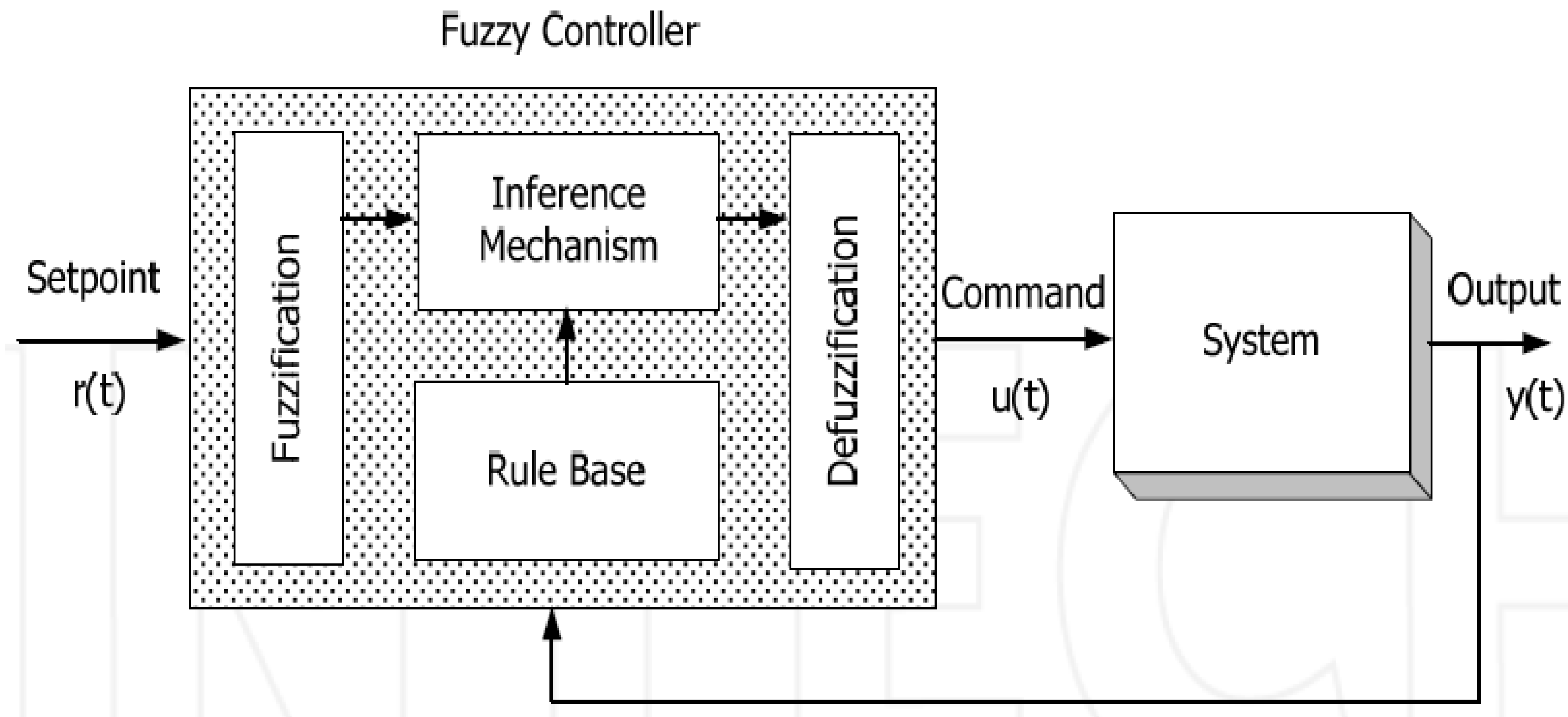
Mathematical model of the plant:

- never perfect
- an abstraction of the real system
- "is accurate enough to be able to design a controller that will work."!
- based on a system of differential equations

$$\dot{x} = Ax + Bu$$
$$y = Cx + Du$$

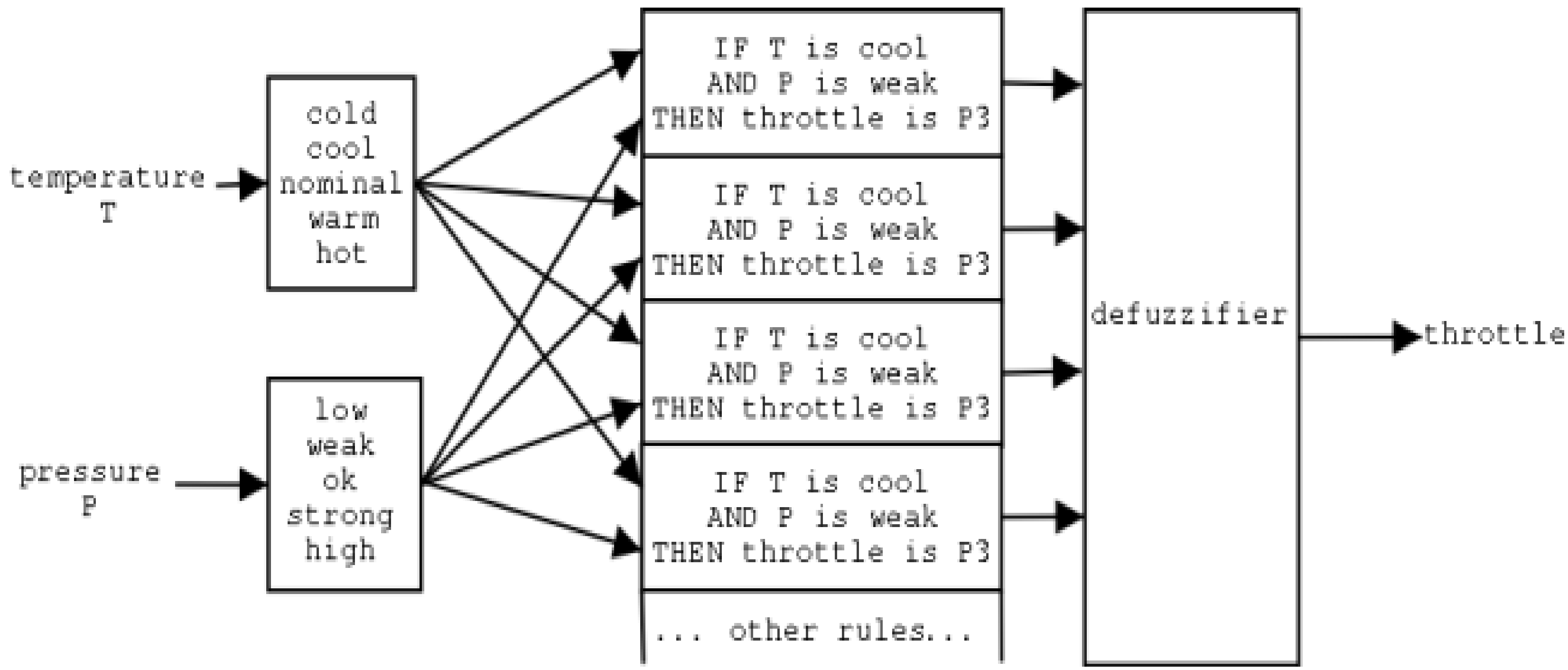
In this case u is the m-dimensional input; x is the n-dimensional state ($\dot{x} = \frac{dx(t)}{dt}$); y is the p dimensional output; and A, B, C, and D are matrices of appropriate dimension.

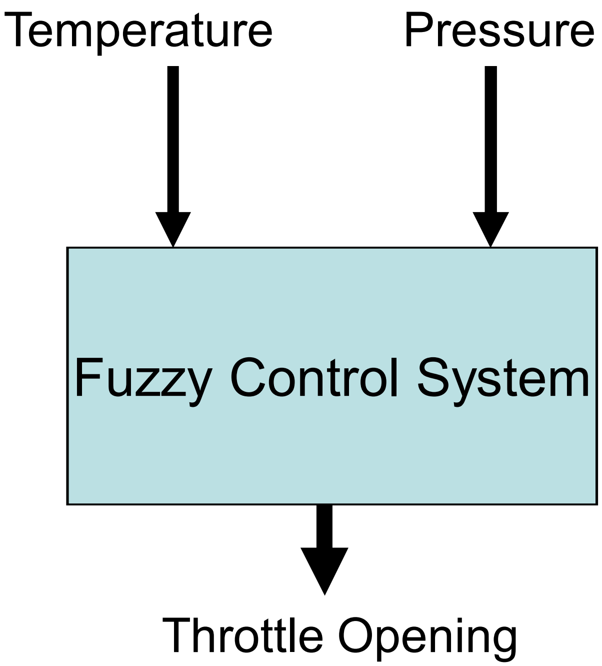
General Structure of Fuzzy Control Systems:



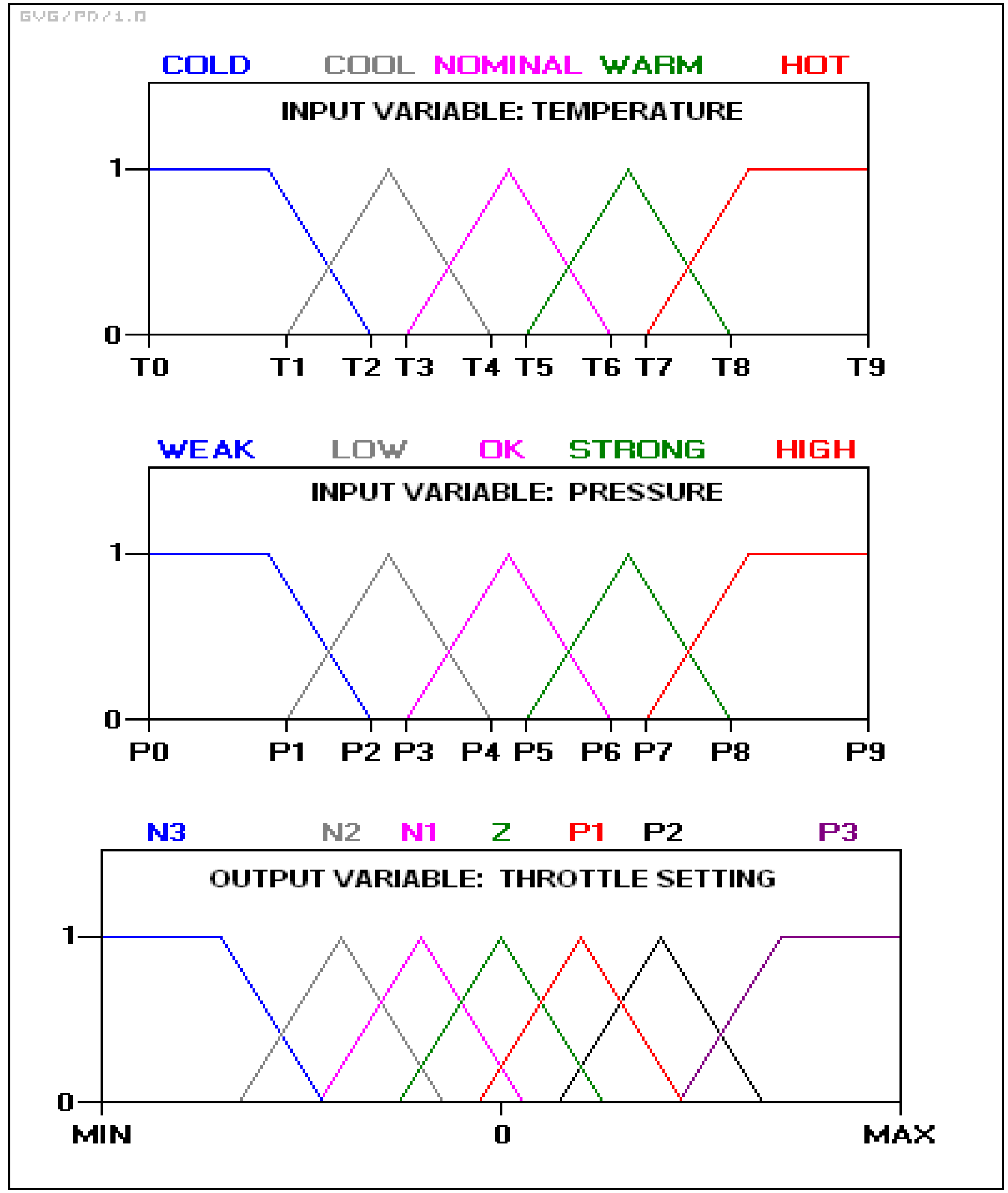
Example: Fuzzy Control System:

Consider the design of a fuzzy controller for a steam turbine. The block diagram of this control system appears as follows :





N3: Large negative.
N2: Medium negative.
N1: Small negative.
Z: Zero.
P1: Small positive.
P2: Medium positive.
P3: Large positive



Fuzzy Rules;

The rule set includes such rules as:

- Rule 1:

  IF temperature IS cool AND pressure IS weak,
  THEN throttle is P3 .

- Rule 2:

  IF temperature IS cool AND pressure IS low,
  THEN throttle is P2 .

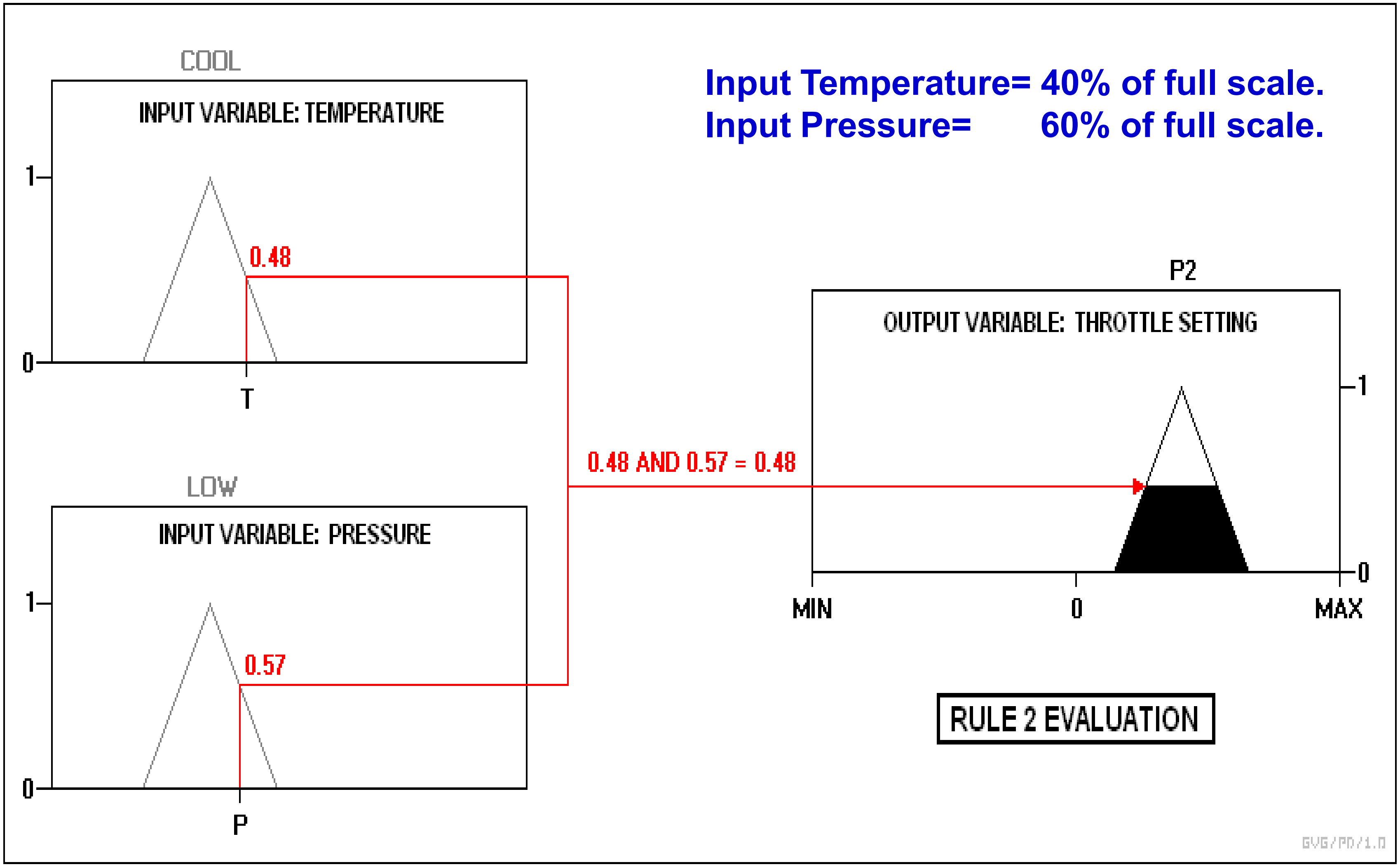
- Rule 3:

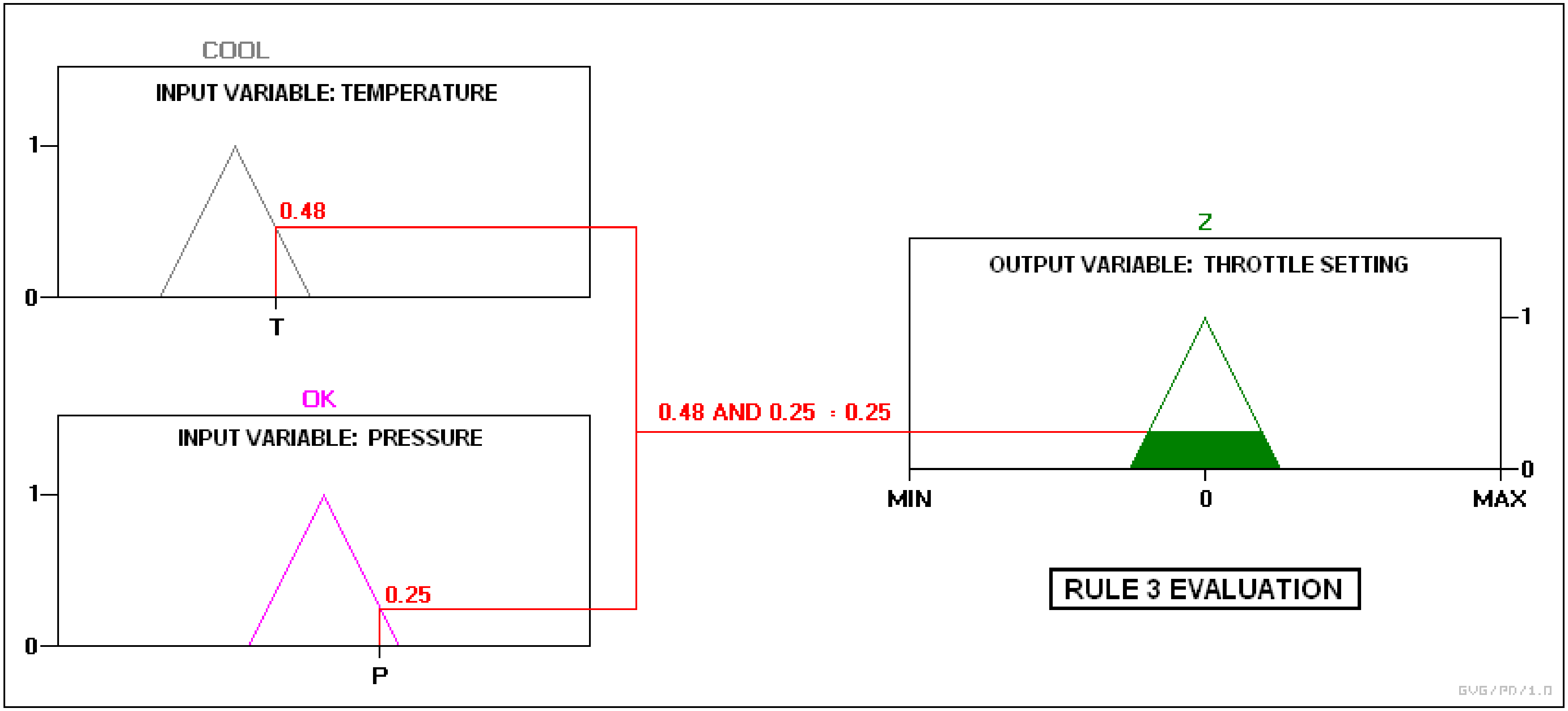
  IF temperature IS cool AND pressure IS ok,
  THEN throttle is Z .

- Rule 4:

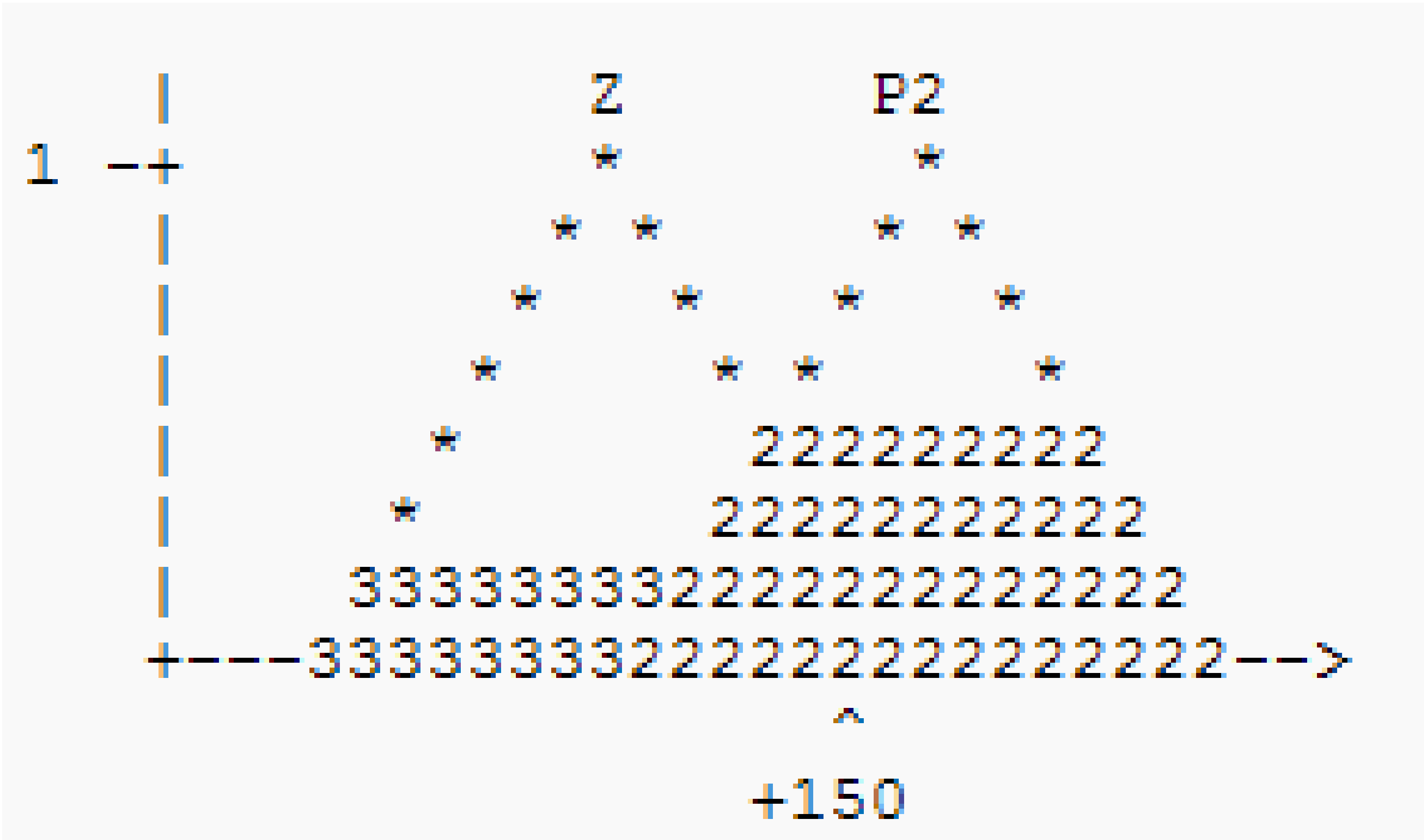
  IF temperature IS cool AND pressure IS strong,
  THEN throttle is N2 .

Rule Evaluation:




COOL
INPUT VARIABLE: TEMPERATURE
1
0
0.48
T
OK
INPUT VARIABLE: PRESSURE
1
0
0.25
P
0.48 AND 0.25 : 0.25
Z
OUTPUT VARIABLE: THROTTLE SETTING
1
0
MIN
0
MAX
RULE 3 EVALUATION

The two outputs are then defuzzified through centroid defuzzification:



The output value will adjust the throttle and then the control cycle will begin again to generate the next value.

Fuzzy Control Approaches:

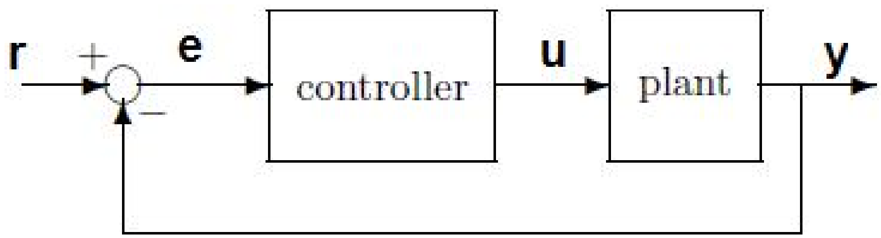
Fuzzy controllers can be used to directly replace a conventional controller in a control loop. There are two approaches; model-free approach and model-based approach.

Model-free approach: without using a mathematical model of the plant.

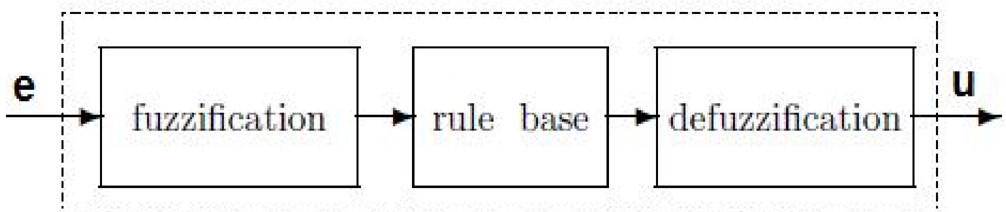
- The plant is a conventional system without a mathematical description and all the signals (the input r(t), output y(t), control u(t), and error e(t) = r(t)- y(t)) are crisp.
- The objective is to design a controller to achieve the goal

$$e(t) \to 0 \text{ as } t \to \infty$$

without any mathematical formula of the plant except for the assumption that its inputs and outputs are measurable by sensors on line.



- FLC does not need plant mathematical model to complete the design, it only uses the plant inputs and outputs which are usually available through sensors on line.

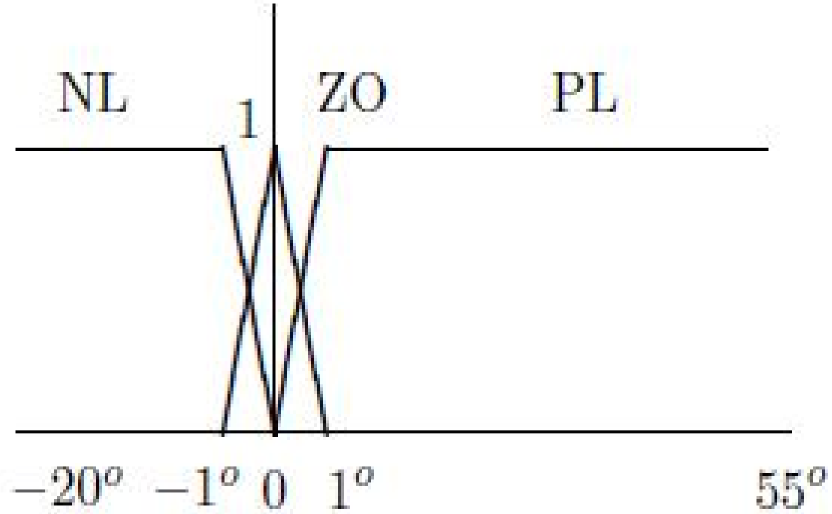


FLC Design:

Using information from both e and e˙, one can completely characterize the changing situation of the output temperature at all times.

$$e(t) = r - y(t)$$

$$\grave{e}(t) = e(t+1) - e(t)$$



$$
\begin{array}{llllllll}
R^{(1)}: & \text{IF} & e(t) > 0 & \text{AND} & \dot{e}(t) > 0 & \text{THEN} & u(t+1) = -u(t) \\
R^{(2)}: & \text{IF} & e(t) > 0 & \text{AND} & \dot{e}(t) < 0 & \text{THEN} & u(t+1) = u(t) \\
R^{(3)}: & \text{IF} & e(t) < 0 & \text{AND} & \dot{e}(t) > 0 & \text{THEN} & u(t+1) = u(t) \\
R^{(4)}: & \text{IF} & e(t) < 0 & \text{AND} & \dot{e}(t) < 0 & \text{THEN} & u(t+1) = -u(t)
\end{array}
$$

$$u(t+1) = u(t) + \Delta u(t)$$

$$\Delta u(t) = \begin{cases} 0 & \text{if rule } R^{(2)} \text{ is executed} \\ -2u(t) & \text{if rule } R^{(1)} \text{ is executed} \end{cases}$$

2. Model-Based Approach:

If a mathematical model of the plant is available, one may be able to design a FLC with better results such as performance specifications and guaranteed stability.

A locally linear fuzzy system model is described by a rule base of the following form:

$$R_S^{(k)}\text{: IF } x_1 \text{ is } X_{k1} \text{ AND} \cdots \text{AND } x_m \text{ is } X_{km} \text{ THEN } \dot{\mathbf{x}} = A_k\mathbf{x} + B_k\mathbf{u}$$

where $\{A_k\}$ and $\{B_k\}$ are given constant matrices,

$\mathbf{x} = [x_1 \ \cdots \ x_m]^\top$ is the state vector,

$\mathbf{u} = [u_1 \ \cdots \ u_n]^\top$ is a controller to be designed

A typical example is the following locally linear single-input system:

$R_S^{(k)}$: IF $x(t)$ is X_{k1} AND$\cdots$AND $x^{(m)}$ is X_{km} THEN $\dot{\mathbf{x}} = A_k\mathbf{x}+\mathbf{b}_k\, u$

where $x^{(j)}(t) = d^j x(t)/dt$, $j = 1, \cdots, m-1$,

$$A_k = \begin{bmatrix} 0 & 1 & 0 & \cdots & 0 \\ 0 & 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots & \\ 0 & o & 0 & \cdots & 1 \\ a_{k1} & a_{k2} & a_{k3} & \cdots & a_{km} \end{bmatrix}, \qquad \mathbf{b}_k = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \\ b_k \end{bmatrix}$$

and $\{a_{ki}\}_{i=1}^{m}$, $k = 1, \cdots, r$, are known constants.

The fuzzy system model may be rewritten as follows:

$$\dot{\mathbf{x}} = \sum_{i=1}^{r} \alpha_i \left(A_k \mathbf{x} + \mathbf{B}_k \mathbf{u} \right) = \mathbf{A}(\mu(\mathbf{x}))\, \mathbf{x} + \mathbf{B}(\mu(\mathbf{x}))\, \mathbf{u}$$

where $\mu(\mathbf{x}) = \{\mu_{X_{ij}}\}_{i,j=1}^{m}$.

Based on this fuzzy model, a fuzzy controller, $\mathbf{u}(t)$, can be designed by using some conventional techniques.

For example, if a negative state-feedback controller is preferred, then one may design a controller described by the following ruse base:

$R_C^{(k)}$: IF x_1 is X_{k1} AND $\cdots$ AND x_m is X_{km} THEN $\mathbf{u}(t) = -K_k \mathbf{x}(t)$

where $\{K_k\}_{k=1}^{r}$ are constant control gain matrices to be determined,

Thus, the closed-loop controlled system becomes

$R_{SC}^{(k)}$: IF x_1 is X_{k1} AND $\cdots$AND x_m is X_{km} THEN $\dot{\mathbf{x}} = [A_k - K_k]\, \mathbf{x}$

Adaptive Fuzzy Control:

In a direct adaptive fuzzy controller, parameters are directly adjusted according to some adaptive law, to reduce the difference between the output of the plant and that of the reference model. Parameters in such a fuzzy controller are those of the membership functions and/or of the rules given in the fuzzy system.

In adaptive control, these parameters are automatically tuned during the control process by an adaptation law.

A direct adaptive fuzzy controller can be designed in three steps:

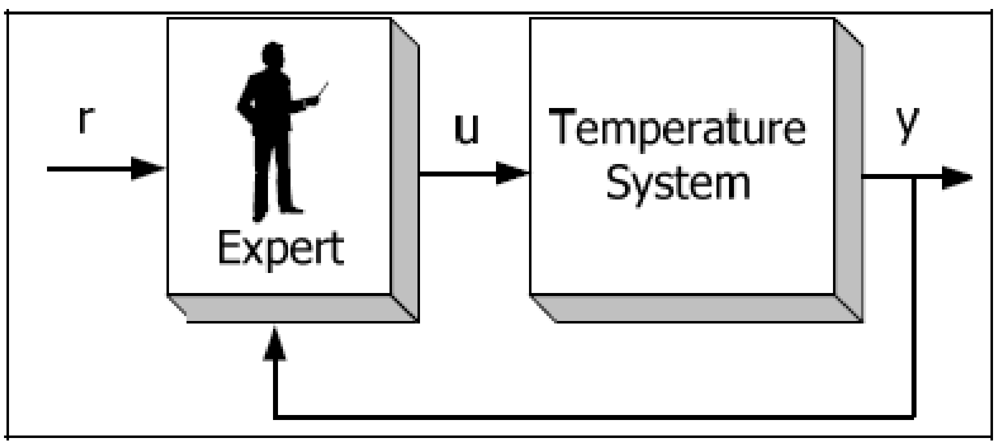
1. determine some fuzzy sets whose membership functions cover the entire operational space for the required control.
2. use some fuzzy IF-THEN rules to construct an initial rule-base for the controller, in which some parameters are free to change.
3. develop an adaptive law, based on the Lyapunov stability theory for control and stabilization, to adjust the free parameters

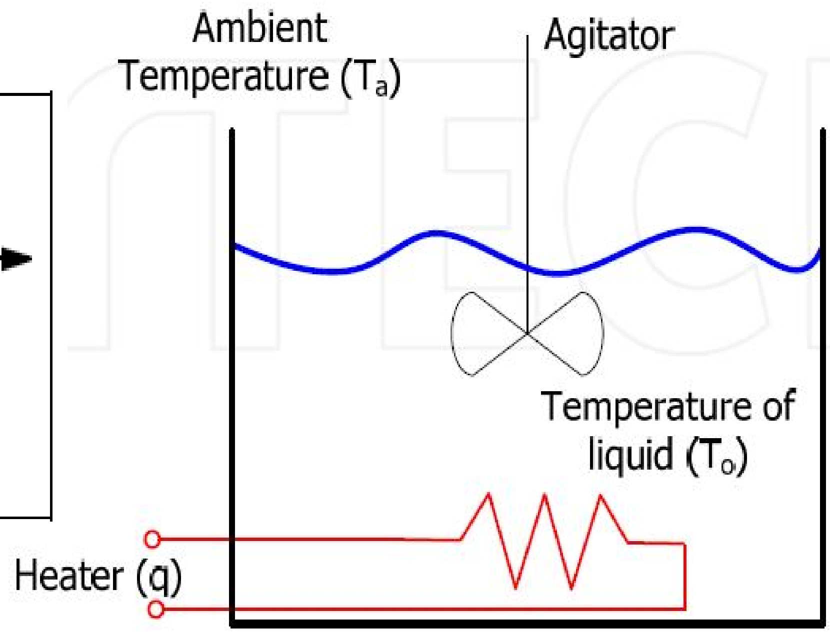
Control Application Using Fuzzy Logic: Design of a Fuzzy Temperature Controller, By: R.M. Aguilar, V. Munoz and Y. Callero

Ref: http://cdn.intechopen.com/pdfs-wm/36643.pdf

Fuzzy logic is based on the method of reasoning that is typically used by experts to handle all kinds of systems, from the simplest to the very complex. This control method can be formulated with rules of the type if-then applied to inexact magnitudes such as "fast", "cold", etc.

Implementing this method of reasoning requires a representation of these vague magnitudes and an associated logic.



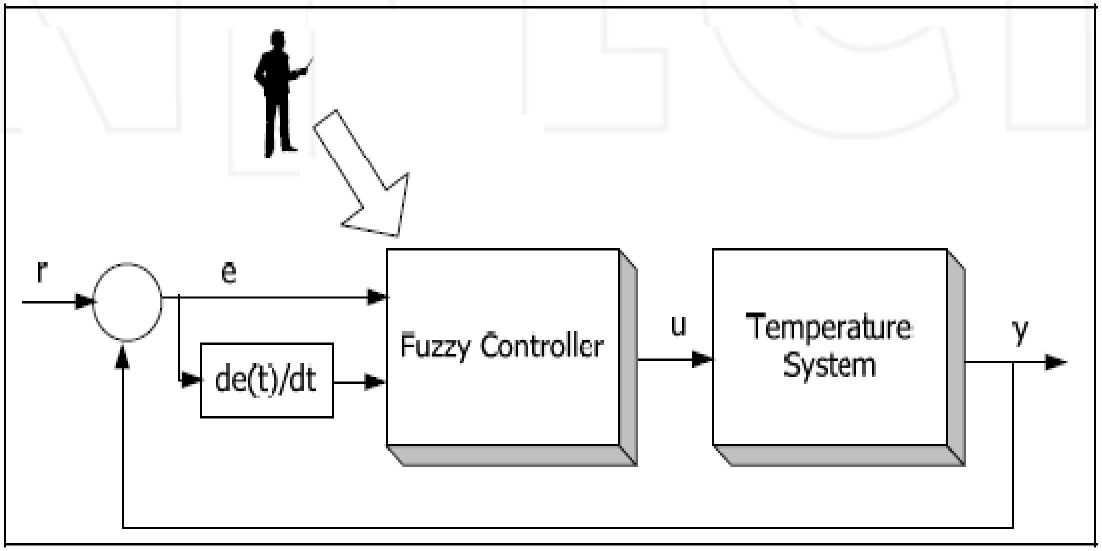


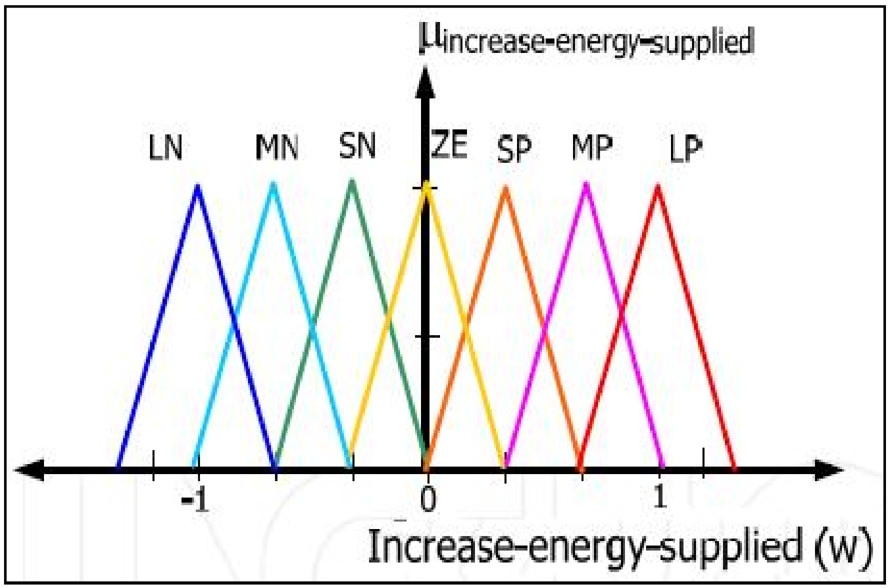
Linguistic description:

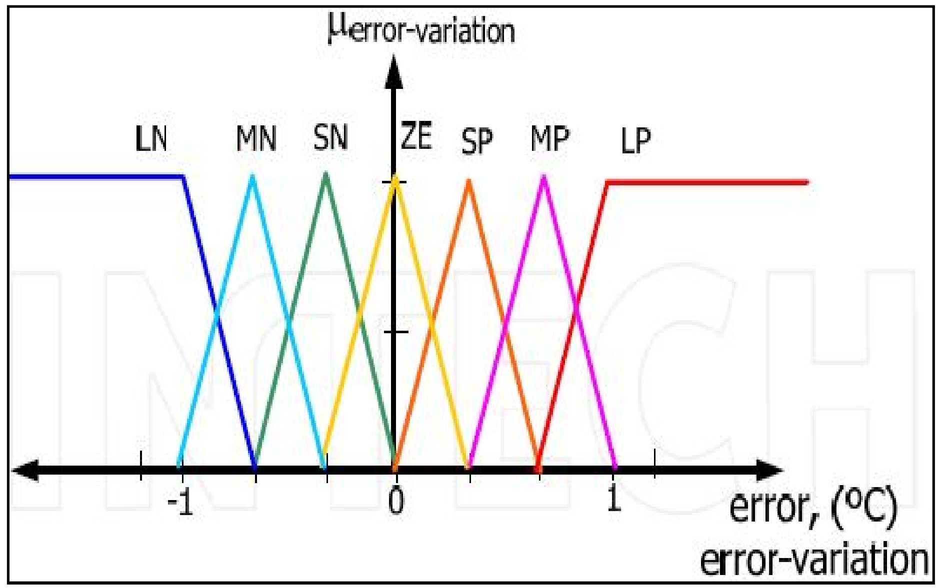
An expert uses linguistic variables to describe the time-varying inputs and outputs of the fuzzy controller.

For this temperature system;

- "error" to describe e(t)
- "error variation" to describe de(t)/dt
- "increase-energy-supplied" to describe $\Delta u(t)$





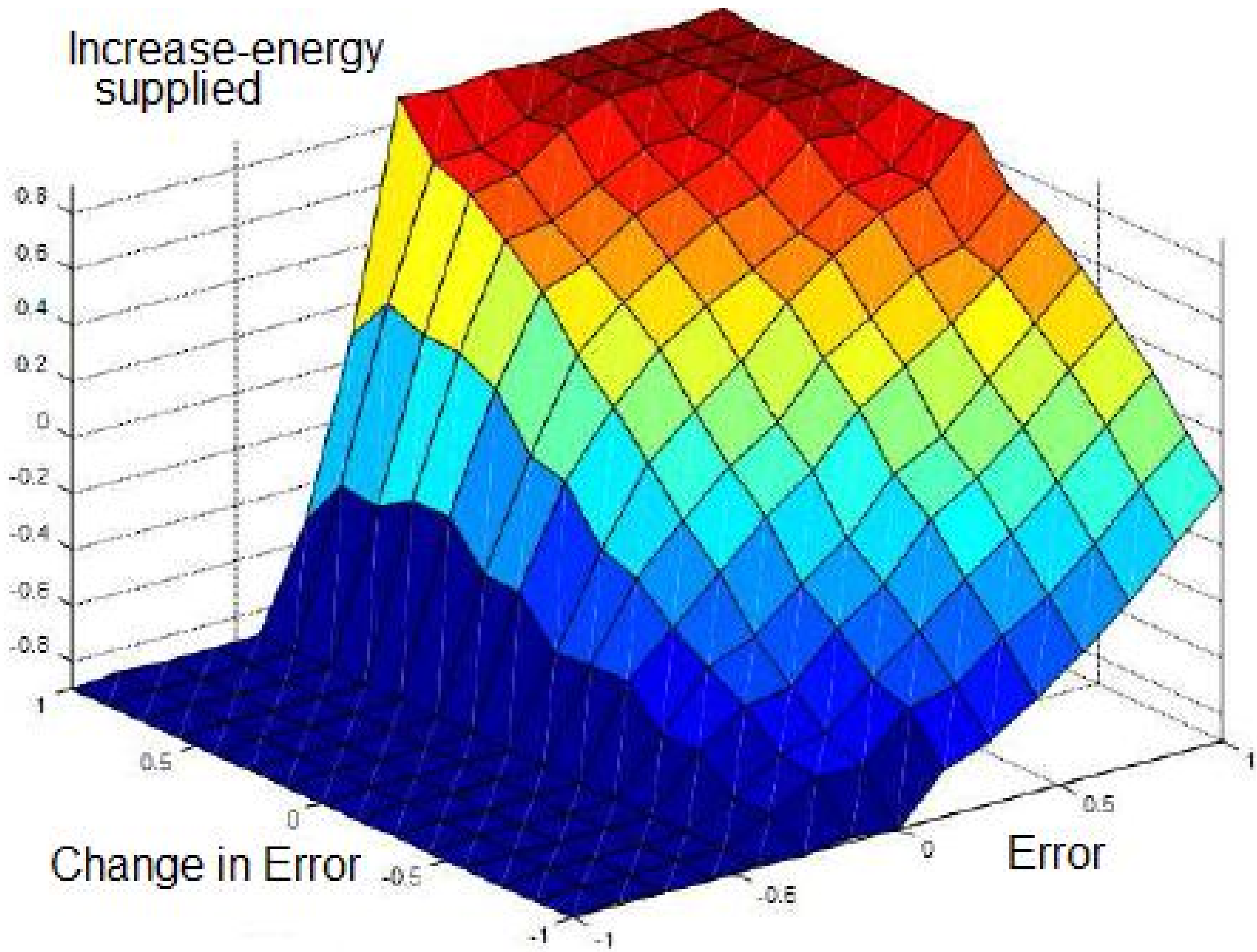


Fuzzy Rules:

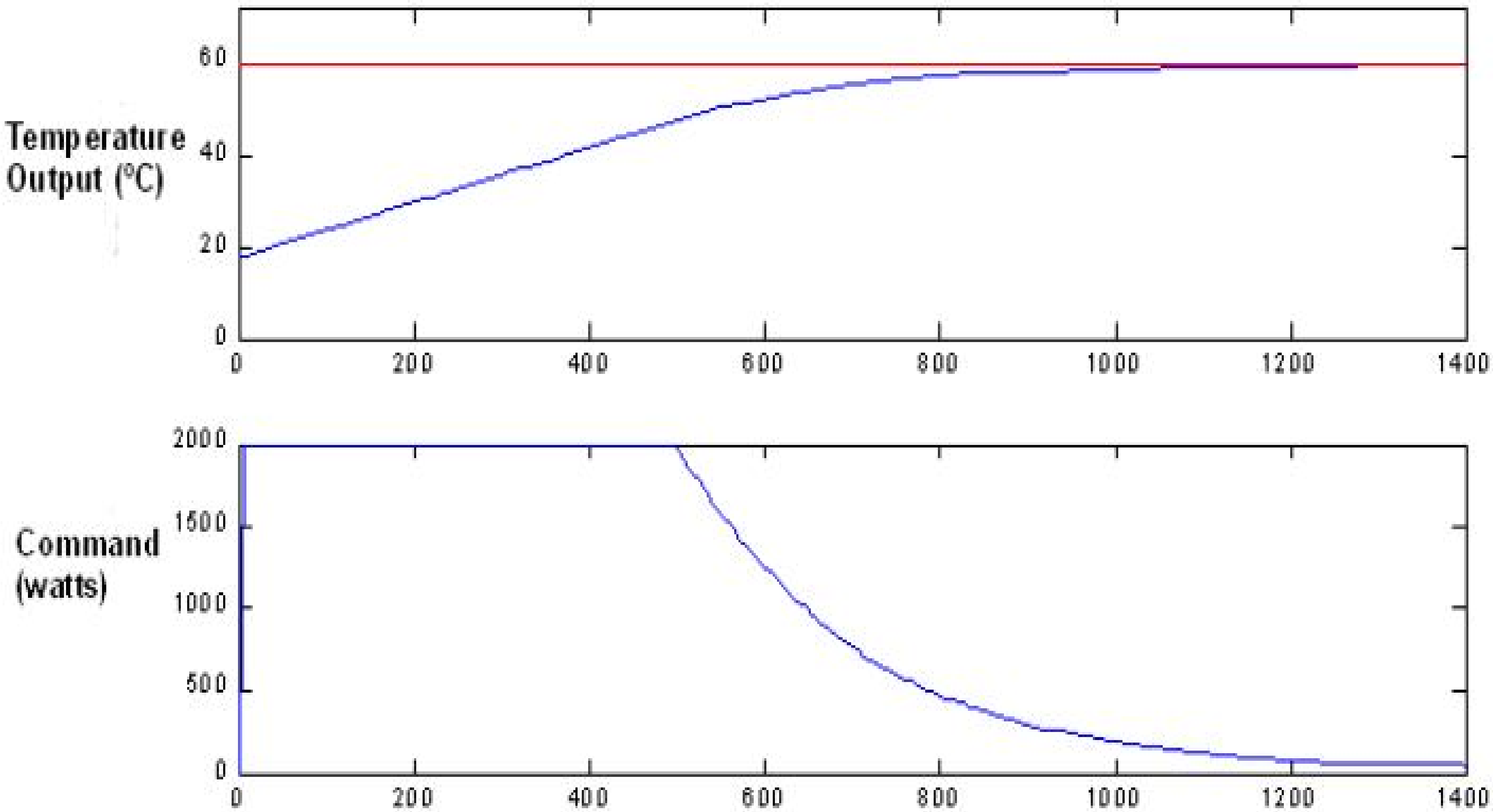
- Arrange the expert's knowledge of how to control a system in an abstract manner. Then, using fuzzy logic to deal with meaning of the linguistic descriptions so as to automate the control rules specified by the expert in a fuzzy controller.
- There are two input variables and single output. Each variable has seven fuzzy sets, then the total number of rules are 49.

Change in Error ($\dot{e}$) \ Error (e)	LN	MN	SN	ZE	SP	MP	LP
LP	LN	LN	LN	LP	LP	LP	LP
MP	LN	LN	LN	MP	LP	LP	LP
SP	LN	LN	LN	SP	SP	LP	LP
ZE	LN	LN	LN	ZE	MP	MP	LP
SN	LN	LN	LN	SN	ZE	SP	MP
MN	LN	LN	LN	MN	SN	ZE	SP
LN	LN	LN	LN	LN	MN	SN	ZE

Simulation of fuzzy temperature control:

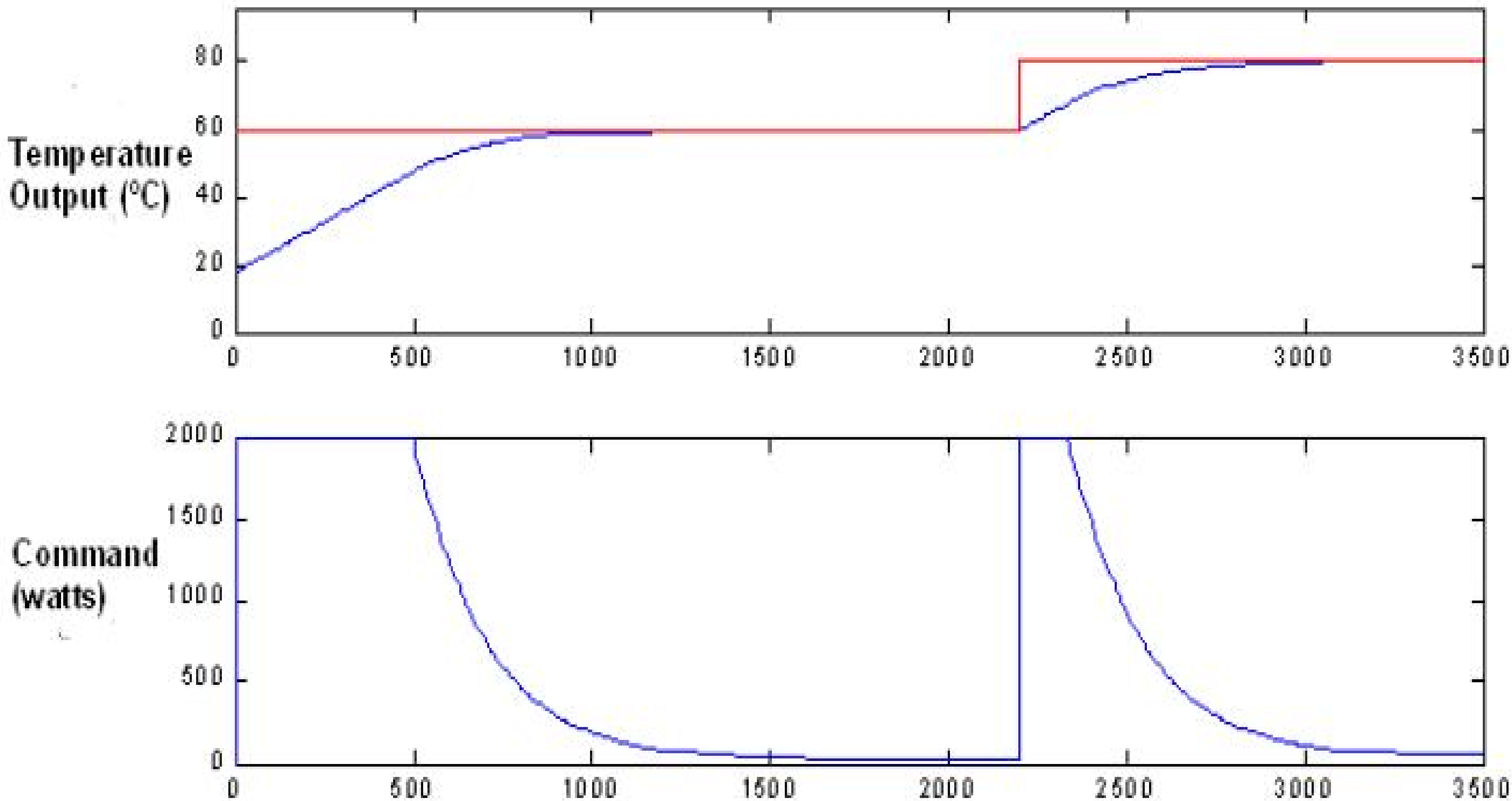


Results:



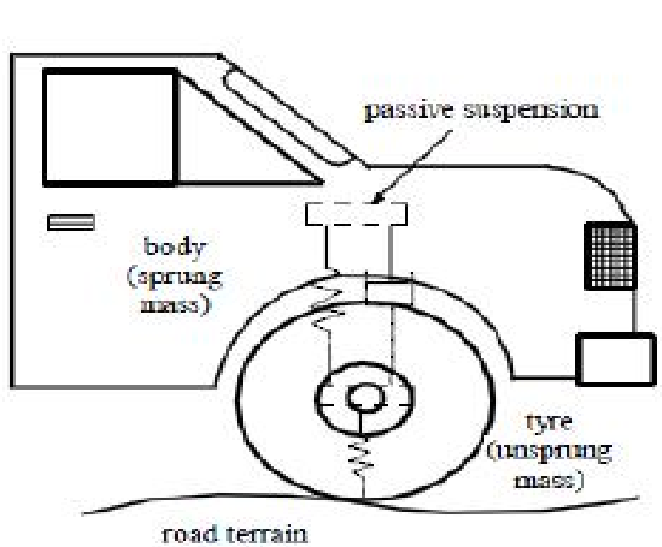
Temperature Output (°C)
60
40
20
0
0
200
400
600
800
1000
1200
1400
Command (watts)
2000
1500
1000
500
0
0
200
400
600
800
1000
1200
1400

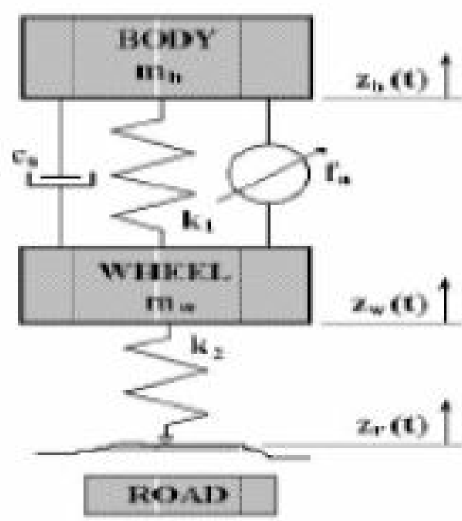
Results:

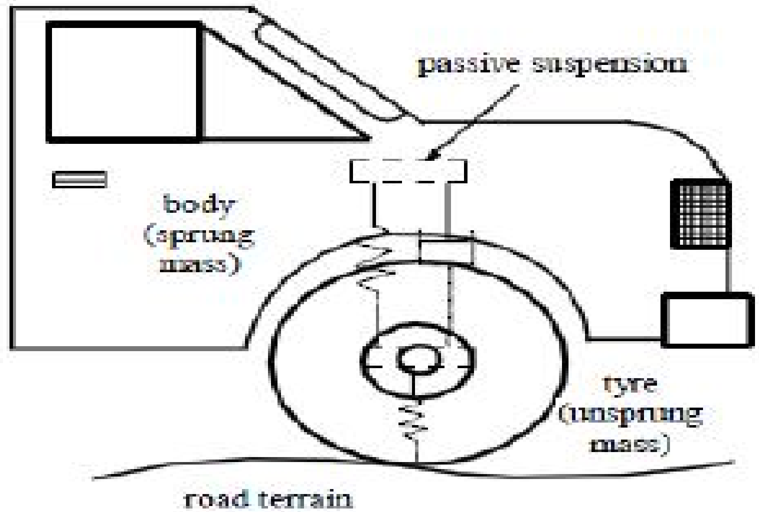

Temperature
Output (°C)
80
60
40
20
0
0
500
1000
1500
2000
2500
3000
3500
Command
(watts)
2000
1500
1000
500
0
0
500
1000
1500
2000
2500
3000
3500

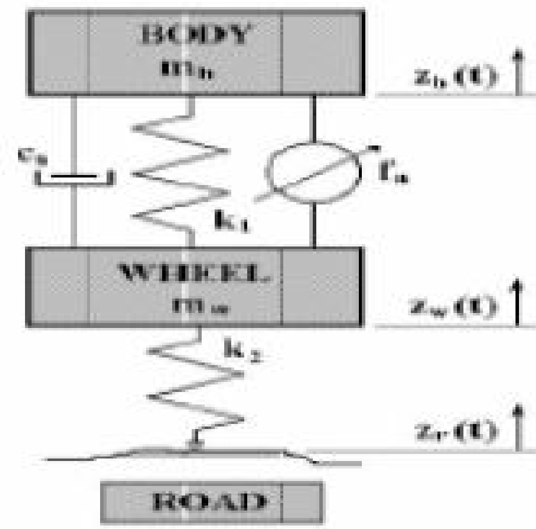
Comparing PID and Fuzzy Logic Control a Quarter-Car Suspension System,
By: Nemat Changizi, & Modjtaba Rouhani, *Available online at http://www.TJMCS.com*
The Journal of Mathematics and Computer Science Vol .2 No.3 (2011) 559-564

- The main aim of suspension system is to isolate a vehicle body from road irregularities in order to maximize passenger ride comfort and retain continuous road wheel contact in order to provide road holding.
- The aim of the work was to illustrate the application of fuzzy logic technique to the control of a continuously damping automotive suspension system. The ride comfort is improved by means of the reduction of the body acceleration caused by the car body when road disturbances from smooth road and real road roughness.
- The paper describes also the model and controller.
- A comparison of active suspension fuzzy control and PID control is given using MATLAB.









The motion equations of the car body and the wheel are:

$$\ddot{z}_b = \frac{f_a - k_1(z_b - z_w) - c_s(\dot{z}_b - \dot{z}_w)}{m_b}$$

$$\ddot{z}_w = \frac{-f_a + k_1(z_b - z_w) + c_s(\dot{z}_b - \dot{z}_w) - k_2(z_w - z_r)}{m_w}$$

Fuzzy logic controller

The fuzzy logic controller used in the active suspension has three inputs: body Acceleration $\ddot{z}_b$, body velocity $\dot{z}_b$, body deflection velocity $\dot{z}_b - \dot{z}_w$ and one output: desired actuator force f_a.

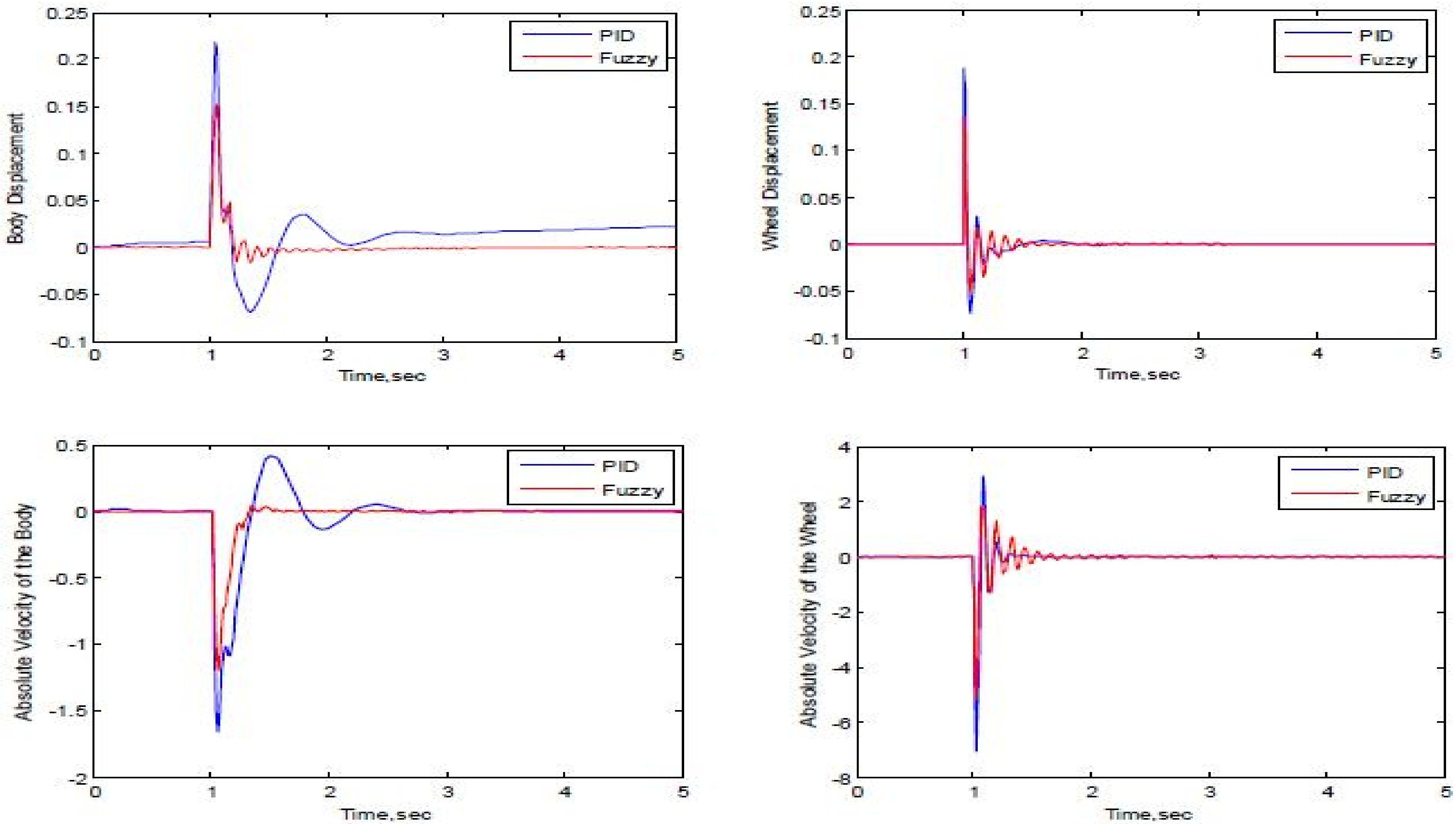
The rule base used for one-half-car model is represented by 75 rules

The controller have the general form of:

$$IF(\dot{z}_b - \dot{z}_w = A)AND(\dot{z}_b = B)AND(\ddot{z}_b = C)THEN(f_a = D)$$

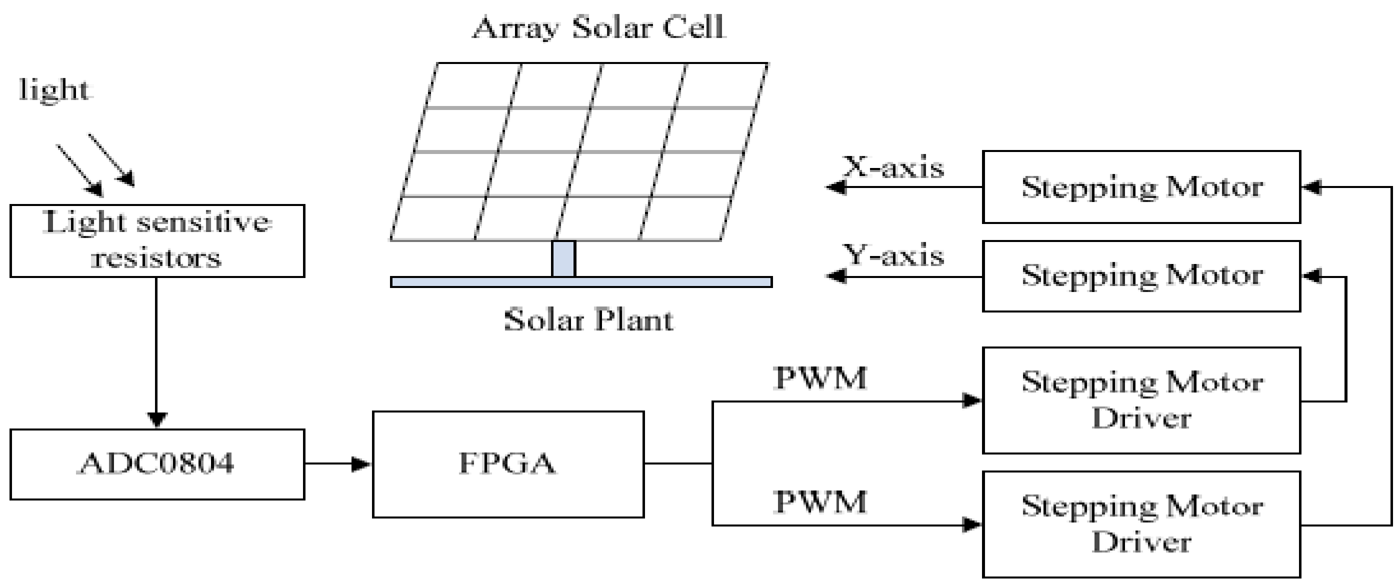
SIMULATION:

Simulation results of active suspension controlled by PID and Fuzzy control are compared . FLC provides good results than PID.



Solar Tracking Fuzzy Control System Design using FPGA
By: Y. J. Huang, *B. C. Wu, C. Y. Chen, C. H. Chang, and T. C. Kuo,*
Ref: Proceedings of the World Congress on Engineering 2009 Vol I, WCE 2009, July 1 - 3, 2009, London, U.K.

An expert controller, sensors and I/O interface are integrated with a tracking mechanism to increase the energy generation efficiency of solar cells. In order to track the sun, cadmium sulfide light sensitive resistors are used. To achieve optimal solar tracking, a fuzzy algorithm is developed. A field programmable gate array is applied to design the controller such that the solar cells always face the sun in most of the day time.



Fuzzy Controller Design:

- For one motor control, the error of output voltages of corresponding sensors are the input variables.
- The rotation time of the stepping motors for clockwise and counterclockwise are output variables.
- Five fuzzy control rules are used;

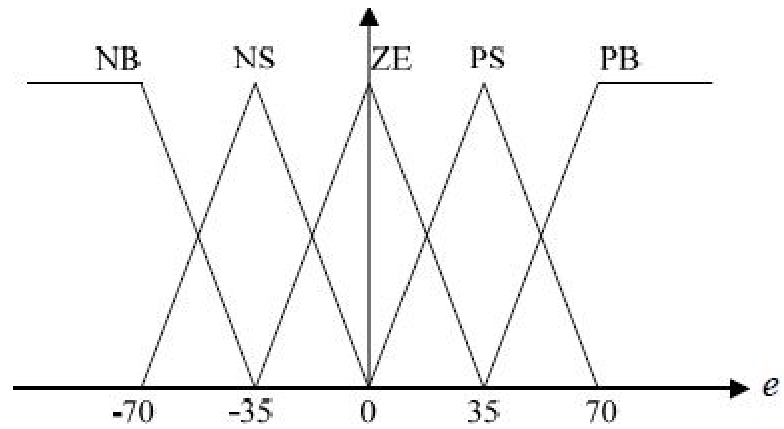
Rule 1 : If e is PB, then U_f is PB.

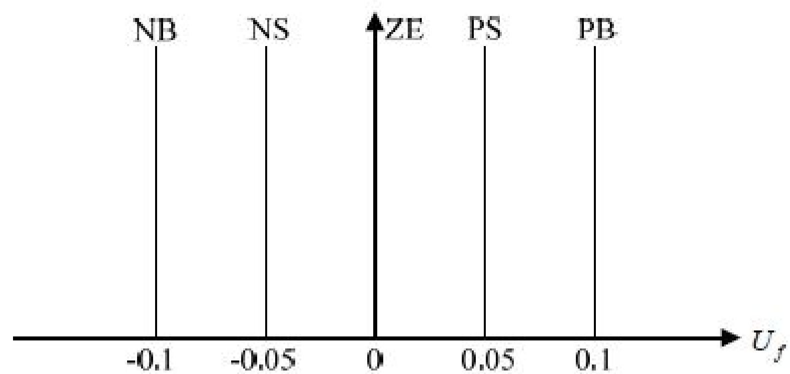
Rule 2 : If e is PS, then U_f is PS.

Rule 3 : If e is ZE, then U_f is ZE.

Rule 4 : If e is NB, then U_f is NB.

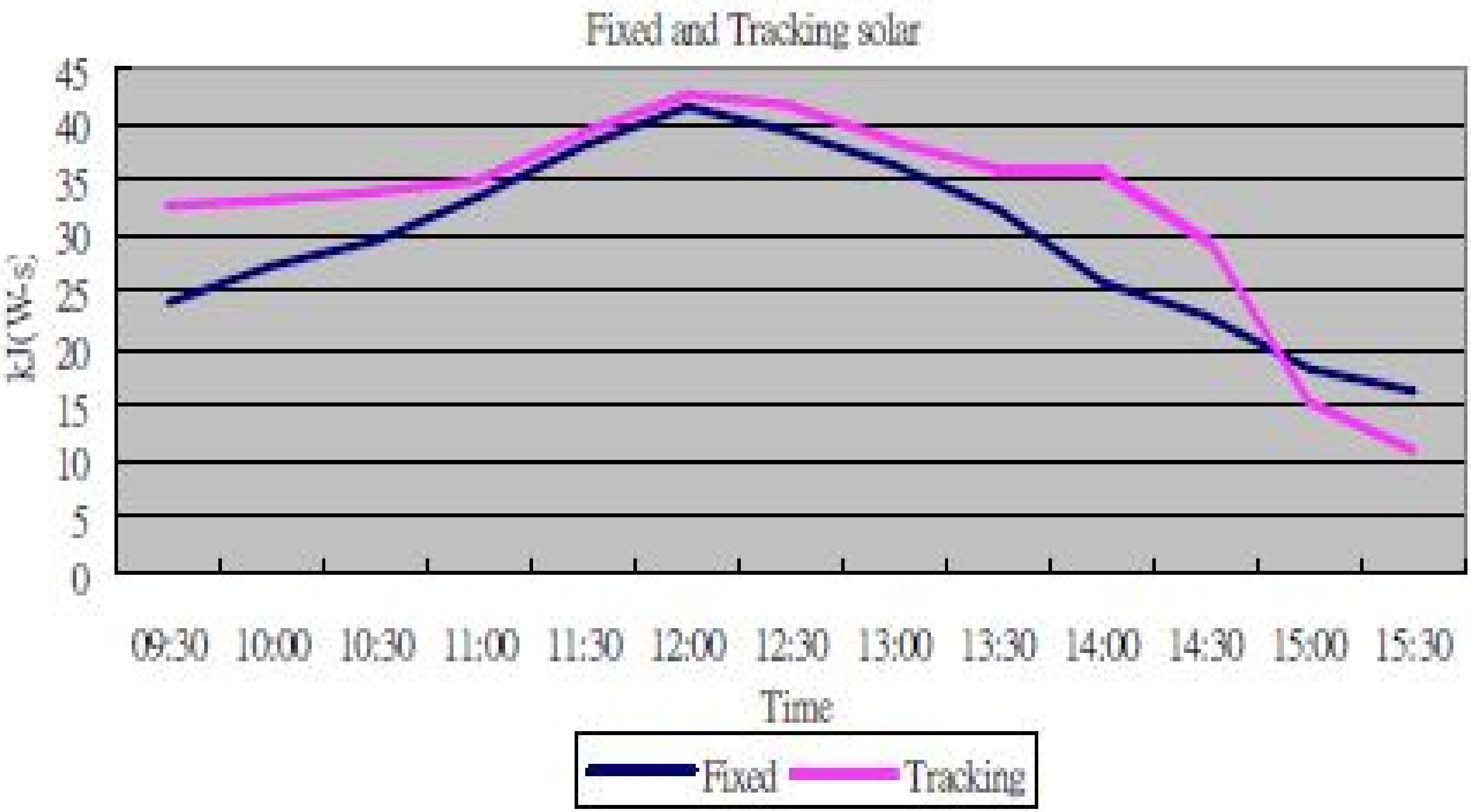
Rule 5 : If e is NS, then U_f is NS.





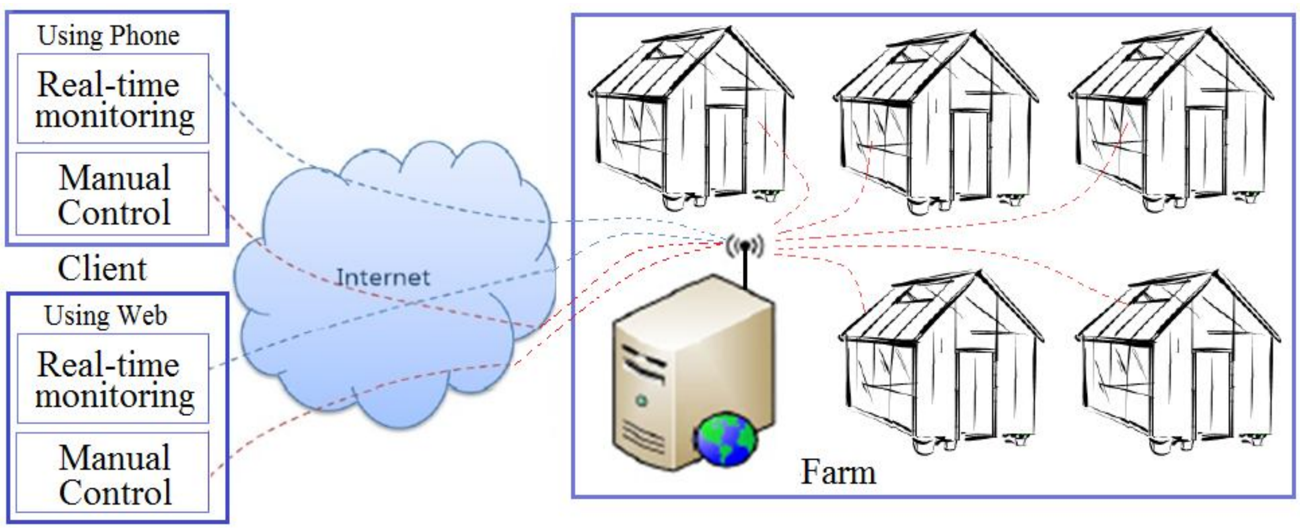
Experimental Results:

- This experiment applies four solar cell panels. Every two panels are connected in series as a set. The two sets were connected in a parallel configuration.
- The experimental data of the solar generating power system are measured outdoors.
- The efficiency with solar tracking methodology is 6.7 percentages higher than that
- with fixed angle.



Real-Time Monitoring and Intelligent Control for Greenhouses Based on WSN,
By: K.M. Al-Aubidy, M.M. Ali, A. M. Derbas & A.W. Al-Mutairi
Ref: IEEE-SSD2014 Conf., Spain, Feb. 2014.

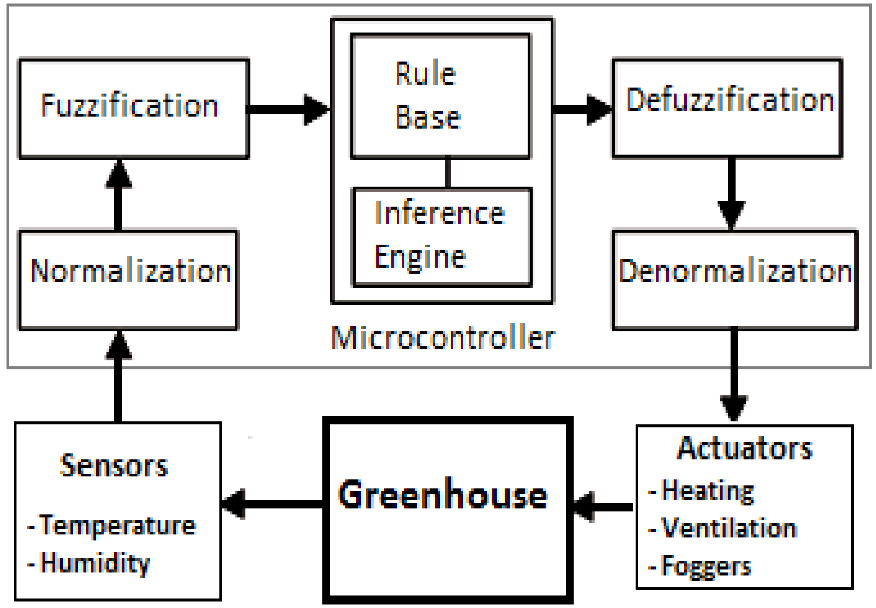
- Design and implement a real-time monitoring and control of several environmental parameters for group of greenhouses. (GHs)
- Each greenhouse is considered as a node in a wireless sensor network.
- A rule-based FC has been designed to control the microclimate of each GH.
- The farmer can monitor both the internal environment of the GH.
- Simulated and real results have been achieved to demonstrate the system performance and real-time remote monitoring and control activities.

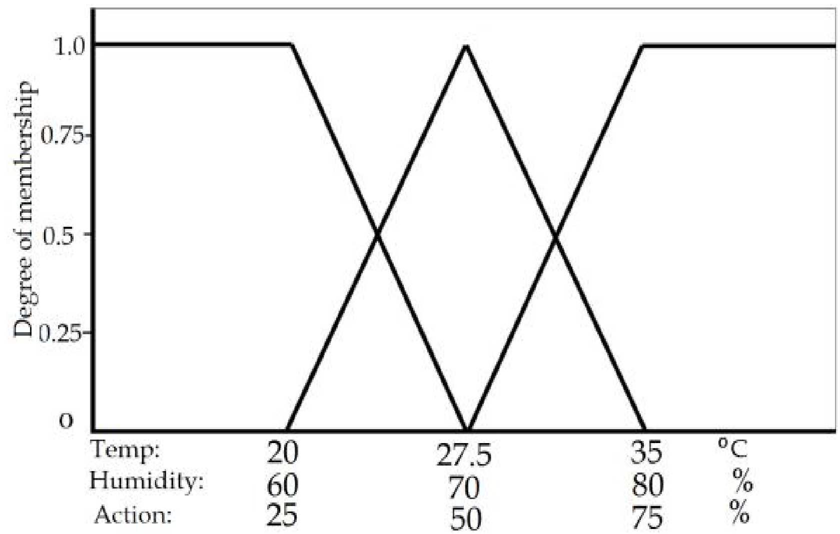


FLC Design:

- One of the important issue in FC design is the choice of I/O variables and output controlled parameters.
- The FLC has two measured variables (temperature &humidity) and three o/p commands (heating, ventilation, and foggers).
- Three fuzzy sets are used to represent i/p & o/p signals. Each variable is represented by Low (L), Normal (N) and High (H) sets, while each output command is represented by Closed (C), Medium (M) and Open (O) sets.
- Nine rules are used for each controlled variable. Each rule is represented by IF-THEN statement such as;

If TH and RL then VO





Humidity	Temperature: TL	TN	TH
RL	VC	VC	VO
RN	VC	VC	VO
RH	VO	VM	VO

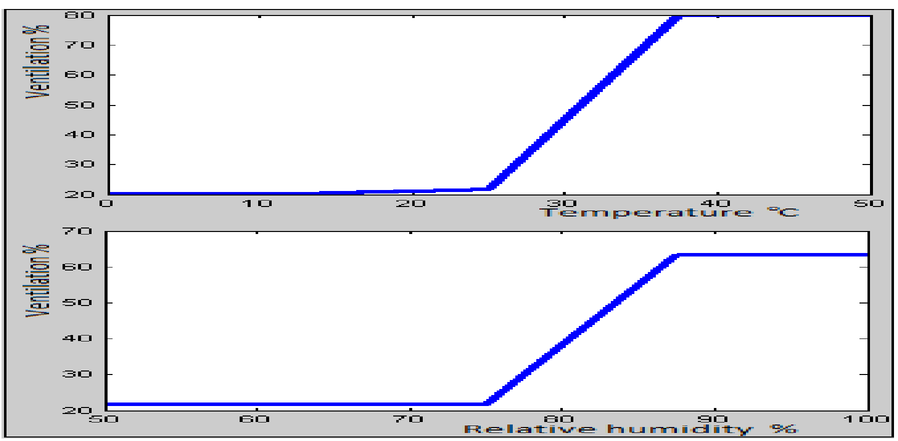
VO: Fully Open windows
VM: Open window for a half
VC: Closed window.

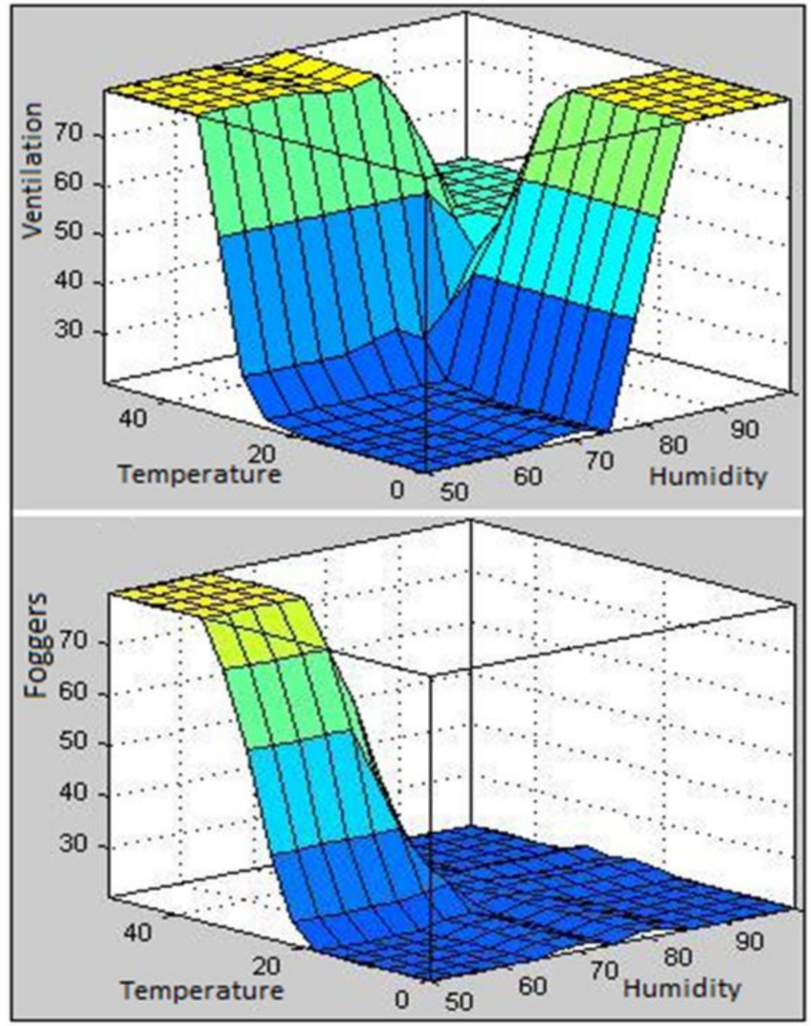
(a). Ventilation rules.

Humidity	Temperature: TL	TN	TH
RL	FC	FM	FO
RN	FC	FC	FC
RH	FC	FC	FC

FO: Fully open fogger
FM: Open fogger for a half
FC: Closed fogger

(b). Fogger rules.





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