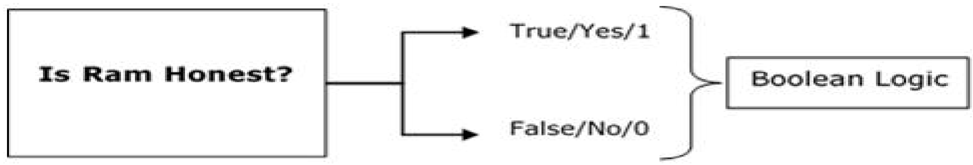

Is Ram Honest?
True/Yes/1
False/No/0
Boolean Logic


Is Ram Honest?
Extremely Honest
Very Honest (0.85)
Sometimes Honest (0.35)
Extremely Dishonest (0.0)
Fuzzy Logic

[illegible]

- [illegible]
- [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

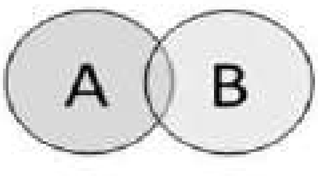
[illegible]

[illegible]

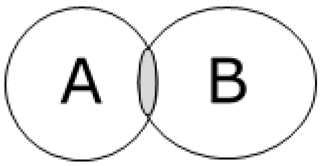
[illegible]

[illegible]

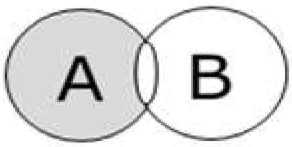
[illegible]



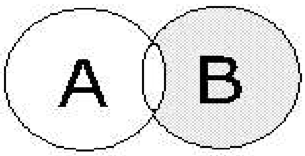
A U B



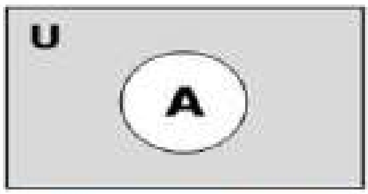
A ∩ B



A - B



B - A



Complement of set A

) [illegible]

V[illegible]

[illegible]

[illegible]

, [illegible]

- [illegible]/[illegible]-

- 2[illegible]/[illegible]2 -

- [illegible]

, [illegible]

- [illegible],[illegible]./,- [illegible].[illegible]

- 2,[illegible]2[illegible]./,- 2[illegible].2[illegible]

3 [illegible]

, [illegible]

- [illegible],[illegible]2[illegible]./,- [illegible].2,- [illegible].[illegible]

- 2,[illegible]./,- 2[illegible].[illegible],- 2[illegible].[illegible]

[illegible]

[illegible]

- [illegible]- /-

- 2- /-

[illegible]

[illegible] 7 [illegible]

- [illegible]8/-

- 27/-

- 28/8

- [illegible]7/7

[illegible]

, [illegible] 9 [illegible]

[illegible]

[illegible] ::/-

3 [illegible]

[illegible]

[illegible]

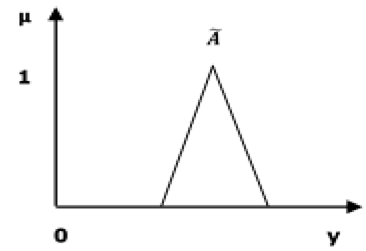
- 2[illegible]/[illegible]

[illegible]

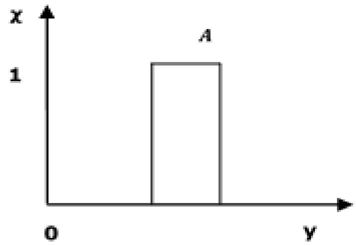
- [illegible]/[illegible] 2[illegible]

[illegible]

[illegible]



Membership Function of Fuzzy set $\tilde{A}$



Membership Function of classical set A

A˜={(y,μA˜(y))|y∈U}

Here $\mu_{\tilde{A}}(y)$ = ... μA˜(y)∈[0,1]

K ...

$$\tilde{A} = \left\{ \frac{\mu_{\tilde{A}}(y_1)}{y_1} + \frac{\mu_{\tilde{A}}(y_2)}{y_2} + \frac{\mu_{\tilde{A}}(y_3)}{y_3} + \ldots \right\}$$

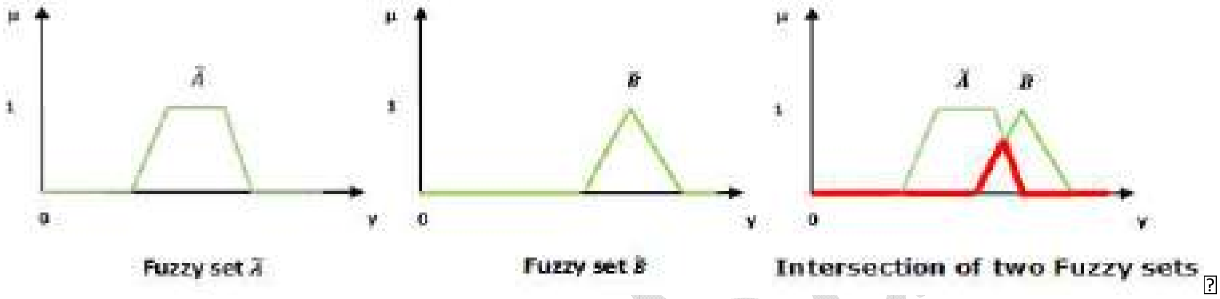
$$= \left\{ \sum_{i=1}^{n} \frac{\mu_{\tilde{A}}(y_i)}{y_i} \right\}$$

K ...

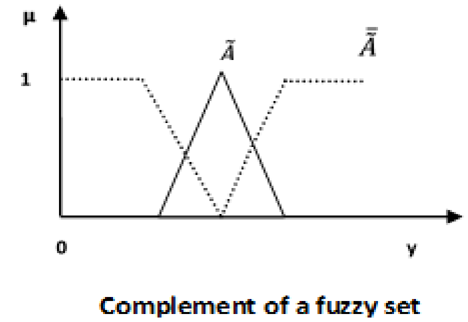
$$\tilde{A} = \left\{ \int \frac{\mu_{\tilde{A}}(y)}{y} \right\}$$

$$\mu_{\tilde{A} \cup \tilde{B}}(y) = \mu_{\tilde{A}} \vee \mu_{\tilde{B}} \quad \forall y \in U$$

$$\mu_{\tilde{A}\cap\tilde{B}}(y) = \mu_{\tilde{A}} \wedge \mu_{\tilde{B}} \quad \forall y \in U$$



$$\mu_{\bar{\tilde{A}}} = 1 - \mu_{\tilde{A}}(y) \quad y \in U$$



$$\tilde{A} \cup \tilde{B} = \tilde{B} \cup \tilde{A}$$

$$\tilde{A} \cap \tilde{B} = \tilde{B} \cap \tilde{A}$$

$$\tilde{A}\cup\left(\tilde{B}\cup\tilde{C}\right)=\left(\tilde{A}\cup\tilde{B}\right)\cup\tilde{C} \qquad \tilde{A}\cap\left(\tilde{B}\cap\tilde{C}\right)=\left(\tilde{A}\cup\tilde{B}\right)\cup\tilde{C}$$

3 [illegible]

[illegible]

$$\tilde{A}\cup\left(\tilde{B}\cap\tilde{C}\right)=\left(\tilde{A}\cup\tilde{B}\right)\cap\left(\tilde{A}\cup\tilde{C}\right) \qquad \tilde{A}\cap\left(\tilde{B}\cup\tilde{C}\right)=\left(\tilde{A}\cap\tilde{B}\right)\cup\left(\tilde{A}\cap\tilde{C}\right)$$

[illegible]

[illegible]

$$\tilde{A}\cup\tilde{A}=\tilde{A} \qquad \tilde{A}\cap\tilde{A}=\tilde{A}$$

[illegible]

[illegible]

$$\tilde{A}\cup\varphi=\tilde{A} \qquad \tilde{A}\cap U=\tilde{A} \qquad \tilde{A}\cap\varphi=\varphi \qquad \tilde{A}\cup U=U$$

[illegible]

[illegible]

$$If\ \tilde{A}\subseteq\tilde{B}\subseteq\tilde{C},\ then\ \tilde{A}\subseteq\tilde{C}$$

[illegible]

[illegible]

$$\overline{\overline{\tilde{A}}}=\tilde{A}$$

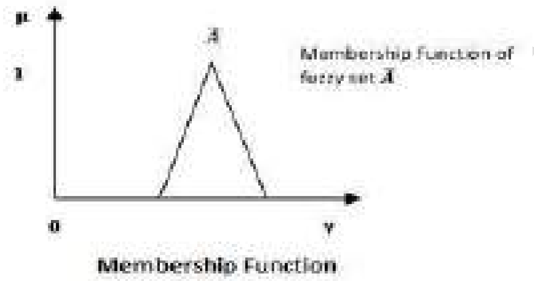
3 [illegible]

[illegible]

$$\overline{\tilde{A}\cap\tilde{B}}=\overline{\tilde{A}}\cup\overline{\tilde{B}} \qquad \overline{\tilde{A}\cup\tilde{B}}=\overline{\tilde{A}}\cap\overline{\tilde{B}}$$

[illegible]

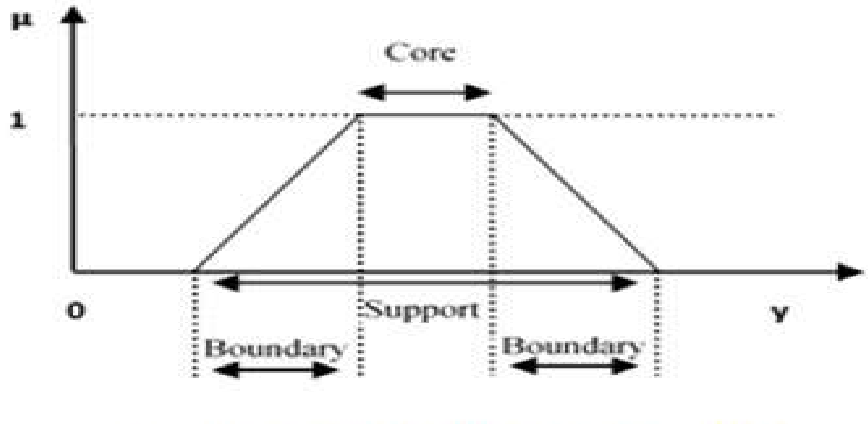
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]


μ
1
A
Membership Function of fuzzy set A
0
y
Membership Function

$$\widetilde{A} = \{(y, \mu_{\widetilde{A}}(y)) \mid y \in U\}$$

$\mu_{\widetilde{A}}(y) > 0$

$1 > \mu_{\widetilde{A}}(y) > 0$



Features of Membership Function

$$\widetilde{A} = \mu_1 Q(x_1) + \mu_2 Q(x_2) + \ldots + \mu_n Q(x_n)$$

$Q(x_i)$

3

- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]
  - [illegible]
  - [illegible]
  - [illegible]

$$x^* = \frac{\sum_{i=1}^{N} x_i \cdot \sum_{k=1}^{n} \mu_{A_k}(x_i)}{\sum_{i=1}^{N} \sum_{k=1}^{n} \mu_{A_k}(x_i)},$$

$\mu_{A_k}(x_i)$

The defuzzified value x^* is defined as :

$$x^* = \frac{\sum_{i=1}^{k} A_i \times \bar{x}_i}{\sum_{i=1}^{k} A_i},$$

Here, A_i represents the firing area of i^{th} rules and k is the total number of rules fired and $\bar{x}_i$ represents the center of area.

The aggregated fuzzy set of two fuzzy sets C_1 and C_2 is shown in Figure 1. Let the area of this two fuzzy sets are A_1 and A_2.

A_1 = ½ * [(8-1) + (7-3)] * 0.5 = ½ * 11 * 0.5 = 55/20=2.75

A_2 = ½ * [(9-3) + (8-4)] * 0.3 = ½ * 10 * 0.3 = 3/2 =1.5

Now the center of area of the fuzzy set C_1 is let say $\overline{x_1}$ = (7+3)/2= 5 and

the center of area of the fuzzy set C_2 is $\overline{x_2}$= (8+4)/2=6.

Now the defuzzified value $x^* = \frac{(A_1\overline{x_1}+A_2\overline{x_2})}{A_1+A_2} = \frac{(2.75 * 5 + 1.5 * 6)}{(2.75 + 1.5)}$ = 22.75/4.25 = 5.35

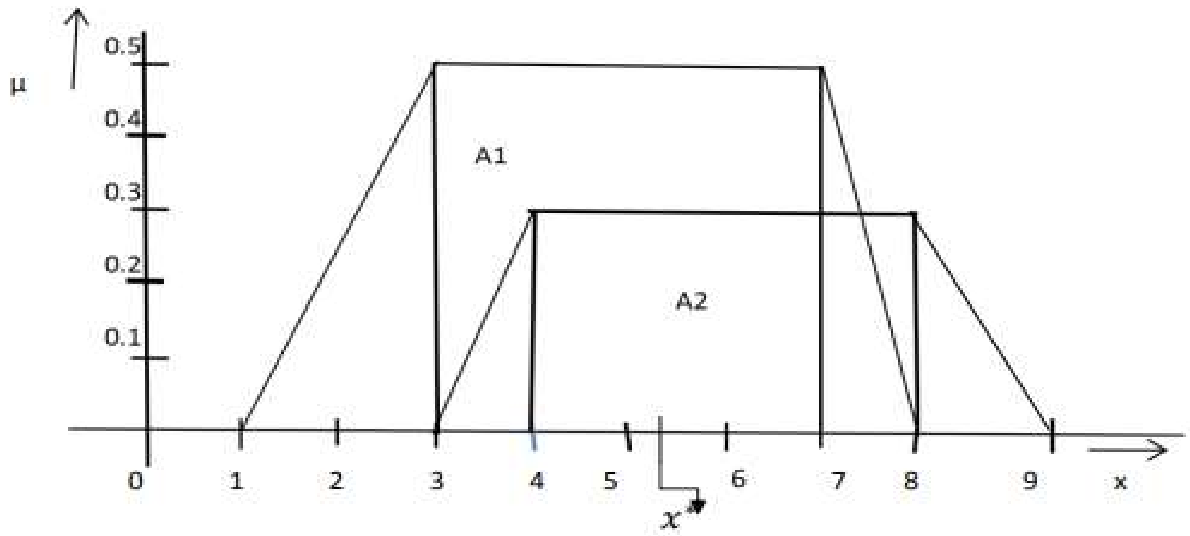


Figure 1 : Fuzzy sets C_1 and C_2

[illegible]

[illegible]

[illegible] x^* [illegible]

$$x^* = \frac{\sum_{i=1}^{n} x_i \cdot \mu(x_i)}{\sum_{i=1}^{n} \mu(x_i)}$$

[illegible] $\mu(x_i)$ [illegible]

$$x^* = \frac{\int x\, \mu_A(x)\, dx}{\int \mu_A(x)\, dx}$$

[illegible] x^* [illegible]

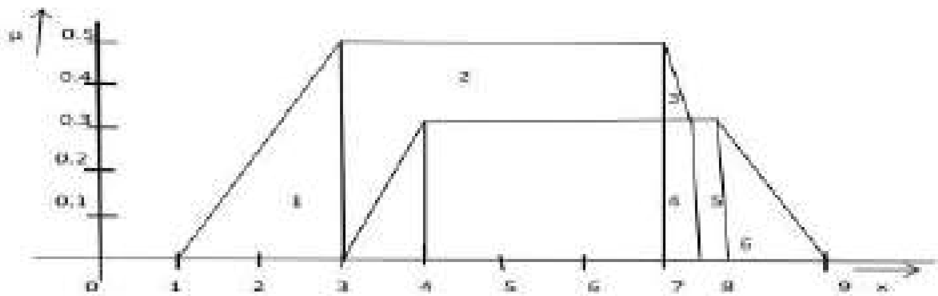


Figure 2 : Fuzzy sets C1 and C2

$$\int_{\alpha}^{x^*} \mu_A(x)\, dx = \int_{x^*}^{\beta} \mu_A(x)\, dx \text{, where } \alpha = \min\{x \mid x \in X\} \text{ and } \beta = \max\{x \mid x \in X\}$$

$$x^* = \frac{\sum \mu(x).x}{\sum \mu(x)}$$

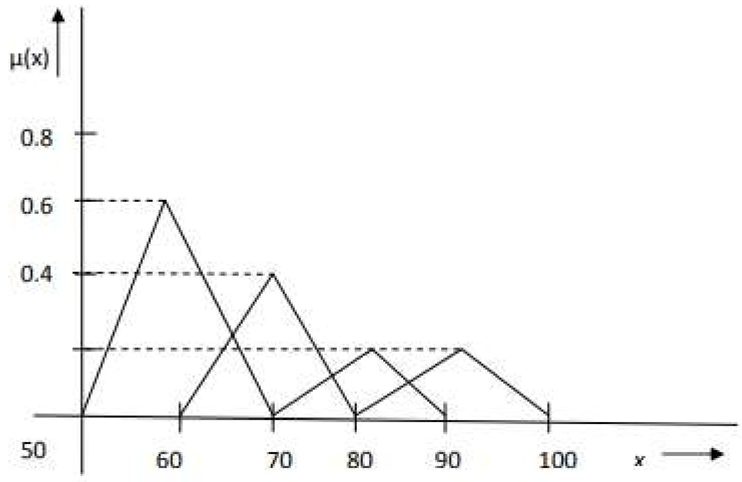


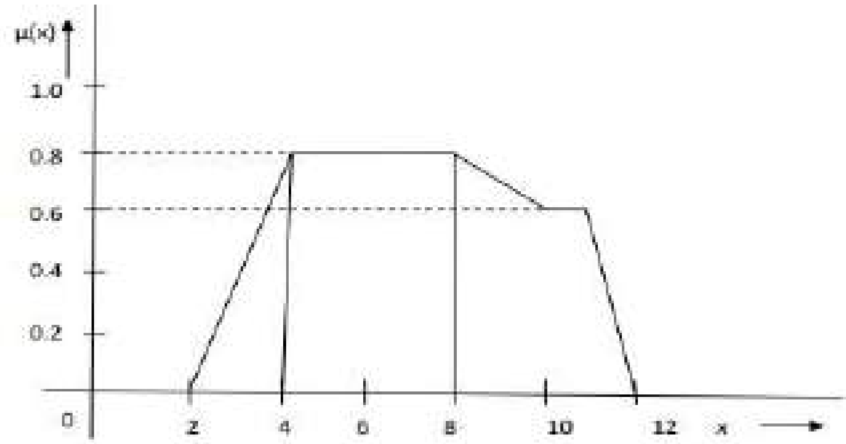
Figure 3: Fuzzy set A

$$x^* = \frac{(60*0.6+70*0.4+80*0.2+90*0.2+100*0)}{0.6+0.4+0.2+0.2+0}$$

$$= 98/1.4 = 70$$

[illegible]

[illegible]



[illegible]

[illegible]

[illegible]

$$x^* = \frac{\sum_{x_i \in M} x_i}{|M|},$$

Here, $M = \{x_i | \mu_A(x_i)$ is equal to the height of the fuzzy set A$\}$ and $|M|$ is the cardinality of the set M.

Example

In the example as shown in Fig. , x = 4, 6, 8 have maximum membership values and hence |M| = 3

According to MOM method, $x^* = \frac{\sum_{x_i \in M} x_i}{|M|}$

Now the defuzzified value x^* will be $x^* = \frac{4+6+8}{3} = \frac{18}{3} = 6.$

[illegible]

[illegible]

[illegible]

[illegible]

- [illegible]
- [illegible]
- [illegible]

[illegible]

[illegible]

[illegible]

- [illegible]
- [illegible]

[illegible]

- [illegible]

[illegible]

[illegible]

- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]

[illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible]	¬[illegible]
[illegible]	[illegible]
[illegible]	[illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

[illegible]

K [illegible]

- [illegible]
- [illegible]
- [illegible]
- - [illegible]
- [illegible]

F [illegible]

[illegible]

- L [illegible]
- - [illegible]

[illegible]

L [illegible]

∃xP(x) [illegible]

- [illegible] **∃xP(x)** [illegible]

[illegible]

- [illegible]

∃xP(x) [illegible]

[illegible] ∃xP(x) [illegible]

[illegible] a b P(x,y) [illegible]

[illegible] a b c P(a,b,c) [illegible]

[illegible] a b P(x,y) ≠ a b P(x,y)

[illegible]

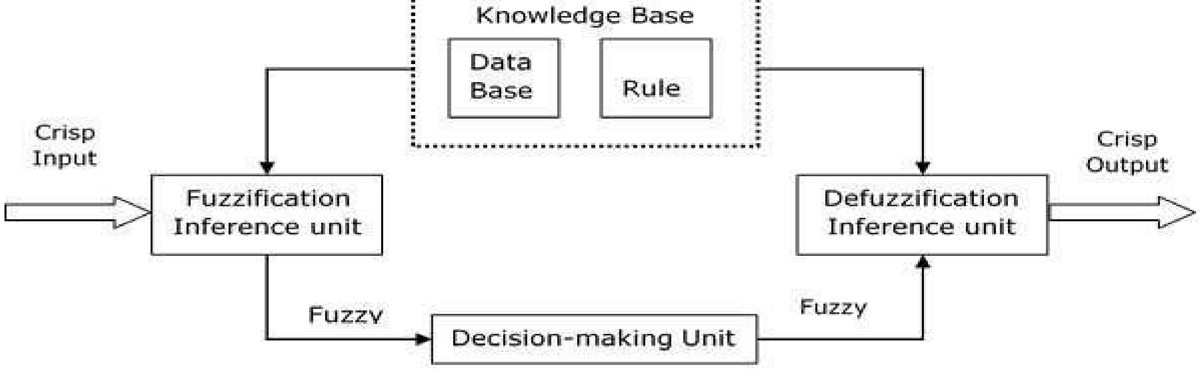
[illegible] ∀ [illegible] ∃ [illegible]

[illegible]

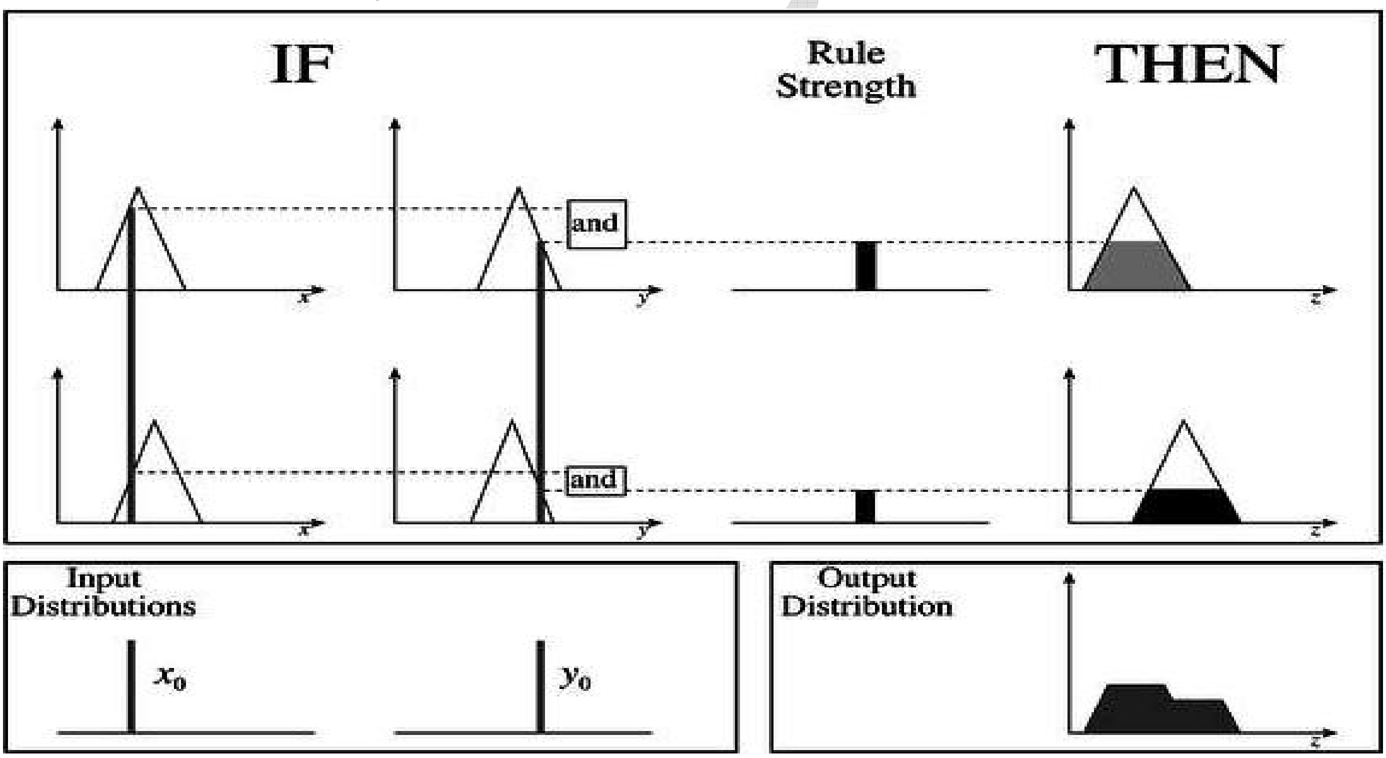
/ [illegible] / [illegible]

/ [illegible] 9 [illegible] / 9

/ [illegible] / [illegible]



Knowledge Base
Data Base
Rule
Crisp Input
Fuzzification Inference unit
Defuzzification Inference unit
Crisp Output
Fuzzy
Decision-making Unit
Fuzzy


IF
Rule Strength
THEN
and
and
Input Distributions
x_0
y_0
Output Distribution

Fuzzy Logic - Database and Queries

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Fuzzy Logic – Quantification

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

$$\left\{ \frac{0.7}{100}, \frac{1}{85}, \frac{0.5}{60}, \right\}$$

3 P

- R ti
- - ti
- ti

3

S K

3 P

-
- $G_i\,(i \in X_n)\,;$
- $C_j\,(j \in X_m)$

I

$G_i\,(a)$ = composition $[G_i\,(a)]$ = $G_i^1\,(G_i\,(a))$ with G_i^1

$C_j\,(a)$ = composition $[C_j\,(a)]$ = $C_j^1\,(C_j\,(a))$ with C_j^1 for $a \in A$

$$F_D = min[i \in X_n^{in} fG_i\,(a)\,, j \in X_m^{in} fC_j\,(a)]$$

3 P

R

x_i to x_j = $N\,(x_i,\, x_j)$

I

0

$SC\,(x_i,\, x_j) = \frac{N(x_i,\, x_j)}{n}$

4 3 P

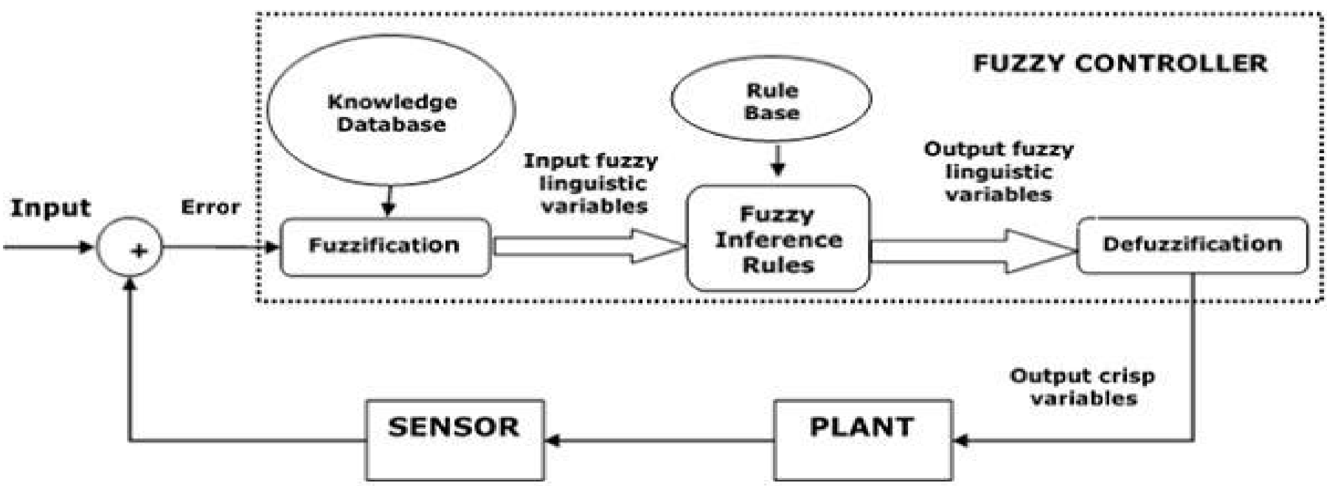
S F F

- E F
- F

S

0] 9 0] 9

) F Q0] 9 Q0] 9


FUZZY CONTROLLER
Knowledge Database
Rule Base
Input fuzzy linguistic variables
Output fuzzy linguistic variables
Input
Error
Fuzzification
Fuzzy Inference Rules
Defuzzification
Output crisp variables
SENSOR
PLANT

[illegible]

[illegible]

- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]

[illegible]

[illegible]

- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]

[illegible]

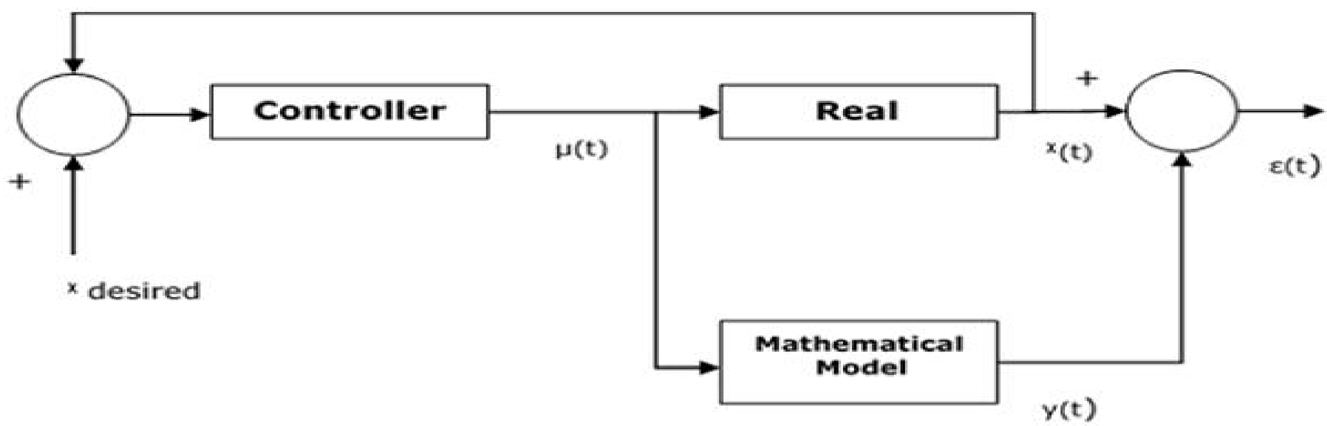
[illegible]

- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]

[illegible]

[illegible]

- [illegible]
- [illegible]
- [illegible]
- [illegible]



Rule 1 – IF $x_1(t_n) \in X_{11}\ AND \ldots AND\ x_i(t_n) \in X_{1i}$

THEN $\mu_1(t_n) = K_{11}x_1(t_n) + K_{12}x_2(t_n) + \ldots + K_{1i}x_i(t_n)$

Rule 2 – IF $x_1(t_n) \in X_{21}\ AND \ldots AND\ x_i(t_n) \in X_{2i}$

THEN $\mu_2(t_n) = K_{21}x_1(t_n) + K_{22}x_2(t_n) + \ldots + K_{2i}x_i(t_n)$

Rule j – IF $x_1(t_n) \in X_{k1}\ AND \ldots AND\ x_i(t_n) \in X_{ki}$

THEN $\mu_j(t_n) = K_{j1}x_1(t_n) + K_{j2}x_2(t_n) + \ldots + K_{ji}x_i(t_n)$

$$\theta^{(n)} = \phi(\theta^{n-1},\, D_n)$$

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

- [illegible]
- [illegible]
- [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]

$$u(t) = K_p e(t) + K_i \int_0^t e(x)\,dx + K_d \frac{de(t)}{dt}$$

Where K_P — proportional gain, a tuning parameter

K_i — integral gain, a tuning parameter

K_d — derivative gain, a tuning parameter

e — error present in the controller

t — time or instantaneous time

x — variable of integration, taken from time 0 to present 1

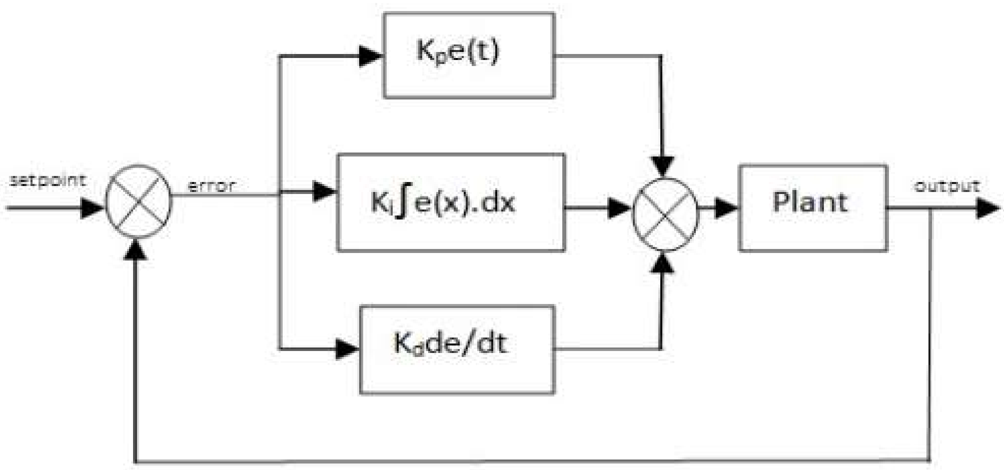


Fig 1:Block diagram of conventional PID controller

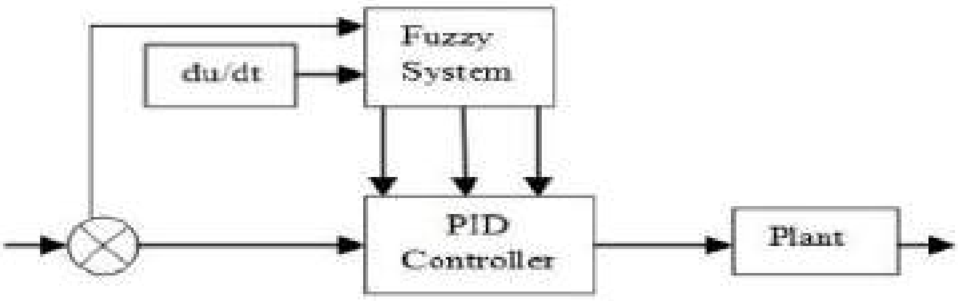
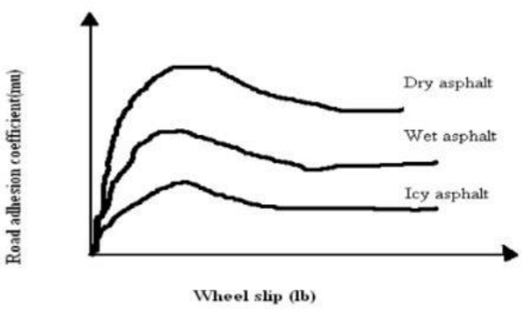
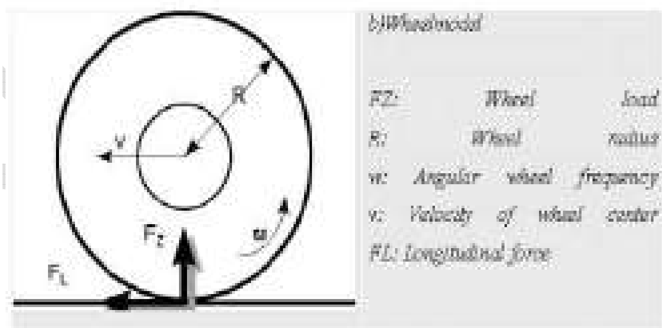
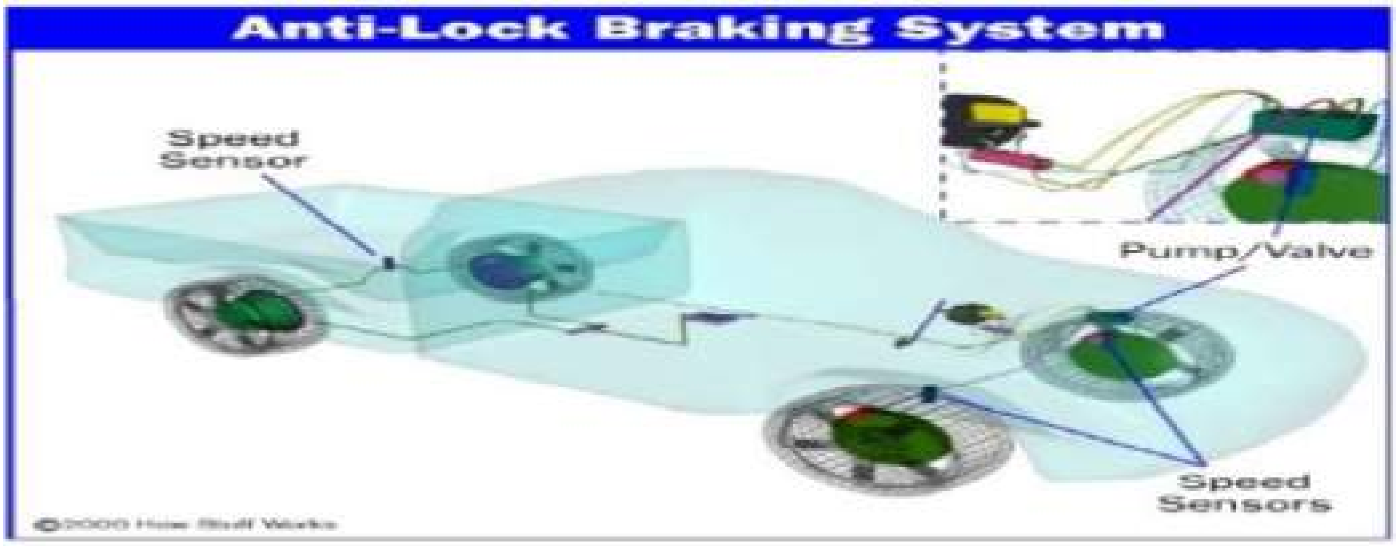
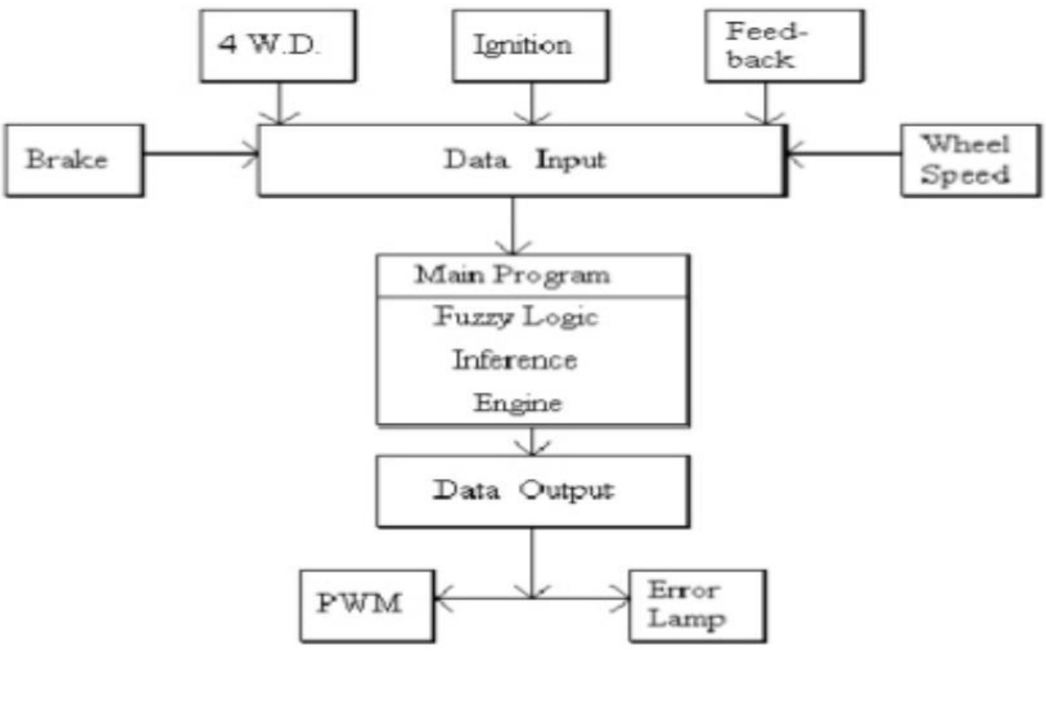


Fig.4 Block diagram of fuzzy PID controller


Road adhesion coefficient(mu)
Dry asphalt
Wet asphalt
Icy asphalt
Wheel slip (lb)


R
V
Fz
FL
b)Wheel model
FZ: Wheel load
R: Wheel radius
w: Angular wheel frequency
v: Velocity of wheel center
FL: Longitudinal force


Anti-Lock Braking System
Speed Sensor
Pump/Valve
Speed Sensors


4 W.D.
Ignition
Feed-back
Brake
Data Input
Wheel Speed
Main Program
Fuzzy Logic
Inference
Engine
Data Output
PWM
Error Lamp

- [illegible]
- I [illegible]
- [illegible]
- [illegible] Q[illegible]

[illegible]

[illegible]

- [illegible]
- , [illegible]
- [illegible]
- K [illegible]
- S [illegible]
- b[illegible]

[illegible]

[illegible]

- [illegible]
- [illegible]
- [illegible]

[illegible]

[illegible]

- [illegible]
- [illegible]
- K [illegible]
- g [illegible] E [illegible]
- [illegible]
- [illegible]

[illegible]

[illegible]

- Q[illegible]
- Q[illegible]

[illegible]

[illegible]

- [illegible]
- Q[illegible]
- [illegible]
- [illegible]

[illegible]

[illegible]

- S [illegible]
- [illegible]
- S [illegible]
- S [illegible]
- / [illegible]
- [illegible]