Chapter – 3

HARDWARE AND SOFTWARE DEVELOPMENT

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3.1 FUZZY CONTROL SYSTEM AND ITS DESIGN :

A general block diagram of Temperature Controller to be implemented using fuzzy logic is shown in fig.3.1[1,2].

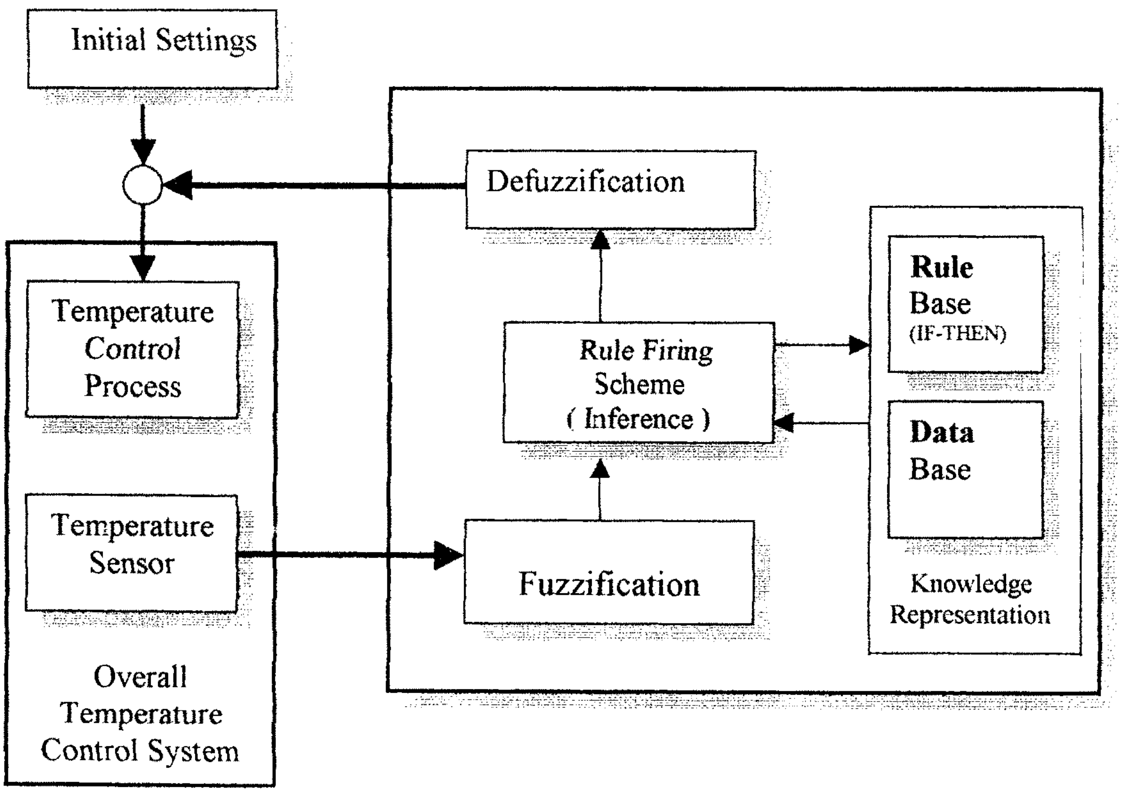


Fig.3.1 : General Schematics of Fuzzy Temperature Controller

The fuzzy logic control describes an algorithm for the temperature control as fuzzy relation between the present temperature to be controlled and the set point and the control action.

The essence of fuzzy control algorithm is the conditional statement between fuzzy input variable - the present temperature and output variable - the pulse width which can be written as

"IF the temperature is A THEN pulse width is B "

a) Hardware Details :

The actual hardware block diagram and design of individual blocks is as shown in fig. 3.2.

Microprocessor Kit :

Anshuman Classic, Pune make 8085 Microprocessor Kit with built-in PPIS e.g. 8255, 8279 and 8253.

Dimmerstat :

Automatic Electric Ltd., Bombay, 0-230 Volt, AC/15 Amp. Output.

Transistor :

Type	Case	V_{CE}	V_{CB}	I_C	h_{fe}	pt_{of}
BC147	TO92	45	50	100 ma	110-800	500 mw

Triac :

Type	Case	V_{DRM}	IT(rms)	IGT	VGT	PG(AV)
BT139	TO220	500	16 Amp	50 ma	1.5	0.5 w

Zener Diode :

1N750, 400 mw, Zener Voltage : 4.7, Test Current : I_{zt} : 20 mA

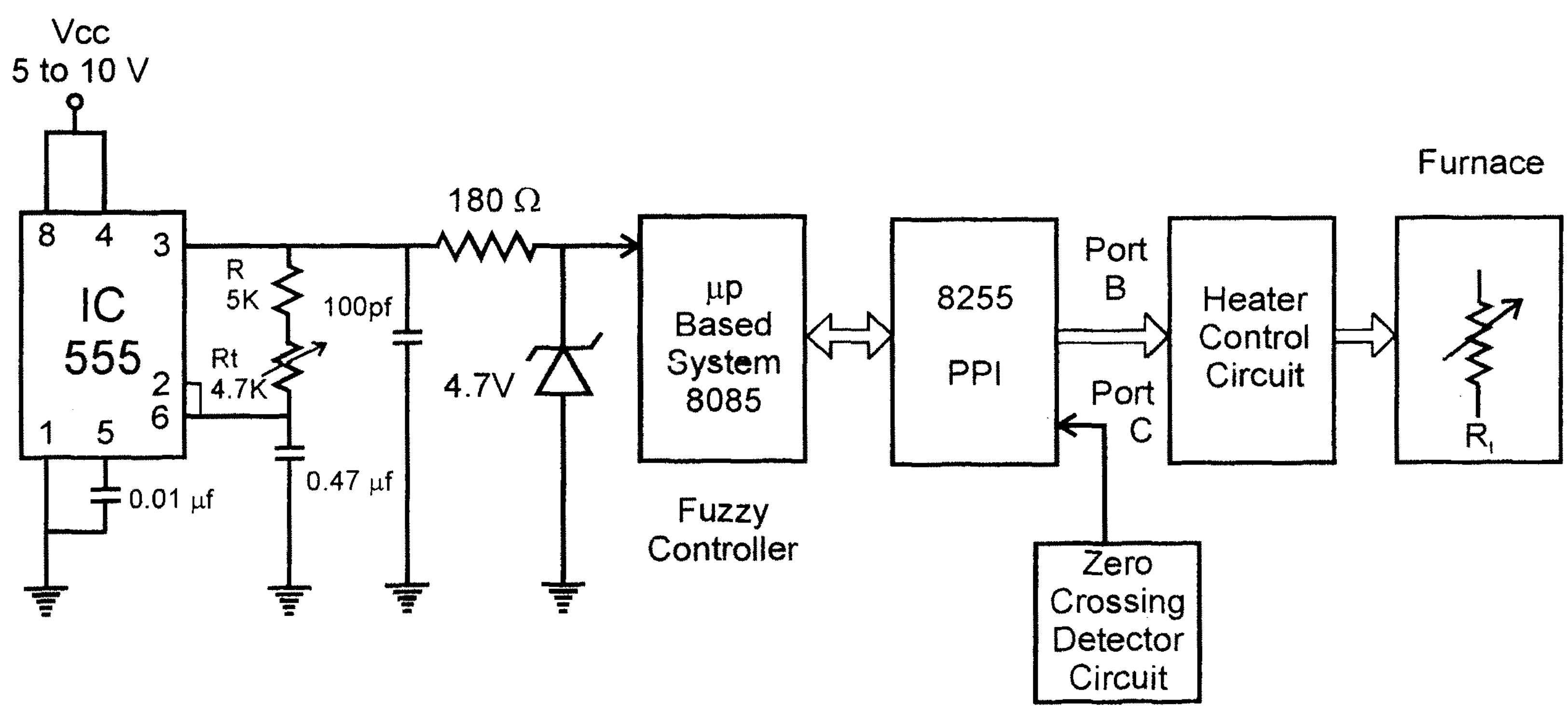


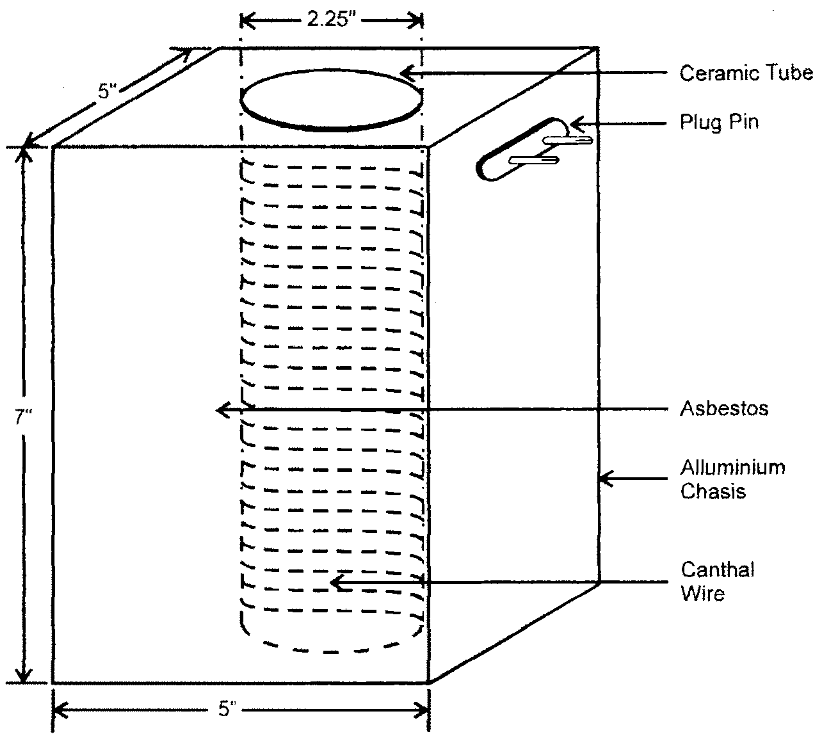
Fig. 3.2 : System Block Diagram of Fuzzy Logic Temperature Controller

Furnace used for Control :

Workshop made

Resistance = 10 Ω   Operating Voltage = 50 to 100 Volts

Power = 250 Watt



Sensor Section :

IC – 555 used in a novel astable mode with thermistor in the timing network forms the sensor part[3]. The output (Pin 3) of IC –555 goes to the interrupt RST 7.5 used to count the pulses as a function of temperature.

Micro Processor based Control Circuit[4-6] :

We have used 8085 based circuit to implement the fuzzy controller. The I/O 8255 has been used for the heater control operation while the temperature in the form of count was measured using the interrupt RST 7.5. The port details of 8255 are given below :

Port name	Address
Port A	00H
Port B	01H
Port C	02H
Control word register	03H

Zero Crossing Detector :

In order to fire Triac exactly at zero point of the AC cycle, zero crossing detector has been employed whose details are shown in fig. 3.3.

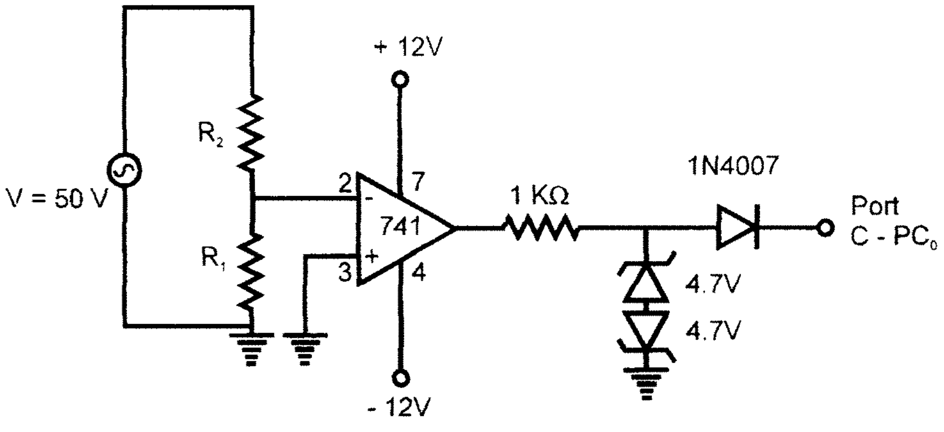


Fig.3.3 : Zero Crossing Detector Circuit

Calculation of R_1 and R_2

$$R_1 + R_2 = 50\ V/1\ mA = 50\ K\Omega$$

Dimmerstat is used to supply 50 V at 1 mA, 1 V is used as input to Pin 2.

$$VR_1 = R_1/(R_1+R_2) * V$$

$$\therefore \quad R_1 = (R_1+R_2) * VR_1/V = 50\ K * 1\ V / 50\ V = 1\ K\Omega$$

$$\therefore \quad R_2 = 49\ K\Omega$$

Zener is used for clipping the output of 741 to 4.7 V.

Diode 1N4007 is used to prevent negative pulse going to port C (Pin 1 – PC_0).

c) Heater Control Circuit :

Port C senses the output of detector and initiates the firing on level change. The heater circuit used for delivering power to the furnace whose temperature is controlled is shown in fig. 3.4[7,8].

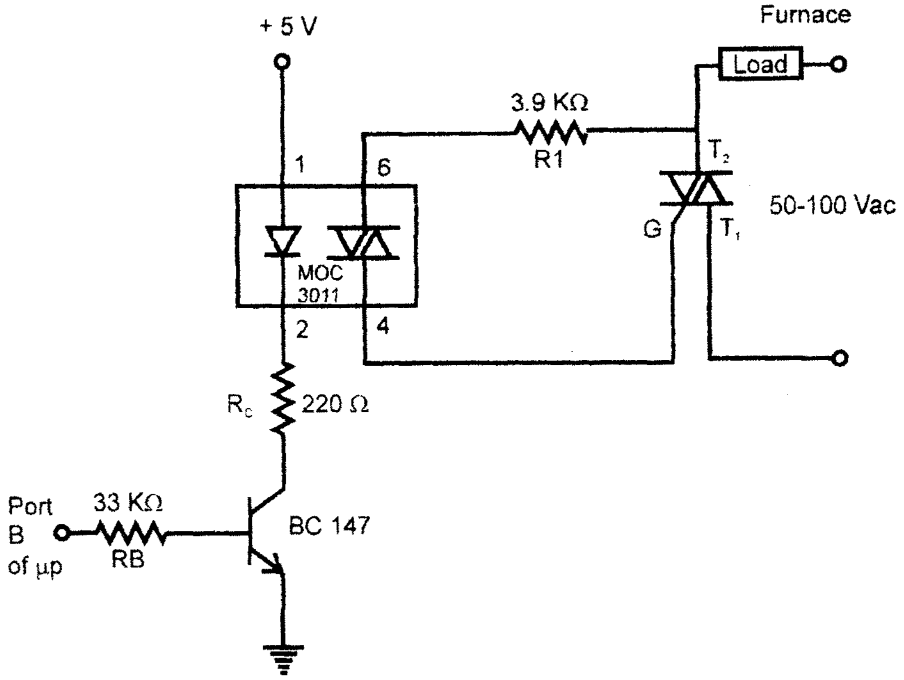
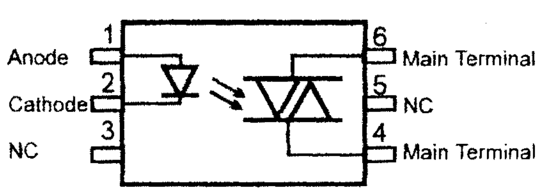


Fig. 3.4 : Heater Control Circuit using Opto-coupler and Triac

MOC 3011 : Opto Coupler



Pin Out of MOC 3011

1) LED with forward drop 1.3 V at 10 mA
2) Reverse breakdown voltage greater than 3 V
3) Maximum current to be passed through LED is 50 mA
4) Detector has minimum blocking voltage 250 V DC in the OFF state
5) In ON state detector will pass 100 mA in either direction with less than 3 V drop across the device

3.2 IMPLEMENTATION OF FUZZY LOGIC TEMPERATURE CONTROLLER[9-12] :

Step –1 : *Defining Inputs and outputs for Fuzzy logic controller :*

The universe of discourse for input and output is from room temperature to 100^0C and PWM uses 20 % to 80 % On time to control the heater circuit. The input temperature is sensed by using thermistor, which is connected in novel astable multivibrator whose frequency varies as a function of temperature. This data is given in table (3.1).

The count corresponding to a particular temperature, is measured with the help of a microprocessor based circuit and the same is stored in a memory location. Here microprocessor acts as a fuzzy logic controller. Thus, count acts as an input variable to the fuzzy logic controller.

By using rule base fuzzy logic controller decides output variable which is % duty cycle.

Table 3.1 : Universe of discourse for input and output of the fuzzy logic controller

Name	Input/Output	Minimum value	Maximum value
Temperature sense	Input	Room Temp.	100
% Duty cycle for PWM	Output	20 %	80 %

Step - 2 : *Fuzzification of Input variable*

The input to the Fuzzy logic controller is temperature sensed. Triangular membership functions have been used to Fuzzify the input. For fuzzifier program it is necessary to determine range of fuzzy variables related to the crisp inputs. Some guidelines are available[12] e.g.

1. Distribute symmetrically Fuzzified values across the universe of discourse.

2. Odd number of fuzzy sets be used for each variable so that some set is to be middle. The use of 4 to 7 sets is good.

3. Adjacent sets are overlapped.

Temperature sensed as input variable is restricted to positive values. The following fuzzy sets have been used.

VVL	– Very Very Low,	VL	– Very Low,
L	– Low,	LL	– Little Low,
ML	– Medium Low,	N – Normal,	
H	– High.		

Table 3.2 : Fuzzy Variable for Temperature

Sr. No.	Crisp input range	Fuzzy variable name
1	30^0C to 40^0C	VVL
2	30^0C to 50^0C	VL
3	40^0C to 60^0C	L
4	50^0C to 70^0C	LL
5	60^0C to 80^0C	ML
6	70^0C to 90^0C	N
7	80^0C to 90^0C	H

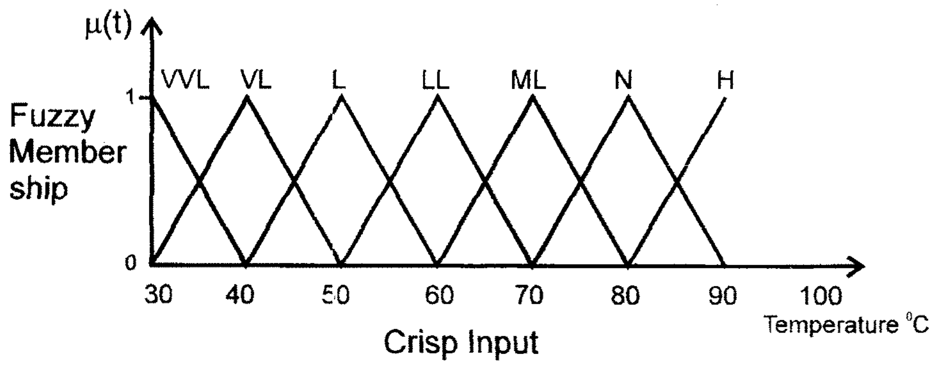


Fig.3.5 : Fuzzy membership function for temperature.

Since temperature is sensed in terms of count, the crisp inputs to fuzzy controller are counts received by controller. The following fuzzy sets for count have been used :

VVLC – Very Very Low Count,	VLC – Very Low Count,
LC – Low Count,	LLC – Little Low Count,
MC – Medium Count,	NC – Normal Count,
HC – High Count.	

Table 3.3 : Fuzzy Variable for temperature sense :

Sr. No.	Crisp input range for count	Fuzzy variable name
1	104 – 123	VVLC
2	104 – 138	VLC
3	123 – 152	LC
4	138 – 164	LLC
5	152 – 171	MC
6	164 – 180	NC
7	171 – 180	HC

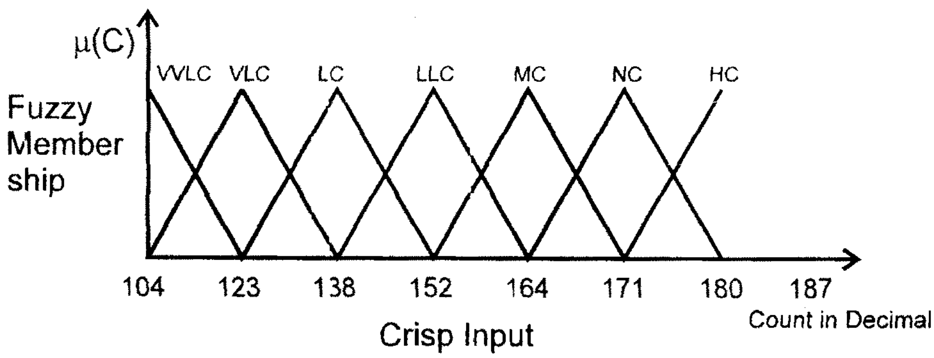


Fig.3.6 : Fuzzy membership function for count as temperature sense.

Step – 3 : *Fuzzy membership functions for outputs.*

We have considered typically one output variable, which is % duty cycle. It is necessary to assign fuzzy memberships to output variable. Similar to input variable this is given in table (3.4) and shown in fig. (3.7). The following fuzzy sets have been used for % duty cycle.

VVLD– Very Very Large Duty Cycle,	VLD – Very Large Duty Cycle,
LD – Large Duty Cycle,	LLD – Little Large Duty Cycle
MD – Medium Duty Cycle,	ND – Normal Duty Cycle,
SD – Small Duty Cycle	

Table 3.4 : Fuzzy Variable ranges for output % Duty Cycle.

Sr. No.	Crisp input range of temp.	Fuzzy variable range for output	Fuzzy variable name for output
1	$30^0C - 40^0C$	75 to 70 %.	VVLD
2	$30^0C - 50^0C$	75 to 65 %	VLD
3	$40^0C - 60^0C$	70 to 60 %	LD
4	$50^0C - 70^0C$	65 to 55 %	LLD
5	$60^0C - 80^0C$	60 to 50 %	MD
6	$70^0C - 90^0C$	55 to 45 %	ND
7	$80^0C - 90^0C$	50 to 45 %	SD

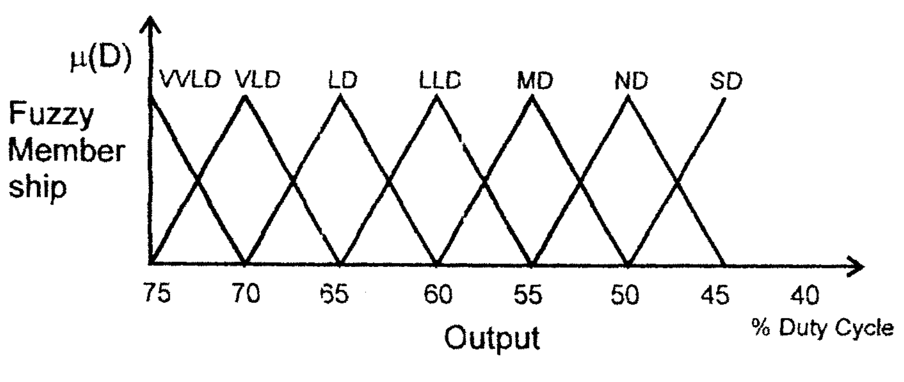


Fig. 3.7 : Fuzzy membership function for the output % duty cycle.

Step - 4 : a) *Create a fuzzy rule base :*

Here we have the inputs and the outputs defined in terms of fuzzy variables. It is necessary to specify what action to be taken under what condition ? therefore set of rules must be constructed that describe the operation of the fuzzy logic controller. Such type of rules take the form of IF-THEN rules and these can be obtained from a human expert through experience. These rules infer from the behaviour of system.

For constructing rule base for our design which consists of one input variable and one output variable, the following guidelines have been used

1. When the temperature of the system is lower than the set point value then it is necessary to increase the on time or power delivered to heater element, so that temperature rises towards set value.
2. When the temperature of system is higher than set point value then it is required to decrease the on time or power delivered to heater element, so that temperature decreases towards set value.
3. When the temperature of system is at set value. Then there is no change in the on time or off time of the heater.
4. The PWM is in proportion to the rise in the temperature till the set point is reached.

By using these guidelines, we have constructed IF –THEN rules as rule base.[13,14]

b) *Creating IF –THEN Rules :*

The temperature control policy is structurally formulated in terms of fuzzy-rules. The relevant information of rules is stored in the data-base. Thus knowledge base consists of rule base and data base.

Data Base :

The Data base contains the following information

(1) Labels of linguistic variables and

(2) Operating range of variable,

Typical membership functions for temperature are defined as follows.

$\mu_{VVL}(t) = L\ (30,40)$

$\mu_{NL}(t) = \wedge\ (30,40,50)$ $\mu_{ML}(t) = \wedge\ (60,70,80)$

$\mu_{L}(t) = \wedge\ (40,50,60)$ $\mu_{N}(t) = \wedge\ (70,80,90)$

$\mu_{M}(t) = \wedge\ (50,60,70)$ $\mu_{H}(t) = \Gamma\ (80,90)$

Typical membership functions for duty cycle are defined as follows.

$\mu_{VVL}(D) = L\ (75,70)$

$\mu_{VL}(D) = \wedge\ (75,70,65)$ $\mu_{M}(D) = \wedge\ (60,55,50)$

$\mu_{L}(D) = \wedge\ (70,65,60)$ $\mu_{N}(D) = \wedge\ (55,50,45)$

$\mu_{LL}(D) = \wedge\ (65,60,55)$ $\mu_{S}(D) = \Gamma\ (50,45)$

Rule Base :

The control policy of heater is structurally formulated in terms of fuzzy rules as given below

1) If the temperature is - **H** THEN duty cycle is - **SD**

1) If the temperature is - **N** THEN duty cycle is - **ND**

2) If the temperature is - **ML** THEN duty cycle is - **MD**

3) If the temperature is - **LL** THEN duty cycle is - **LLD**

4) If the temperature is - **L** THEN duty cycle is - **LD**

5) If the temperature is - **VL** THEN duty cycle is - **VLD**

7) If the temperature is - **VVL** THEN duty cycle is - **VVLD**

Here output and input to fuzzy rule base are fuzzy variables. For any crisp input value, there may be fuzzy membership in several fuzzy input variables determined by fuzzifications. Each fuzzy input variable activation will cause different fuzzy output rule to fire.

Step - 5 : *Defuzzify the outputs :*

In order to control the duty cycle, we need to obtain a crisp temperature reading. There are several IF – THEN rules of the fuzzy rule base firing at once, because the inputs have been fuzzified. To arrive at single crisp output, there are several methods of defuzzification. To obtain crisp value of duty cycle from clipped fuzzy set a height defuzzification has been employed as shown in fig.(3.8). The crisp-duty cycle is given by [1,2]

$$D^* = \frac{\sum_{r=1}^{q} P_m^{(r)} h^{(r)}}{\sum_{r=1}^{q} h^{(r)}}$$

where

q = number of fuzzy rules fired.

$P_m^{(r)}$ = Peak Value of r^{th} Clipped fuzzy set

$h_{(r)}$ = height of r^{th} clipped fuzzy set

Sample results : Consider typical case when

1) The set temperature = 80^0C

2) The current temperature = 42.5^0C

3) Rule fired a) IF Temp. is L THEN Duty Cycle LD

b) IF Temp. is VL THEN Duty Cycle VLD

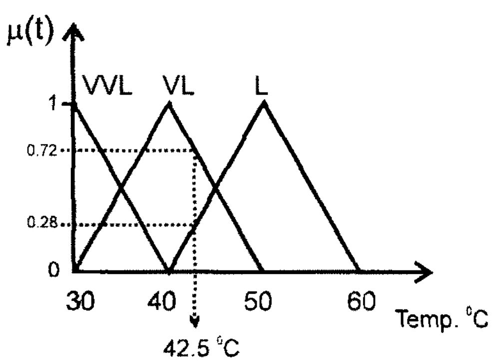


Fig.3.8(a) Temp. Sense

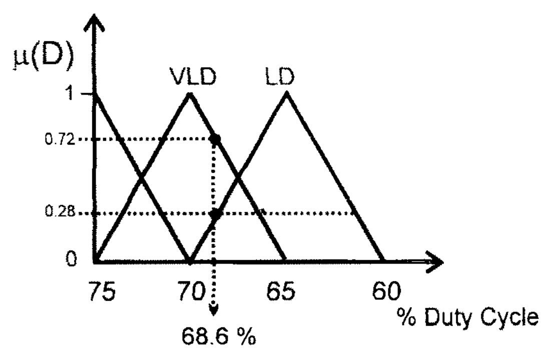


Fig.3.8(b) : Defuzzyfication of Duty Cycle

Rule Fired :

Temp. VL with DoS of 0.72 Duty Cycle VLD with DoS = 0.72

Temp. L with DoS of 0.28 Duty Cycle LD with DoS = 0.28

(Dos = Degree of Satisfaction)

$$\text{Defuzzified duty cycle } D^* = \frac{70 \times 0.72 + 0.28 \times 65}{0.72 + 0.28}$$

$$= 68.6\ \%$$

Similarly data for different value of temperature and corresponding defuzzified duty cycle is calculated for Set I, Set II, Set III and Set IV and represented in corresponding tables.

3.3 FLOW CHART :

This program after initialization of 8255 as o/p device calls the heater-on program corresponding to the room temperature ON and OFF time i.e. fuzzified counts from the table. The comparison with the defuzzified count corresponding to the set-point fires the rule and accordingly ON and OFF times (counts) get modulated till the set-point temperature is attained. At this stage the defuzzified counts corresponding to the ON and OFF times are evaluated and the heater power is controlled to maintain the temperature constant. The temperature is displayed and the entire process repeats. The system flow chart shown in fig.(3.9).

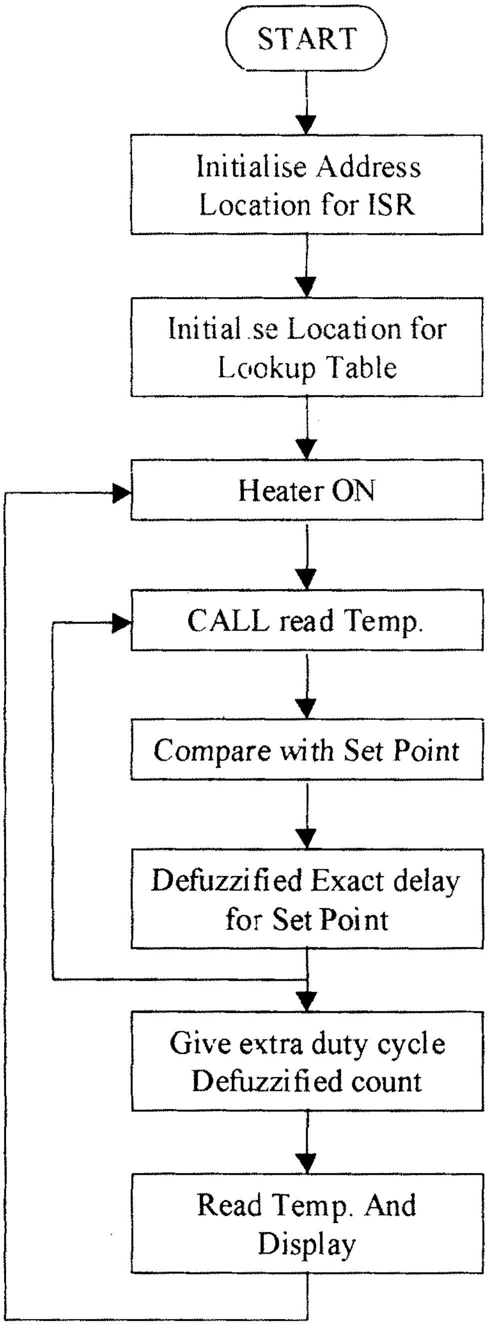


Fig. 3.9 : System Scftware Flow Chart

3.4 ASSEMBLY LANGUAGE PROGRAMME LISTING :

Memory Location	Machine Code	Label	Mnemonics	Comments
6000	3E,00		MVI A,00	:Initialise ISR Routine
6002	32,5E,20		STA 205E	at 6100H
6005	3E,61		MVI A,61	
6007	32,5F,20		STA 205F	
600A	3E,80		MVI A,89	: Initialise 8255 Port A, B
600C	D3,03		OUT CWRG	Output and Port C Input
600E	31,00,23		LXI SP 2300	: Initialise Stack pointer
6011	21,00,22		LXI H 2200	at 2300 H
6014	01,00,00		LXI B,0000 H	: Load BC Register = 0000 H
6017	C3,50,60		JMP 6050	: Jump heater control routine

Heater Control Sub Routine

Memory Location	Machine Code	Label	Mnemonics	Comments
6050	21,00,64	PWM1	LXIH,6400 H	:HL points 6400 H
6053	7D		MOV A,L	Look up table for T_{ON}.
6054	81		ADD C	
6055	6F		MOV L,A	
6056	7E		MOV A,M	: Load T_{ON} delay count in
6057	5F		MOV E,A	Reg DE
6058	2C		INR L	
6059	0C		INR C	
605A	OC		INR C	
605B	7E		MOV A,M	
605C	57		MOV D,A	
605D	CD,D0,60		CALL ZCD	CALL ZCD Sub routine
6060	3E,FF	TON	MVI A,FF	: Produce
6062	D3,01		OUT Port B	Delay for T_{ON}
6064	1B		DCDX	
6065	7B		MOV A,E	

Memory Location	Machine Code	Label	Mnemonics	Comments
6066	B2		ORA D	
6066	C2,6060		JNZ TON	
606A	21,00,65		LXI H,6500	: HL Points 6500H
606D	7D		MOVA,L	Look up table for T_{OFF}
606E	68		ADD B	
606F	6F		MOV L,A	
6070	7E		MOV A,M	: Load T_{OFF} delay count in
6071	5F		MOV E,A	Reg DE
6072	2C		INR L	
6073	04		INR B	:Increment register
6074	04		INR B	B.
6075	7E		MOV A,M	
6076	57		MOV D,A	
6077	3E, 00	TOFF	MVI A,OO	: Produce delay for T_{OFF}
6079	D3, 01		OUT Port B	
607B	1B		DCX D	
607C	7B		MOV A,E	
607D	B2		ORA D	
607E	C2,74,60		JNZ TOFF	
6081	CD,20,60	REPEAT	CALL RDTEMP;	: CALL sub routine RD Temp.
6084	3E,8A		MVI A,SP	: Set point is loaded here
6086	47		MOV D,A	
6087	7D		MOV A,L	
6088	FE,39		CPI 39	
608A	CA, 14, 60		JZ 6014 H	
608D	3A,00,22		LDA,2200	
6090	92		SUB D	
6091	CA,AO,60		JZ:OK	
6094	DA,50,60		JC PWMI	
6097	D2,AO,60		JNC OK	

Sub Routine OK

Memory Location	Machine Code	Label	Mnemonics	Comments
60A0	26,64	OK	MVI H,64	
60A2	7E		MOV A,M	
60A3	5F		MOV E,A	
60A4	2C		INR L	
60A5	7E		MOV A,M	
60A6	57		MOV D,A	
60A7	CD,DO,60		CALL ZCD	CALL ZCD Routine
60AA	3E,FF	TON OK	MVI A,FF	: Produce Delay, for TON
60AC	D3,01		OUT Port B	Of PWM for When
60AE	1B		DCX D	Set point Temp. is reached
60AF	7B		MOV A,E	
60BO	B2		ORA D	
60B1	C2,AA,60		JNZ TON OK	
60B4	2D		DCR L	
60B5	26,65		MVI H,65	: HL points 65XX for set
60B7	7E		MOV A,M	Temp. T_{ON} delay
60B8	5F		MOV E,A	
60B9	2C		INR L	
60BA	7E		MOV A,M	
60BB	57		MOV D,A	
60BC	3E,OO	TOFF OK	MVI A,OO	Produce Deldy for T_{OFF} when set point temp. reached.
60BE	D3,01		OUT Port B	
60CO	1B		DCX D	
60C1	7B		MOV A,E	
60C2	B2		ORA D	
60C3	C2,BC,60		JNZ, TOFF OK	
60C6	C3,81,60		JMP Repeat	Call RTD Temperature.

Sub Routine ZCD

Memory Location	Machine Code	Label	Mnemonics	Comments
60DO	DB,02	ZCD	IN PORT C	: Input from ZCD Circuit
60D2	E6,01		ANI,01	is compared
60D4	FE,01		CPI 01	
60D6	CA, D0, 60		JZ ZCD	
60D7	C9		RET	

Sub Routine RDTEMP.

Memory Location	Machine Code	Label	Mnemonics	Comments
6020	F5	RDTEMP	PUSH PSW	
6021	C5		PUSH B	
6022	D5		PUSH D	
6023	E5		PUSH H	
6024	21,00,22		LXI H,2200	Initialise HL at 2200 H
6027	36,00	START	MVI M,OO	: Clear memory LOC=00H
6029	3E,0B		MVI A,OB	: Initialise interrupts 7.5
602B	30		SIM	
602C	FB		EI	
602D	11 IF F9		LXI D,IFF9	
6030	FB	LOOP	EI	
6031	1B		DCX D	
6032	7B		MOV A,E	Delay of 1 sec is produced
6033	B2		ORA D	
6034	C2,30,60		INR LOOP	
6037	7E		MOV A,M	00
6038	CD, 80,61		CALL TDISPLY	CALL TEMP. LOOK up
603B	CD,00,66		CALL DISPLAY	Call display routine
603E	E1		POP H	Regain register
603F	D1		POP D	Content from
6040	C1		POP B	Stack
6041	F1		POP PSW	
6042	C9		RET	

Sub Routine Interrupt (ISR)

Memory Location	Machine Code	Label	Mnemonics	Comments
6100	34	ISR	INR M	: Interrupt service routine to
6101	3E,1B		MVI A,1B	Store count in memory
6103	30		SIM	Location 2200H
6104	FB		EF	
6105	C9		RET	

Sub Routine T-Display

Memory Location	Machine Code	Label	Mnemonics	Comments
6180	D5		PUSH BC	: Save register content
6181	0E, 00		MVI C,00	: Initialise register to 00
6183	47		MOV B,A	: load recent count in B reg.
6184	21,00,63		LXI H 63,00	: Initialise HL at 6300
6187	7E	NEXT C	MOV A,M	: lookup table count acc.
6188	B8		CMP B	: Compare acc with reg B
6189	CA,91,61		JZ, DTEMP	
618C	0C		INR C	
618D	69		MOV L,C	
618E	C3,87,61		JMP NEXT C	: jump to next count
6191	25	DTEMP	DCR H	
6192	7E		MOV A,M	
6193	31,01,22		STA 2201	: store count at M. 2201 H
6196	D1		POP BC	: Regain reg content
6197	C9		RET	

Sub Routine Display :

Memory Location	Machine Code	Label	Mnemonics	Comments
6600	3E,3E		MVI A,3E	: Initialise 8279
6602	D3,11		OUT CWR	
6604	3E,00		MVI A,00	
6606	D3,11		OUT CWR	
6608	3E,90		MVI A,90	
660A	D3,11		OUT CWR	
660C	CD,30,66		CALL : BCD 7 DISP	CALL sub routine BCD 7 DISP
660F	21,80,22		LXI H,2280	: Initialise HL at 2280 H
6612	0E,06		MVI C, COUNTER	
6614	7E	NEXT	MOV A,M	
6615	D3,10		OUT DATA	: Display Data
6617	23		INXH	
6618	0D		DCRC	
6619	C2,14,66		JNZ NEXT	
661C	C9		RET	

Output Buffer at 2280

Memory Location	Data	Comments
2280	XX	: Temp. to be displayed
2281	XX	
2282	XX	
2283	00	: Code for blank space
2284	63	: Code for to display ^{0}C
2285	29	

Sub Routine BCD7D :

Memory Location	Machine Code	Label	Mnemonics	Comments
6630	01,80,22		LXI B,C	: Initialise output buffer
6633	3A,01,22	UNPB	LDA 2201	: Get temp. In ACC
6636	27		DAA	
6637	3E,00		MVI A,00	
6639	17		RAL	
663A	CD,60,66		CALL LEDCOD	: CALL LEDCOD Sroutine
663D	03		INX B	
663E	3A, 01,22		DA 2201	
6641	27		DAA	
6642	E6,F0		ANI F0	Mask LSB of BCD
6644	0F		RRC	
6645	0F		RRC	
6646	0F		RRC	
6647	0F		RRC	
6648	CD,60,66		CALL LEDCOD	: Call LED COD Routine
664B	03		INX B	
664C	3A,01,22		LDA 2201	
664F	27		DAA	
6650	E6,OF		ANI OF	: Mask MSB of BCD
6652	CD,60,66		CALL LEDCOD	: Call LED COD Routine
6655	C9		RET	

Sub Routine LEDCOD :

Memory Location	Machine Code	Label	Mnemonics	Comments
6660	E5	LED COD	PUSH H	: HL content stored
6661	21,70,66		LXI H CODE	: Initialise code
6664	85		ADD L	Memory pointer
6665	6F		MOV L,A	: Load 7 Segment
6666	7E		MOV A.M	Code in Accumulator
6667	02		STAX B	: Store 7 Segment code in
6668	E1		POP H	Output buffer
6669	C9		RET	

CODE : Look-up table :

Memory Location	Hex Code	Decimal Digit
6670	3F	0
6671	06	1
6672	5B	2
6673	4F	3
6674	66	4
6675	6D	5
6676	7D	6
6677	07	7
6678	7F	8
6679	6F	9

3.5 LOOK-UP TABLES :

Look-up Table 3.5

Temperature and Corresponding Hex Count

Memory Location	Temp. ^0C	Memory Location	Hex Count	Memory Location	Temp. ^0C	Memory Location	Hex Count
6200	28	6300	63	6224	64	6324	9B
6201	29	6301	65	6225	65	6325	9C
6202	30	6302	68	6226	66	6326	9A
6203	31	6303	69	6227	67	6327	9F
6204	32	6304	6C	6228	68	6328	A1
6205	33	6305	6E	6229	69	6329	A3
6206	34	6306	6F	622A	70	632A	A4
6207	35	6307	70	622B	71	632B	A4
6208	36	6308	73	622C	72	632C	A5
6209	37	6309	75	622D	73	632D	A6
620A	38	630A	76	622E	74	632E	A6
620B	39	630B	78	622F	75	632F	A7
620C	40	630C	7B	6230	76	6330	A8
620D	41	630D	7C	6231	77	6331	A9
620E	42	630E	7D	6232	78	6332	A9
620F	43	630F	7E	6233	79	6333	AA
6210	44	6310	7F	6234	80	6334	AB
6211	45	6311	80	6235	81	6335	AC
6212	46	6312	82	6236	82	6336	AD
6213	47	6313	84	6237	83	6337	AE
6214	48	6314	86	6238	84	6338	AF
6215	49	6315	88	6239	85	6339	B0
6216	50	6316	8A	623A	86	633A	B1
6217	51	6317	8B	623B	87	633B	B2
6218	52	6318	8D	623C	88	633C	B2
6219	53	6319	8E	623D	89	633D	B3
621A	54	631A	90	623E	90	633E	B4
621B	55	631B	91	623F	91	633F	B5
621C	56	631C	92	6240	92	6340	B6
621D	57	631D	93	6241	93	6341	B6
621E	58	631E	94	6242	94	6342	B7
621F	59	631F	96	6243	95	6343	B8
6220	60	6320	98	6244	96	6344	B8
6221	61	6321	99	6245	97	6345	B9
6222	62	6322	9A	6246	98	6346	B9
6223	63	6323	9A	6247	99	6347	BA

Pulse Width Modulation :

Loop T State (T_{ON} and T_{OFF}) = 38   μp Clock Period T = 0.56 sec.

Time delay = Loop T State * Count in Dec * Period

Count for 1 sec = 1 sec / 38 * 0.56 μs = 46992 Dec = 8790 Hex

% Duty Cycle = T_{ON} / (T_{ON} + T_{OFF}) * 100

by using this formula Table 3.6 is prepared.

Table 3.6

Percentage Duty Cycle and corresponding Hex Count

% Duty Cycle	Dec Count	Hex Count	% Duty Cycle	Dec Count	Hex Count
20	9398	2436	51	23966	5DAD
21	9868	268C	52	24436	5F76
22	10338	2862	53	24906	614C
23	10808	2A38	54	25376	6322
24	11278	2COE	55	25846	64F8
25	11748	2DE4	56	26316	66CE
26	12218	2FBA	57	26785	68A4
27	12688	3190	58	27255	6A7A
28	13158	3366	59	27725	6C50
29	13628	353C	60	28195	6E26
30	14098	3712	61	28665	6FFC
31	14568	38E8	62	29135	71D2
32	15037	3ABE	63	29605	73A8
33	15507	3C94	64	30075	757E
34	15977	3E6A	65	30545	7754
35	16447	4040	66	31015	792A
36	16917	4216	67	31485	7B00
37	17387	43EC	68	31955	7CD6
38	17857	45C2	69	31424	7EAC
39	18327	4789	70	32894	8082
40	18797	496E	71	33364	8258
41	19267	4B44	72	33834	842E
42	19737	4D1A	73	34304	8604
43	20207	4EFO	74	34774	87DA
44	20676	50C6	75	35244	89B0
45	21146	529C	76	35714	8B86
46	21616	5472	77	36184	8D5C
47	22086	5648	78	35654	8F32
48	22556	581E	79	37124	9108
49	23026	59F4	80	37594	92DE
50	23496	53CA			

3.6 MEMBERSHIP FUNCTIONS :

By using table 3.6 we prepared duty cycle and defuzzified hex count for PWM as follows :

Set (I) Table 3.7 : Duty Cycle and Defuzzified Hex Count for PWM

Temp. In ^0C	**Hex *Count***	**% Duty *Cycle***	**Memory *Location***	**T_{ON}**	**Memory *Location***	**T_{OFF}**
28	63	80	6400	DE	6500	B6
29	65		6401	92	6501	24
30	68	80	6402	DE	6502	B6
31	69		6403	92	6503	24
32	6C	79	6404	08	6504	8C
33	6E		6405	91	6505	26
34	6F	78	6406	32	6506	62
35	70		6407	8F	6507	28
36	73	77	6408	5C	6508	38
37	75		6409	8D	6509	2A
38	76	76	640A	86	65DA	0E
39	78		640B	8B	650B	2C
40	7B	75	640C	B0	650C	E4
41	7C		640D	89	650D	2D
42	7D	74	640E	DA	650E	BA
43	7E		640F	87	650F	2F
44	7F	73	6410	04	6510	90
45	80		6411	86	6511	31
46	82	72	6412	2E	6512	66
47	84		6413	84	6513	33
48	86	71	6414	58	6514	3C
49	88		6415	82	6515	35
50	8A	70	6416	84	6516	12
51	8B		6417	80	6517	37
52	8D	69	6418	AC	6518	E8
53	8E		6419	7E	6519	38
54	90	68	641A	D6	651A	3E
55	91		641B	7C	651B	8A

Temp. In ^0C	Hex Count	% Duty Cycle	Memory Location	T_{ON}	Memory Location	T_{OFF}
56	92	67	641C	00	651C	94
57	93		641D	7B	651D	3C
58	94	66	641E	2A	651E	6A
59	96		641F	79	651F	3E
60	98	65	6420	54	6520	40
61	99		6421	77	6521	40
62	9A	64	6422	7E	6522	16
63	9A		6423	75	6523	42
64	9B	63	6424	A8	6524	EC
65	9C		6425	73	6525	43
66	9A	62	6426	D2	6526	C2
67	9F		6427	71	6527	45
68	A1	61	6428	FC	6528	98
69	A3		6429	6F	6529	47
70	A4	60	642A	26	652A	6E
71	A4		642B	6E	652B	49
72	A5	59	642C	50	652C	44
73	A6		642D	6C	652D	4B
74	A6	58	642E	7A	652E	1A
75	A7		642F	6A	652F	4D
76	A8	57	6430	A4	6530	F0
77	A9		6431	68	6531	4E
78	A9	56	6432	CE	6532	C6
79	AA		6433	66	6533	50
80	AB	55	6434	F8	6534	9C
81	AC		6435	64	6535	52
82	AD	54	6436	22	6536	72
83	AE		6437	63	6537	54
84	AF	53	6438	4C	6538	48
85	B0		6439	61	6539	56

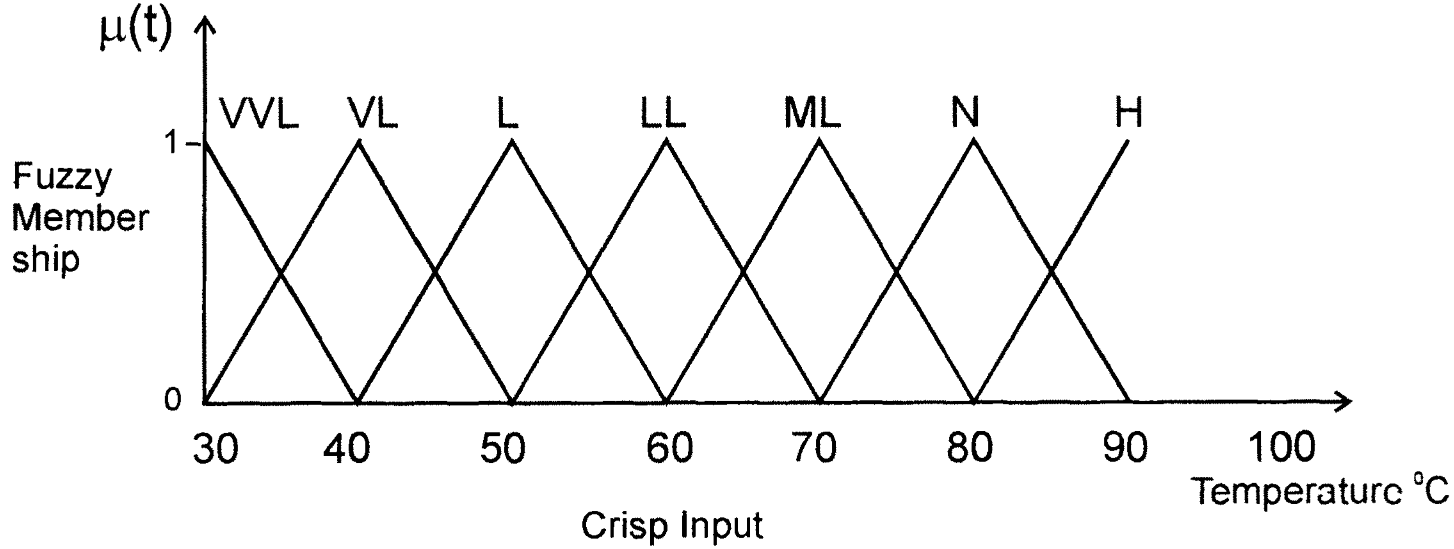


Fig.3.10(a) : Membership Function for Temperature

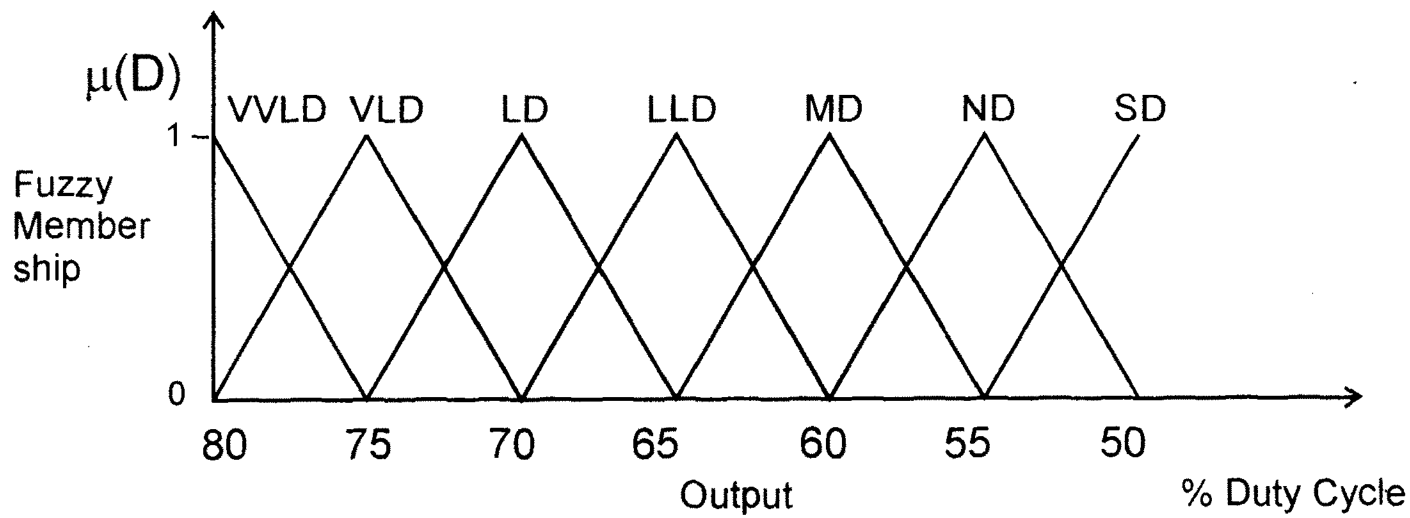


Fig.3.10(b) : Membership Function for % Duty Cycle

Set (II) Table 3.8 : Duty Cycle and Defuzzified Hex Count for PWM

Temp. In ^{0}C	Hex Count	% Duty Cycle	Memory Location	T_{ON}	Memory Location	T_{OFF}
28	63	76	6400	86	6500	0E
29	65		6401	8B	6501	2C
30	68	75	6402	30	6502	E4
31	69		6403	89	6503	2D
32	6C	74	6404	DA	6504	BA
33	6E		6405	87	6505	2F
34	6F	73	6406	04	6506	90
35	70		6407	86	6507	31
36	73	72	6408	2E	6508	66
37	75		6409	84	6509	33
38	76	71	640A	58	65DA	3C
39	78		640B	82	650B	35
40	7B	70	640C	84	650V	12
41	7C		640D	80	650D	37
42	7D	69	640E	AC	650E	E8
43	7E		640F	7E	650F	38
44	7F	68	6410	D6	6510	3E
45	80		6411	7C	6511	8A
46	82	67	6412	00	6512	94
47	84		6413	7B	6513	3C
48	86	66	6414	2A	6514	6A
49	88		6415	79	6515	3E
50	8A	65	6416	54	6516	40
51	8B		6417	77	6517	40
52	8D	64	6418	7E	6518	16
53	8E		6419	75	6519	42
54	90	63	641A	A8	651A	EC
55	91		641B	73	651B	43

Temp. In ^0C	Hex Count	% Duty Cycle	Memory Location	T_{ON}	Memory Location	T_{OFF}
56	92	62	641C	D2	651C	C2
57	93		641D	71	651D	45
58	94	61	641E	FC	651E	98
59	96		641F	6F	651F	47
60	98	60	6420	26	6520	6E
61	99		6421	6E	6521	49
62	9A	59	6422	50	6522	44
63	9A		6423	6C	6523	4B
64	9B	58	6424	7A	6524	1A
65	9C		6425	6A	6525	4D
66	9A	57	6426	A4	6526	F0
67	9F		6427	68	6527	4E
68	A1	56	6428	CE	6528	C6
69	A3		6429	66	6529	50
70	A4	55	642A	F8	652A	9C
71	A4		642B	64	652B	52
72	A5	54	642C	22	652C	72
73	A6		642D	63	652D	54
74	A6	53	642E	4C	652E	48
75	A7		642F	61	652F	56
76	A8	52	6430	76	6530	1E
77	A9		6431	5F	6531	58
78	A9	51	6432	AO	6532	F
79	AA		6433	5D	6533	59
80	AB	50	6434	CA	6534	CA
81	AC		6435	5B	6535	5B
82	AD	49	6436	F	6536	A0
83	AE		6437	59	6537	5D
84	AF	48	6438	1E	6538	76
85	B0		6439	58	6539	5F

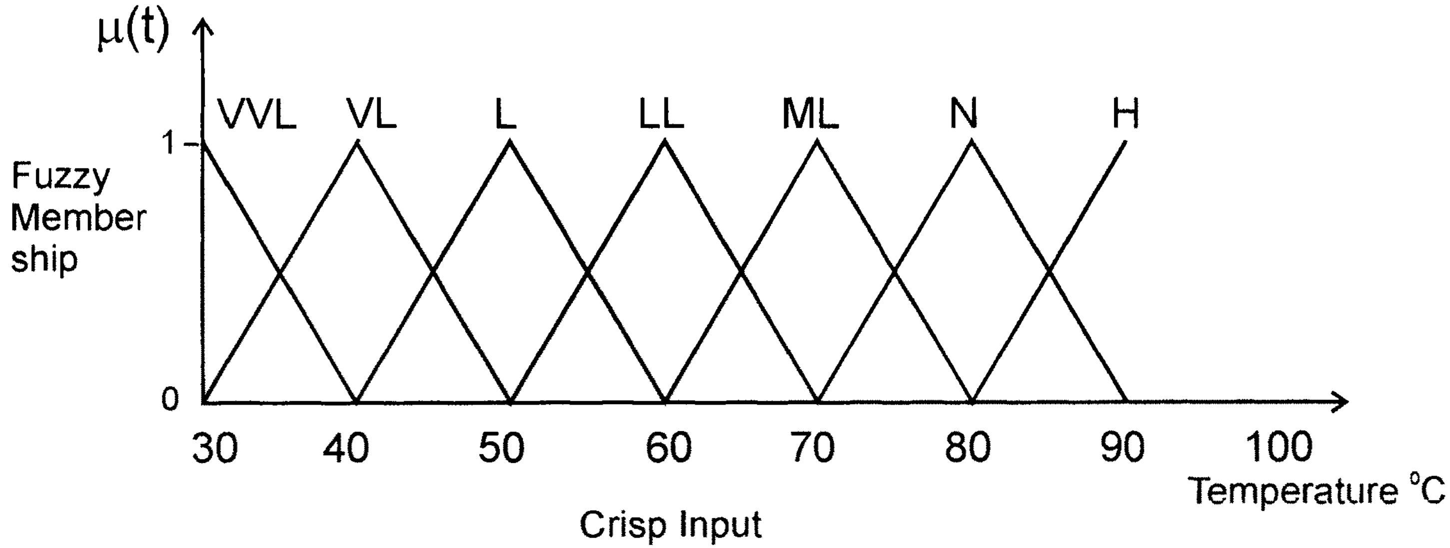


Fig.3.11(a) : Membership Function for Temperature

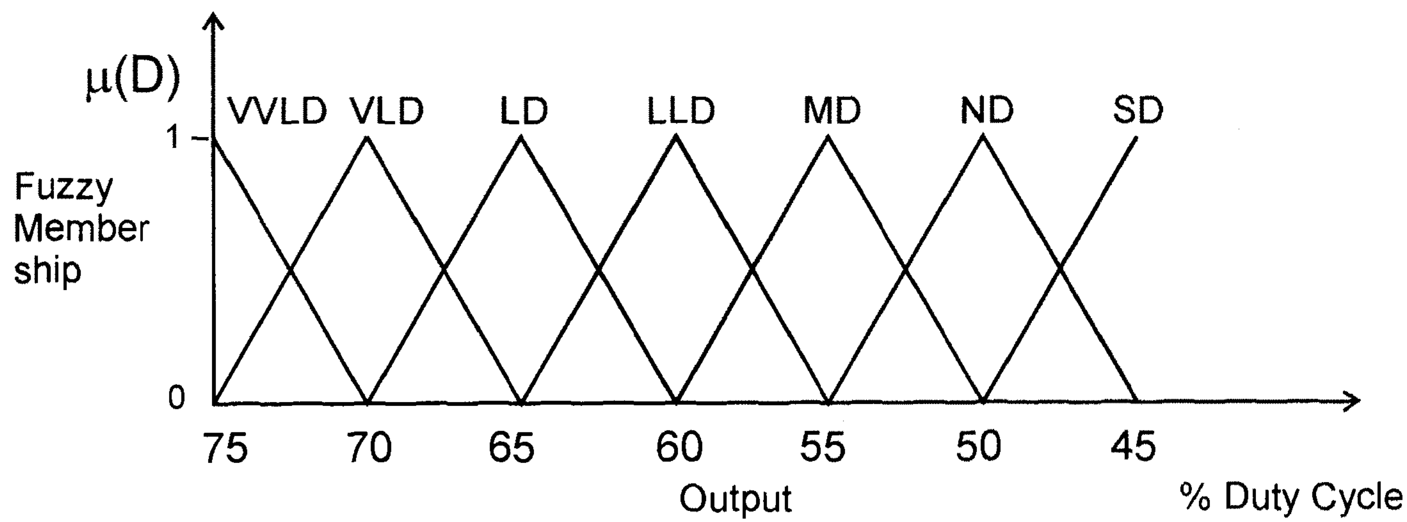


Fig.3.11(b) : Membership Function for % Duty Cycle

Set (III) Table 3.9 : Duty Cycle and Defuzzified Hex Count for PWM

Temp. In ^{0}C	Hex Count	% Duty Cycle	Memory Location	T_{ON}	Memory Location	T_{OFF}
28	63	71	6400	58	6500	3C
29	65		6401	82	6501	35
30	68	70	6402	82	6502	12
31	69		6403	80	6503	37
32	6C	69	6404	AC	6504	E8
33	6E		6405	7E	6505	38
34	6F	68	6406	D6	6506	BE
35	70		6407	7C	6507	3A
36	73	67	6408	00	6508	94
37	75		6409	7B	6509	3C
38	76	66	640A	2A	65DA	6A
39	78		640B	79	650B	3E
40	7B	65	640C	54	650V	40
41	7C		640D	77	650D	40
42	7D	64	640E	7E	650E	16
43	7E		640F	75	650F	42
44	7F	63	6410	A8	6510	EC
45	80		6411	73	6511	43
46	82	62	6412	D2	6512	C2
47	84		6413	71	6513	45
48	86	61	6414	FC	6514	98
49	88		6415	68	6515	47
50	8A	60	6416	26	6516	6E
51	8B		6417	6E	6517	49
52	8D	59	6418	50	6518	44
53	8E		6419	6C	6519	4B
54	90	58	641A	7A	651A	1A
55	91		641B	6A	651B	4D

Temp. In ^0C	Hex Count	% Duty Cycle	Memory Location	T_{ON}	Memory Location	T_{OFF}
56	92	57	641C	A4	651C	F0
57	93		641D	68	651D	4E
58	94	56	641E	CE	651E	C6
59	96		641F	66	651F	50
60	98	55	6420	58	6520	9C
61	99		6421	64	6521	52
62	9A	54	6422	22	6522	72
63	9A		6423	63	6523	54
64	9B	53	6424	4C	6524	48
65	9C		6425	61	6525	56
66	9A	52	6426	76	6526	1E
67	9F		6427	5F	6527	58
68	A1	51	6428	A0	6528	F4
69	A3		6429	5D	6529	59
70	A4	50	642A	CA	652A	CA
71	A4		642B	5B	652B	5B
72	A5	49	642C	F4	652C	A0
73	A6		642D	F9	652D	5D
74	A6	48	642E	1E	652E	76
75	A7		642F	58	652F	5F
76	A8	47	6430	48	6530	4C
77	A9		6431	56	6531	61
78	A9	46	6432	72	6532	22
79	AA		6433	54	6533	63
80	AB	45	6434	9C	6534	F8
81	AC		6435	52	6535	64
82	AD	44	6436	C6	6536	CE
83	AE		6437	50	6537	66
84	AF	43	6438	F0	6538	A4
85	B0		6439	4A	6539	68

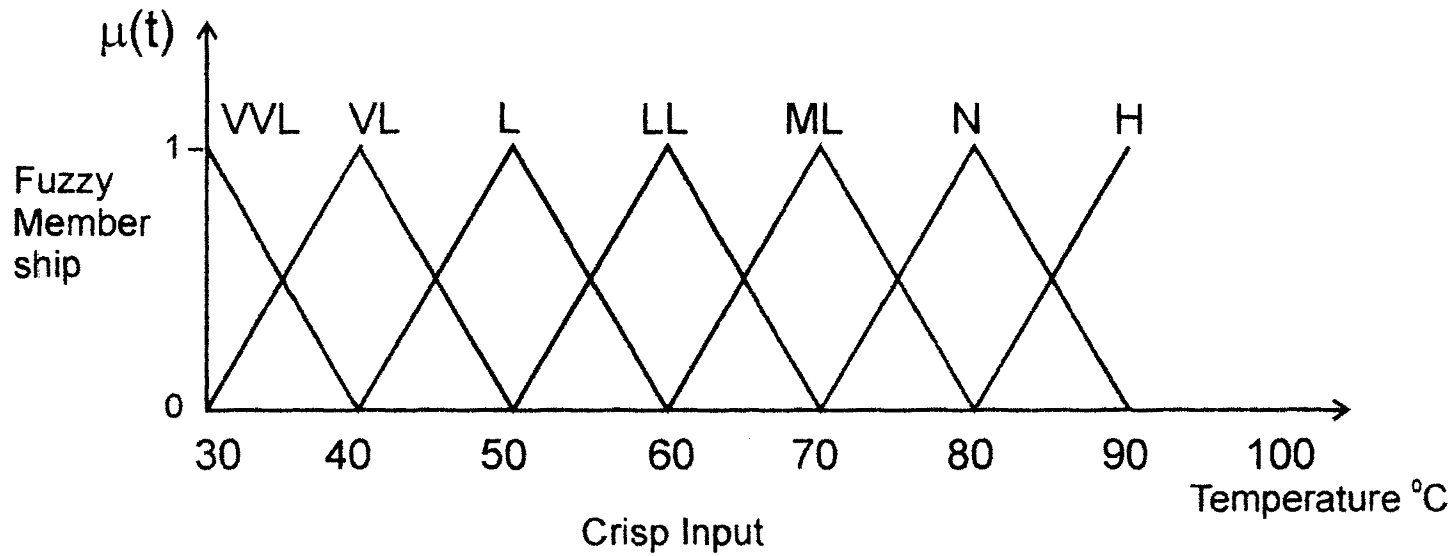


Fig.3.12(a) : Membership Function for Temperature

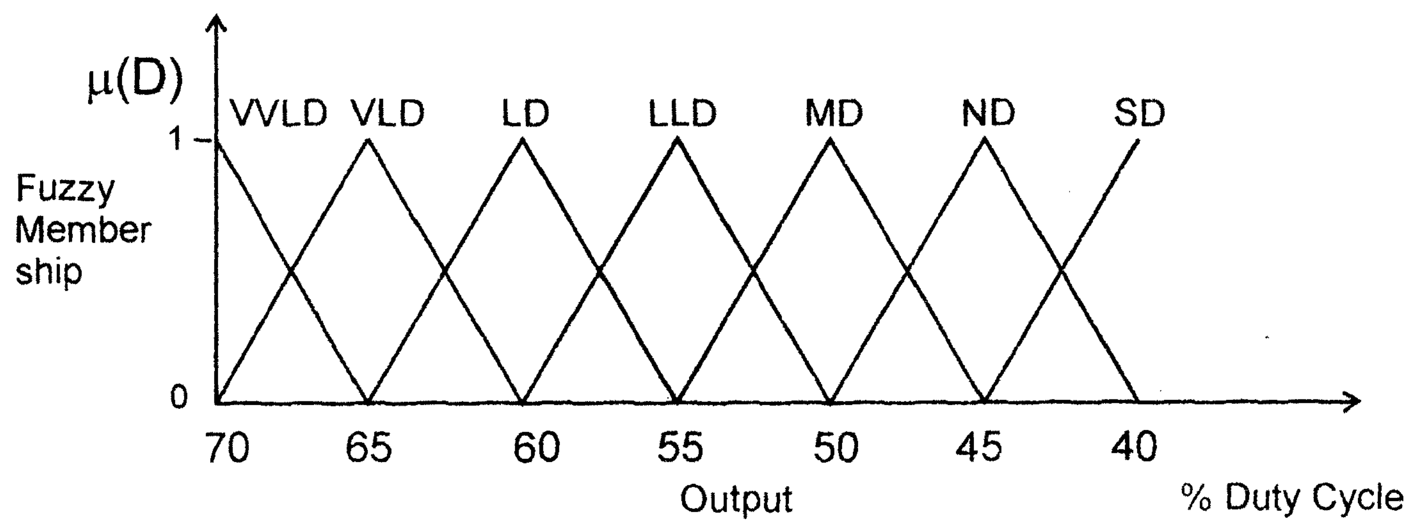


Fig.3.12(b) : Membership Function for % Duty Cycle

Set (IV) Table 3.10 : Duty Cycle and Defuzzified Hex Count for PWM

Temp. In ^{0}C	**Hex Count**	**% Duty Cycle**	**Memory Location**	T_{ON}	**Memory Location**	T_{OFF}
28	63	66	6400	2A	6500	6A
29	65		6401	79	6501	3E
30	68	65	6402	54	6502	40
31	69		6403	77	6503	40
32	6C	64	6404	7E	6504	16
33	6E		6405	75	6505	42
34	6F	63	6406	A8	6506	EC
35	70		6407	73	6507	43
36	73	62	6408	D2	6508	C2
37	75		6409	71	6509	45
38	76	61	640A	FC	65DA	98
39	78		640B	68	650B	47
40	7B	60	640C	26	650V	6E
41	7C		640D	6E	650D	49
42	7D	59	640E	50	650E	44
43	7E		640F	6C	650F	4B
44	7F	58	6410	7A	6510	1A
45	80		6411	6A	6511	4D
46	82	57	6412	A4	6512	F0
47	84		6413	68	6513	4E
48	86	56	6414	CE	6514	C6
49	88		6415	66	6515	50
50	8A	55	6416	F8	6516	9C
51	8B		6417	64	6517	52
52	8D	54	6418	22	6518	72
53	8E		6419	63	6519	54
54	90	53	641A	4C	651A	48
55	91		641B	61	651B	56

Temp. In ^{0}C	Hex Count	% Duty Cycle	Memory Location	T_{ON}	Memory Location	T_{OFF}
56	92	52	641C	76	651C	1E
57	93		641D	5F	651D	58
58	94	51	641E	A0	651E	F4
59	96		641F	5D	651F	F9
60	98	50	6420	CA	6520	CA
61	99		6421	5B	6521	5B
62	9A	49	6422	F4	6522	A0
63	9A		6423	59	6523	5D
64	9B	48	6424	1E	6524	76
65	9C		6425	58	6525	5F
66	9A	47	6426	48	6526	4C
67	9F		6427	56	6527	61
68	A1	46	6428	72	6528	22
69	A3		6429	54	6529	63
70	A4	45	642A	9C	652A	F8
71	A4		642B	52	652B	64
72	A5	44	642C	C6	652C	CE
73	A6		642D	50	652D	66
74	A6	43	642E	F0	652E	A4
75	A7		642F	4E	652F	68
76	A8	42	6430	1A	6530	7A
77	A9		6431	4D	6531	6A
78	A9	41	6432	44	6532	50
79	AA		6433	4B	6533	6A
80	AB	40	6434	6E	6534	26
81	AC		6435	49	6535	6E
82	AD	39	6436	89	6536	FC
83	AE		6437	47	6537	6F
84	AF	38	6438	C2	6538	D2
85	B0		6439	45	6539	71

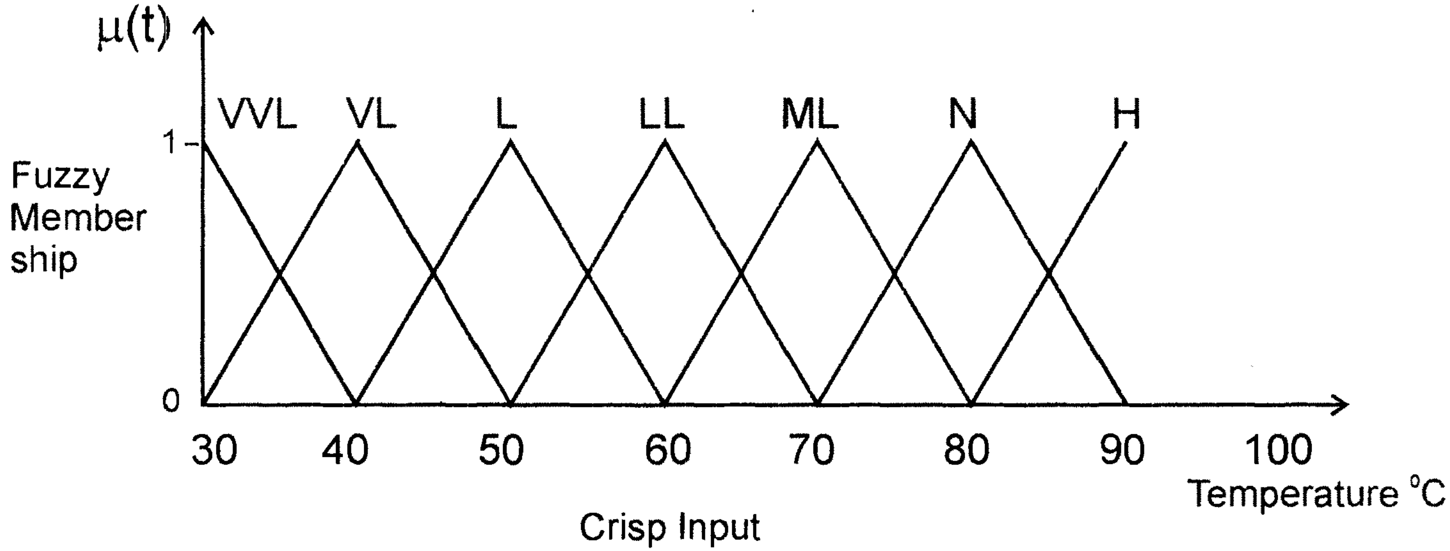


Fig.3.13(a) : Membership Function for Temperature

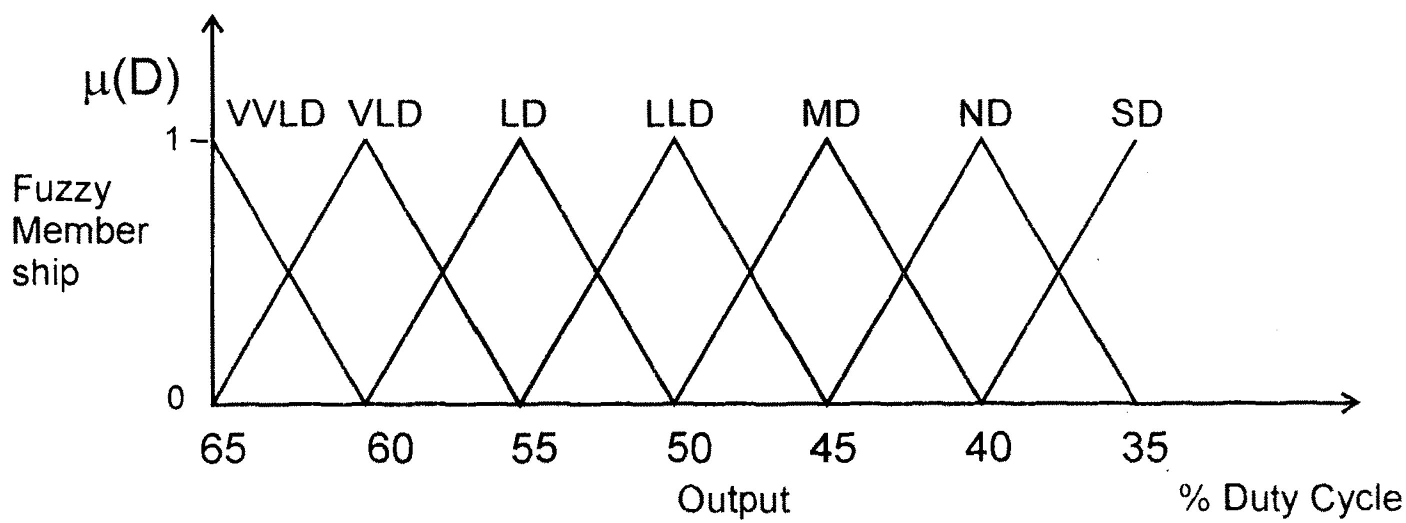


Fig.3.13(b) : Membership Function for % Duty Cycle

3.7 TUNING PROCESS :

Parameters tuning is effected to scale or affect the shape of the membership function to achieve precise and smooth control action. These are three categories of tuning method[9,10,15].

Type 1: Three parameters of each fuzzy set are to be tuned.

Type 2 : One parameter of each fuzzy set is to be tuned and

Type 3: The scaling factor of the total set is to be tuned

Type 3 tuning process being simple assumes that bases of the triangular fuzzy sets are same and only one parameter is to be tuned. Because of this only scaling factors needs to be determined. For our work we have employed type 3 process the scaling factor used is 1.072 with domain size of 5 for the base.

I) Set point 80^0C

Table 3.11

Duty cycle & steady state temperature (set point 80^0C)

Set	% Duty cycle	Steady state temp.
V	60 %	98^0C
I	55 %	87^0C
II	50 %	81^0C
III	45 %	78^0C
IV	40 %	76^0C

II) Set point 50^0C

Table 3.12

Duty cycle & steady state temperature (set point 50^0C)

Set	% Duty cycle	Steady state temp.
I	70 %	80^0C
II	65 %	78^0C
III	60 %	65^0C
IV	55 %	60^0C
V	50 %	53^0C

Tables 3.11 and 3.12 give details of the set point and the temperature attained for the shown duty cycle for two set points, namely 80^0C and 50^0C. In both the cases it is seen that the results are accurate with duty cycle of 50%. It is also seen that deviation from the set point is more for the lower set-point i.e. 50^0C and for higher duty cycle. All the duty cycles presented in the tables have been selected with many trials and it was also observed that results are unsatisfactory if the duty cycle is < 50%.

It is possible to implement self tuning[9-19] process by fixing the variation of set-point within particular range e.g. $80^0 \pm 1^0C$ and change the look-up table should deviation occur beyond the range in order to output the exact count corresponding to the required set-point value.

3.8 REFERENCES :

1. G.J.Klir and B.Yuan, "Fuzzy Sets and Fuzzy Logic," Prentice-Hall of India, New Delhi, chap.1,8,10,12,pp.11-27,212-289,280-300,327-338, 1997.

2. D.Driankov, H.Hellendoorn and M.Reinfrank, "An Introduction to Fuzzy Control," Narosa Publishing House, New Dehli, Chap.1,-3,pp.1-36,37-144, 1996.

3. E.R. Hantek, Applications of Linear Integrated Circuits, John Wiely and Sons N.Y.1975, pp.438-445.

4. R.S.Gaonkar, Microprocessor Architecture, Programming and Applications with 8085/8080a, Wiley Eastern Ltd, New Delhi, 1993.

5. B.Ram, Fundamentals of Microprocessors and Microcomputers, Dhanpat Rai and Sons, New Delhi,1993.

6. Microprocessor Data Hand Book, BPB Publications, New Delhi, 1989.

7. B.W. Williams, Power Electronics, Devices, Drivers, Application and Passive Componets, ELBS with McMillan, 1992, pp.123-200.

8. Motorola Opto Electronic Device Data by Motorola Semiconductor Product Inc., 1981, pp 35-52.

9. K.Tanaka (Translated by T.Tiimira), "An Introduction to Fuzzy Logic for Practical Applications", Springer-Verlag,New York, Chap.4,5, pp.86-107,121-136,1997.

10. T.Terano, K.Asai and M.Sugeno, "Applied Fuzzy Systems," AP Professional, London, chap.1, pp.1-7, chap.2, pp.26-49, chap.3, pp.51-56, 1997.

11. E.Cox, "The Fuzzy Systems Handbook-A Practitioners Guide to building, using and maintaining Fuzzy Systems", AP-Professional, Boston, Chap.3,7,9, pp.45-105,269-348,447-469, 1998.

12. V.B.Rao & H.V.Rao , C++ Neural Networks And Fuzzy Logic, BPB Publications, New Delhi,1998, pp.1-50, 497-509.

13. A.M.Ibrahim, "Introduction to Applied Fuzzy Electronics", Prentice-Hall, Inc., New Jersey, U.S.A., Chap.1,5, pp.1-3.76-96, 1995.

14. Riza C. Berkan, Fuzzy System design and principles building fuzzy "IF-THEN" rule basis, IEEE Press, Standard publication distribution, Delhi, 2000, pp 102, 189.

15. Z.Bien and K. C. Min, Fuzzy Logic and its Applications to Engineering Information Sciences and Intelligent Systems, Kluwer Academic Publishers, Netherlands, 1995, pp 81-90, 147-156.

16. Parvati C.S. and A.B Kulkarni, Design and Development of Fuzzy Logic Controllers For Industrial Systems , NCEMDS-1999, pp.471-476.

17. T.J.Ross, Fuzzy Logic with Engineering Applications,Mc-Graw Hill, 1995,pp-130-147.

18. Y.Singh and O.Singh , Fuuzy Logic Based Equipments For High Energy Efficiency, Proc. National Renewable Energy Convention-1999,pp.284-86.

19. R.K.Mudi and N.R.Pal, A Self Tuning PD Controller, IETE journal of Research, vol.44,1998,pp-177-189.