DEVELOPMENT OF A FUZZY CONTROL PROGRAM TO REDUCE UNCERTAINTY IN THE MEASUREMENT OF DC HV RESISTIVE DIVIDERS

Serhat YILMAZ[1] Hasan DiNCER[2]

e-mail:serhaty@kou.edu.tr *e-mail:hdincer@kou.edu.tr*

[1]Kocaeli University, Faculty of Engineering, Department of Electronics & Communications, Veziroglu, İzmit, Turkey

[2]Kocaeli University, Electronics and Comm. Research and Application Center-EHSAM , Veziroglu, İzmit, Turkey

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ABSTRACT

Self heating of the resistors and any temperature gradient along the resistor column are major error sources in precise measurements. A dc voltage divider designed for highly precise measurement up to 5 kV is realized in the research laboratory of KOU EHSAM. A fuzzy control approach is suggested and used in the system to reduce the uncertainties. Thermal stabilisation of the device reduces the uncertainty in measurement on a large scale. Computer aided control of peltier cooling elements are added to keep the temperature at some certain degree and computer aided control of the circulation motor is added to approximate the temperature gradient to insignificant values. Several control methods are applied to eliminate the self-heating and heat gradient effects in the DC HV Resistive Divider. In this study, fuzzy control program developed to control these effects, and sample results obtained in the fuzzy control application are given.

I. INTRODUCTION

Accurate measurements of DC voltages at values above 10 V and calibrating other dividers are achieved by standart voltage dividers. The improvements of HV measurements and standards are requested with the advancements in HV engineering and quality assurance in HV field, and also to satisfy requirements of IEC 60060. To assure the reliability of energy distribution at any time and at any occasion, HV devices must be installed due their acceptances before they are installed in HV energy distribution systems [1]. These tests carried out at high DC, AC and impulse voltages that are specified in national or international test standards.

It is required that the use of approved measuring systems traceable to national standards. To cover these requirements, the measuring device should be designed as a highly precise voltage divider. As to the effect of temperature, resistive dividers for high voltages are caused to error in measurements. The self-heating of the resistors is the most significant parameter of uncertainty. Therefore the temperature should be kept at some certain degree and the temperature coefficients of the resistors have to be approximated to zero. [2] In this study, a new design for a resistive voltage divider improved with fuzzy heat and heat gradient controllers has been devised. The controller is used to eliminate the self-heating effect, which increases uncertainties in the measurement of the resistors.

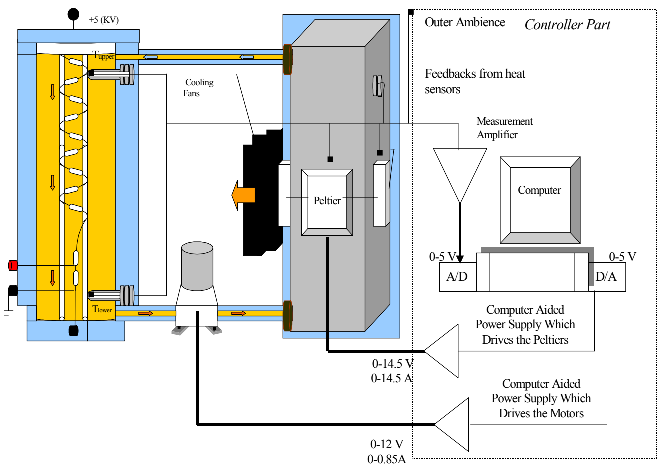

Fig.1. Heat Controlled HV Divider Mechanism.

A closed mechanism which contains a pair of tanks is used for heat control of DC HV Resistive Divider. A polyemide cylinder which conserves the resistive divider is located in the left. An aluminium cooling tank which removes the heat produced by the resistors, is located in the right.

The fluid oil is used as a heat convection element between the tanks, by means of a circulation pump. The tank and the transmission tubes are isolated against the heat transfer. The heat is absorbed from one side of the peltiers to the other side and it is removed to the outer ambience by the air forced cooling fans [3].

II. STRUCTURAL FEATURES

The resistive divider's features are given below;

- Maximum input voltage is 5 kV
- Total resistance is 5 MΩ and it is consist of 4x1 MΩ+9x100 KΩ+10x10KΩ
- Voltage division ratio is 1 000:1 and the maximum output voltage is 5V.

III. PREPARATION OF THE FUZZY CONTROL ALGORITHM

In this application, two fuzzy controllers are used. The first determines current of the power supply which drives the peltiers to fix temperature of the system while the second adjusts speed of the circulation motor to reduce T_{upper}-T_{lower} heat gradient along the resistors column.

DESINGNING THE TEMPERATURE CONTROLLER

The first fuzzy controller adjusts cooling rate of the peltiers according to E and η_c where;

E : Error between the real and the required temp. values
η_c : Cooling efficiency of the peltier cooling system which depends on motor speed (MS) and T_h-T_c (Temperature difference between hot and cold side of the peltier cooling elements)

The relation between inputs (η_c = f (MS, T_h-T_c) , E) and control output (OD: Output Data) may be derived from experimental results [4] and they are represented by fuzzy rules such as;

IF E = ZG **AND** η_c = H (MS=L VE T_h-T_c= SC) **THEN** ÇV = CL

ZG: Zero Grade, H: High, L: Low, CL: Cool Less

S: Small , M: Medium , B: Big , N: Negative , PM: Positive Medium , PB: Positive Big

Input variables concerned with temperature control;

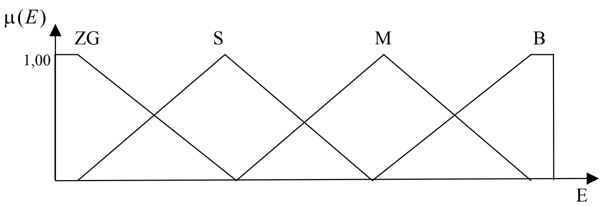

Fig.2. Membership functions which belong to the variable that represents Error.

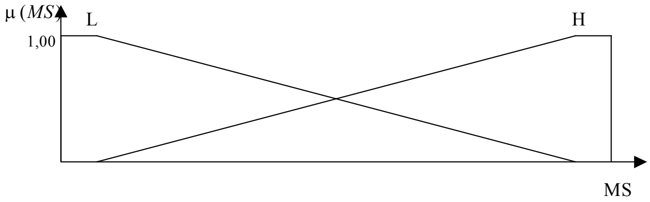

Fig.3. Membership functions which belong to the variable that represents Motor Speed.

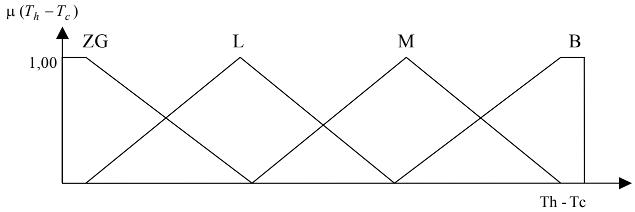

Fig.4. Membership functions which belong to the variable that represents T_h-T_c

Output variable concerned with temperature control;

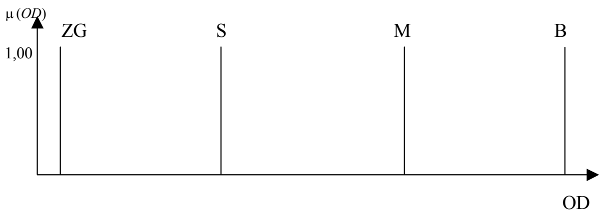

Fig.5. Membership functions which belong to the variable that represents the Output Data

DESINGNING THE TEMPERATURE GRADIENT CONTROLLER

The second controller adjusts the motor speed according to T_{upper}-T_{lower} and its derivative, to reduce the temperature gradient which occurs along the resistor column. Fuzzy rules are again derived from experimental results:

IF T_{upper}-T_{lower} is big **AND** it is increasing **THEN** speed the motor up ....etc.

Input variables concerned with the gradient control;

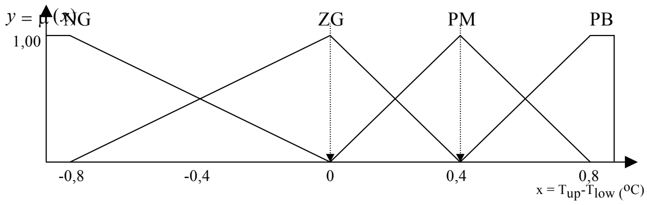

Fig.6. Membership functions which belong to the variable that represents T_{upper}-T_{lower}.

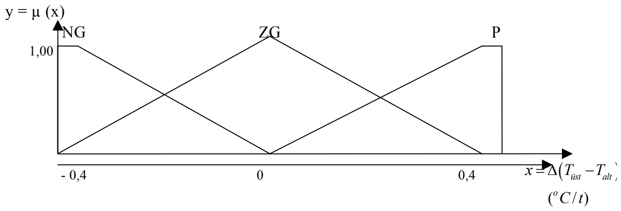

Fig.7. Membership functions which belong to the variable that represents the derivative of T_{upper}-T_{lower}.

Output variable concerned with the gradient control;

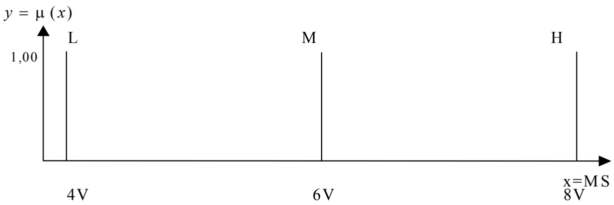

Fig.8. Membership functions which belong to the variable that represents the Output Data

IV. FUZZY CONTROL PROGRAM DEVELOPMENT AND CONTROL RESULTS

Main menu interface of the prepeared fuzzy control program is shown in Figure 9 [5]. Program interface dialogs are written in Turkish Language. Under the title "Analog-Giriş Çıkış Kartı Bilgileri" , reports are given about the situation of ADC card. The menu also reports dates and starting time of the experiments. Title "Denetim Bilgileri" represents the knowledge about control of peltier cooling rate and motor speed.

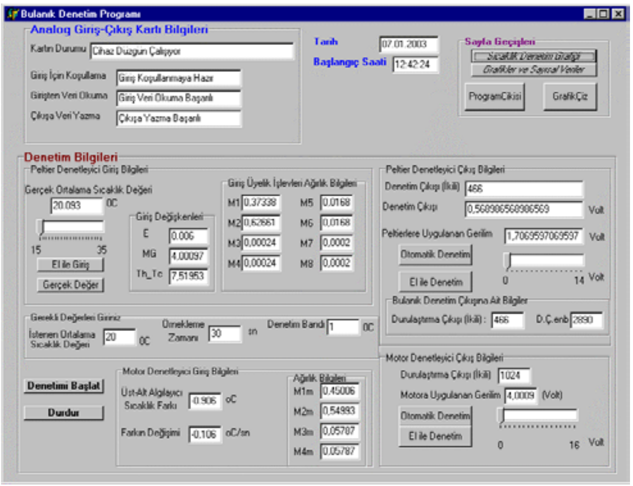

Fig 9. Fuzzy Control Interface

CONTROL RESULTS

In Fig. 10, "Sıcaklık Bulanık Denetim Grafiği" reports the average temperature of the tank in the left versus time. The dashed line represents the required temperature value.

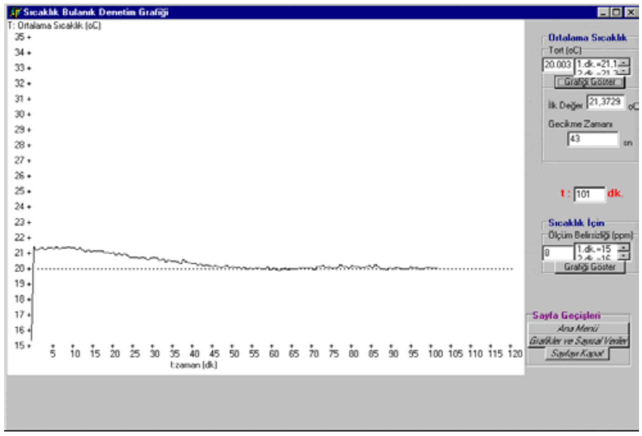

Fig 10. Average temperature value of the fluid in the tank which keeps the resistors.

Under the caption "Ortalama Sıcaklık", left box shows the temperature value which belongs to current sampling time. The box in the right stores the previous values by 1 minute intervals. They are recorded to a file while the program is closed. These data are used to calculate the transient state criterias such as maximum overshoot, delay time, settling time, rise time etc.

Similarly, measurement uncertainty sourced by the heat is graphed as shown in Fig. 11.

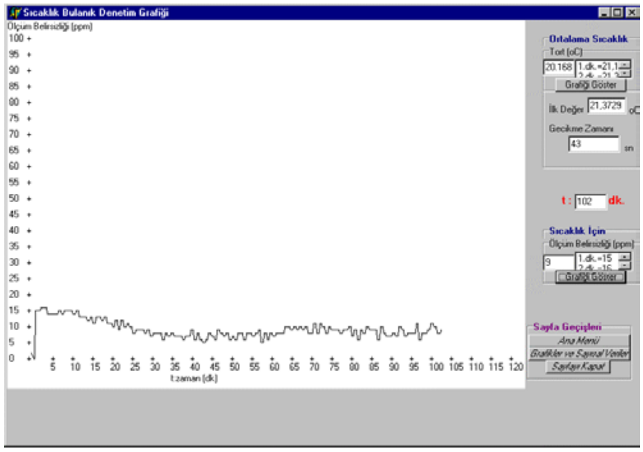

Fig.11. Measurement uncertainty sourced by the heat

TEMPERATURE GRAPHS AND DATA

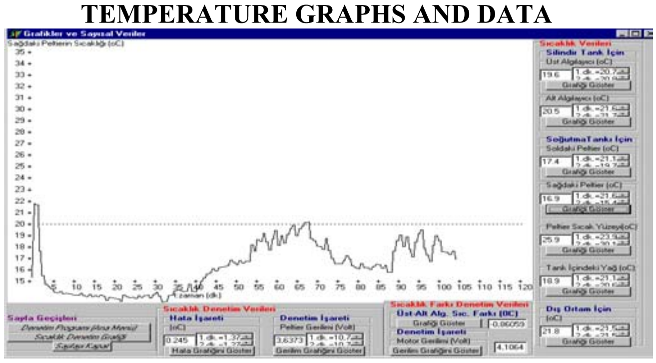

Fig.12. Cold side of the peltier elements

In this section, temperature data acquired from upper and lower sensors, from the sensors located to hot and cold side of the peltier elements, from the sensor which is plunged in the liquid inside the cooling tank, and the data acquired from the ambient is drawed versus time. These graphs are used to observe the delay times and the effects of control voltage of peltier cooling element in various points.

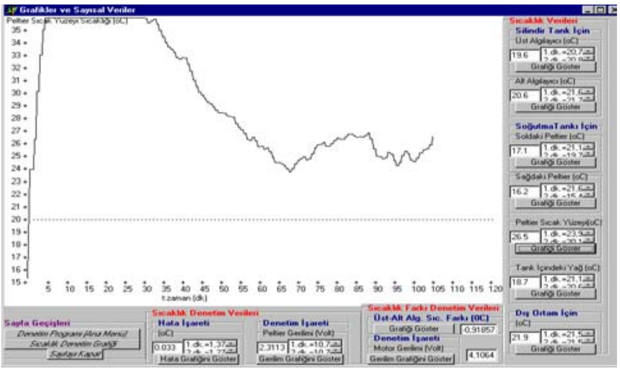

Fig.12. Hot side of the peltier elements

CONTROL GRAPHS AND DATA

Input values of the controllers are derived and shown from the temperature data above. The corresponding control output values such as voltages applied to peltiers and to motor are shown (Example Fig. 13).

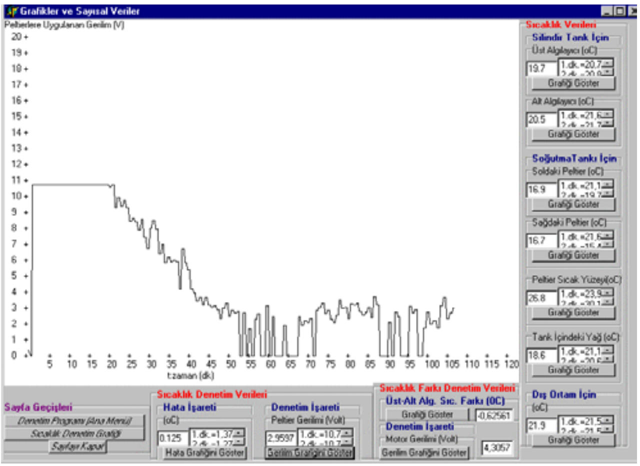

Fig 13. Fuzzy control voltage applied to peltiers.

V. CONCLUSIONS

In this study, a fuzzy control program which includes temperature and temperature gradient control is developed to reduce uncertainty of a system. The temperature controller has fixed the temperature arround the required value. The gradient controller has kept the the temperature gradient close to zero. Details of the program is given in Appendix-A.

Neural control and PID control methods or their combinations may be applied to reduce oscillations and steady state errors.

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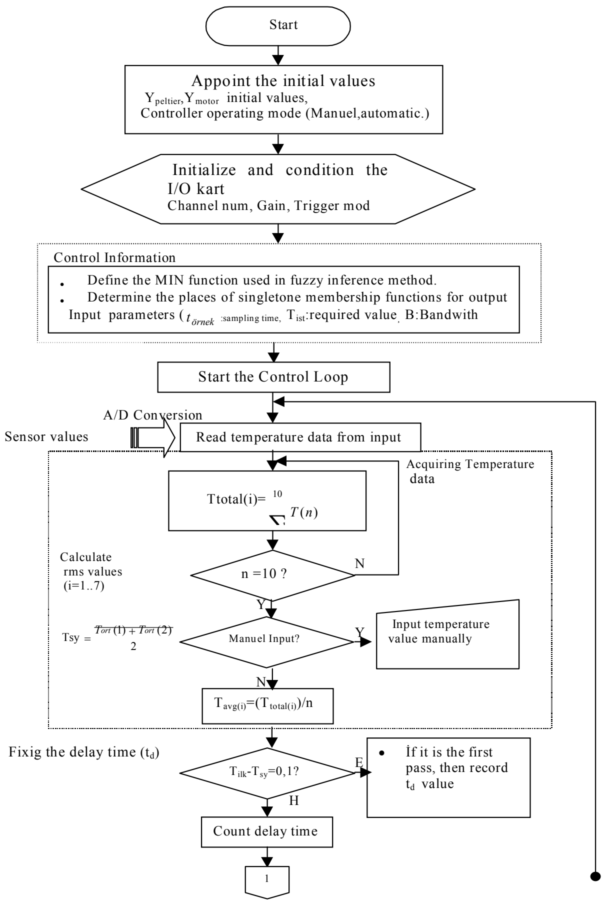
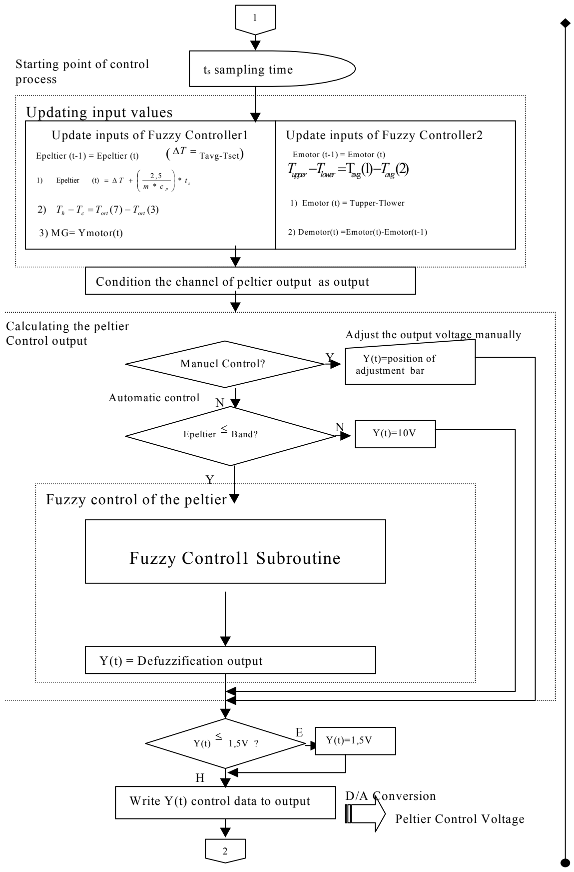
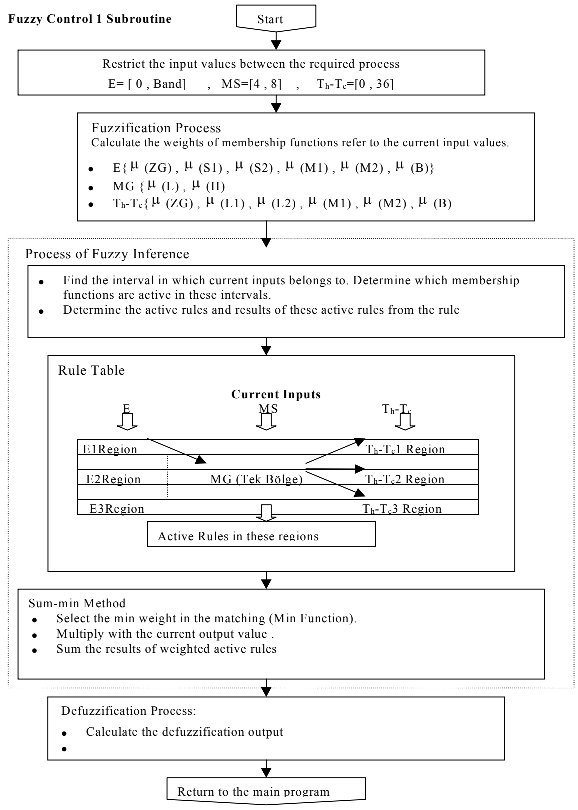
APPENDIX-A. FUZZY CONTROL ALGORITHM

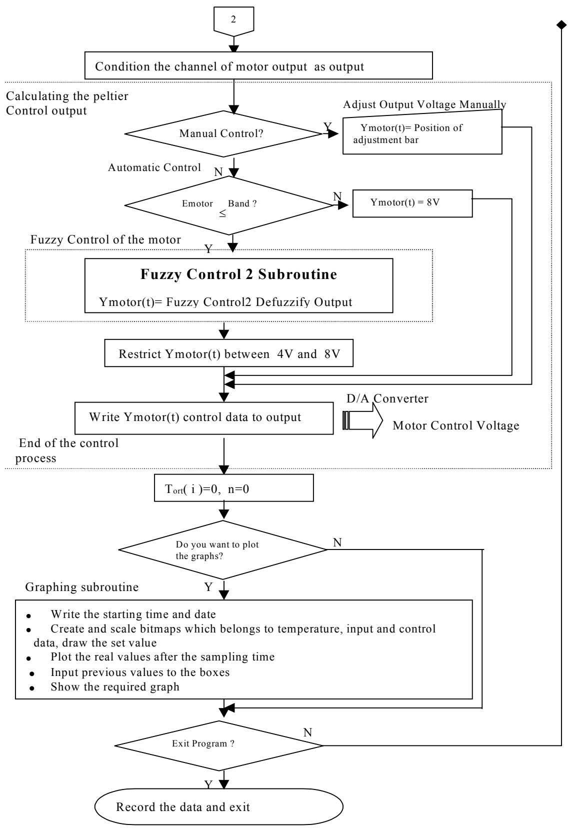




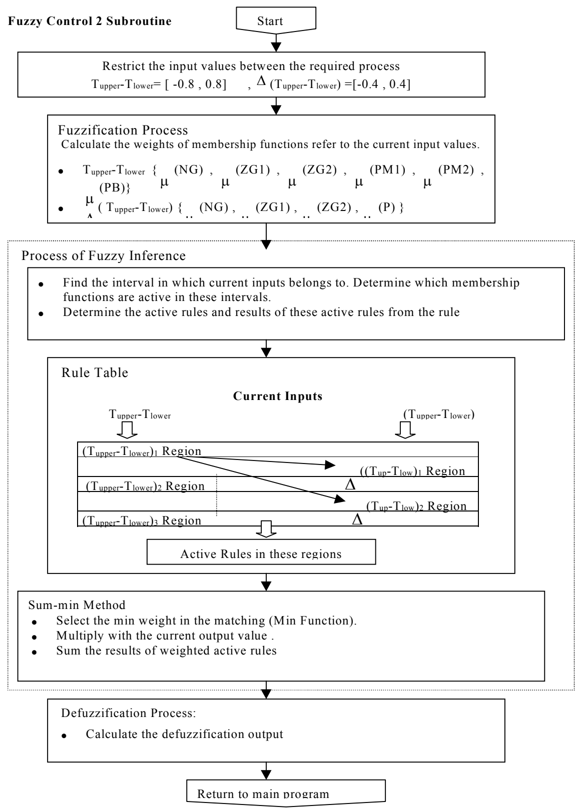
1
Starting point of control process
ts sampling time
Updating input values
Update inputs of Fuzzy Controller1
Epeltier (t-1) = Epeltier (t)
(ΔT = Tavg-Tset)
1) Epeltier (t) = ΔT + (2,5 / m * cp) * ts
2) Th - Tc = Tort(7) - Tort(3)
3) MG= Ymotor(t)
Update inputs of Fuzzy Controller2
Emotor (t-1) = Emotor (t)
Tupper - Tlower = Tavg(1) - Tavg(2)
1) Emotor (t) = Tupper-Tlower
2) Demotor(t) =Emotor(t)-Emotor(t-1)
Condition the channel of peltier output as output
Calculating the peltier Control output
Adjust the output voltage manually
Manuel Control?
Y
Y(t)=position of adjustment bar
Automatic control
N
Epeltier ≤ Band?
N
Y(t)=10V
Y
Fuzzy control of the peltier
Fuzzy Control1 Subroutine
Y(t) = Defuzzification output
Y(t) ≤ 1,5V ?
E
Y(t)=1,5V
H
Write Y(t) control data to output
D/A Conversion
Peltier Control Voltage
2



Fuzzy Control 1 Subroutine
Start
Restrict the input values between the required process
E= [0 , Band] , MS=[4 , 8] , Th-Tc=[0 , 36]
Fuzzification Process
Calculate the weights of membership functions refer to the current input values.
E{μ (ZG) , μ (S1) , μ (S2) , μ (M1) , μ (M2) , μ (B)}
MG {μ (L) , μ (H)
Th-Tc{μ (ZG) , μ (L1) , μ (L2) , μ (M1) , μ (M2) , μ (B)
Process of Fuzzy Inference
Find the interval in which current inputs belongs to. Determine which membership functions are active in these intervals.
Determine the active rules and results of these active rules from the rule
Rule Table
Current Inputs
E
MS
Th-Tc
E1Region
Th-Tc1 Region
E2Region
MG (Tek Bölge)
Th-Tc2 Region
E3Region
Th-Tc3 Region
Active Rules in these regions
Sum-min Method
Select the min weight in the matching (Min Function).
Multiply with the current output value .
Sum the results of weighted active rules
Defuzzification Process:
Calculate the defuzzification output
Return to the main program



2
Condition the channel of motor output as output
Calculating the peltier Control output
Adjust Output Voltage Manually
Manual Control?
Y
Ymotor(t)= Position of adjustment bar
Automatic Control
N
Emotor ≤ Band ?
N
Ymotor(t) = 8V
Fuzzy Control of the motor
Y
Fuzzy Control 2 Subroutine
Ymotor(t)= Fuzzy Control2 Defuzzify Output
Restrict Ymotor(t) between 4V and 8V
Write Ymotor(t) control data to output
D/A Converter
Motor Control Voltage
End of the control process
Tort(i)=0, n=0
Do you want to plot the graphs?
N
Graphing subroutine
Y
Write the starting time and date
Create and scale bitmaps which belongs to temperature, input and control data, draw the set value
Plot the real values after the sampling time
Input previous values to the boxes
Show the required graph
Exit Program ?
N
Y
Record the data and exit



Fuzzy Control 2 Subroutine
Start
Restrict the input values between the required process
Tupper-Tlower= [-0.8 , 0.8] , Δ (Tupper-Tlower) =[-0.4 , 0.4]
Fuzzification Process
Calculate the weights of membership functions refer to the current input values.
Tupper-Tlower { μ (NG) , μ (ZG1) , μ (ZG2) , μ (PM1) , μ (PM2) , (PB)}
μΔ (Tupper-Tlower) { (NG) , (ZG1) , (ZG2) , (P) }
Process of Fuzzy Inference
Find the interval in which current inputs belongs to. Determine which membership functions are active in these intervals.
Determine the active rules and results of these active rules from the rule
Rule Table
Current Inputs
Tupper-Tlower
(Tupper-Tlower)
(Tupper-Tlower)1 Region
((Tup-Tlow)1 Region
Δ
(Tupper-Tlower)2 Region
(Tup-Tlow)2 Region
Δ
(Tupper-Tlower)3 Region
Active Rules in these regions
Sum-min Method
Select the min weight in the matching (Min Function).
Multiply with the current output value .
Sum the results of weighted active rules
Defuzzification Process:
Calculate the defuzzification output
Return to main program