MODELING OF A THERMOELECTRIC BRAIN COOLER BY ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM

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ABSTRACT

The object of the present study is to determine the most suitable method for control design for thermoelectric cooler headgear developed for brain hypothermia applications. Hypothermia refers to a medical treatment method protecting the brain in which the temperature of the brain drops below the level required for reducing oxygen consumption of tissues. The temperature of the headgear is controlled by current. We were examined by using Fuzzy Logic Control, one of the artificial intelligence techniques. Initial membership functions were determined and used for obtaining the data by an expert. ANFIS model were constructed on MATLAB medium and new membership functions were determined. The optimal results will be obtained by re-programming the system with these new membership functions.

1. INTRODUCTION

That traffic accidents cause people die or injured is an important problem in the world. Traffic accidents mostly cause brain traumas and post-trauma disabilities. Various techniques are applied for post-trauma brain treatment and protection in the world. Traumatic brain damage is one of the main problems, which should be overcome by physicians found in emergency services and also intensive care units. The first treatment to a patient, who has brain trauma, must be done in the place in which the event has occurred but not in emergency service or intensive care unit. A systematic and rapid life support must be launched and maintained at every stages beginning from the moment on which the trauma has occurred to reaching to the clinic in which the continuous treatment will be applied. Considering that 20% of trauma patients die at the trauma moment or during transportation due to mostly hypotension and hypoxia, the importance of early detection and treatment will be better understood. According to the data obtained from State Statistics Institute (DİE), the ratio of deaths caused by brain traumas in traffic accidents is quite high among other deaths.

Cranio-Cerebral Hypothermia (CCH) method is used for post-trauma brain treatment and protection in the world. Hypothermia reduces oxygen consumption of tissues and thus, protects the organism and especially the brain against fatal effect of hypoxia. Traumatic brain needs much more oxygen than a normal brain does. A hypoxia limit, which may be tolerated in case of a normal brain, can cause damage in a traumatic brain. Therefore, the first medical treatment is very important. Early treatment has a priority for a sufficient cerebral oxygenation. Preventing hypoxia is one of the most important problems. [1-4]

Brain protection is another of the most important problems in Arcus aorta operation. Ischemic and embolic lesions of central nervous system and perioperative blooding beyond control are important problems causing increase in morbidity and mortality. Because the energy required by central nervous system is satisfied by aerobic glucose, ischemic cerebral damage can occur in a short time like 3-5 minutes in normal-thermal conditions caused by interruption or insufficiency in oxygen through the brain. Therefore, many methods were developed for protecting central nervous system against ischemic damage. Hypothermia is used most frequently among others. Furthermore, various methods were developed for supporting this. Hypothermia makes operator's job easier by providing a dry and calm operational environment. Protective effect of hypothermia is based on decrease in intracellular enzymatic reactions and metabolic rate as heat surface. Accordingly, oxygen and surface requirements of tissues decrease. The effect of hypothermia on high energy phosphates was evidenced. [5,6]

As mentioned above, the clearest aim of hypothermia is to protect the organs by reducing metabolic rate and oxygen consumption during brain trauma and open heart operations. Brain is the organ, which is most likely to ischemic damage. The main reasons of ischemia are low blood pressure and embolic events, which it is considered that they occur during KPB. Hypothermia establishes a protective effect against ischemia by reducing oxygen requirement of the brain.

Another advantage of using CCH in brain traumas is that this method is very easy and suitable to clinical conditions. The basic problem in brain hypothermia is

to cool the brain rapidly (the first one hour) to the required temperature and maintain this temperature for a long time in a controlled way. The acceptable temperature error is ±0.5 ˚C.
For solving these problems, a device will be designed, wherein the device can run by DC voltage, thus may be used easily in transportation vehicles, may be moved to the place, where the accident occurred, is suitable to clinical conditions and when required, its warm and cold surfaces may be altered by changing polarities. Its form will be a headwear and 120 flexible thermoelectric modules are used in the design. These modules are serially connected and draw the current up to 40 Ampere. Temperature control of the headwear will be done by using fuzzy logic. The device to be designed will allow dropping the temperature of the brain to 22-26 ˚C or lower temperatures. This establishes the unique superiority of CCH method. Furthermore, the device may be used in heart and vessel operations. The device may be used in emergency neurology operations. Especially, it may be used for providing CCH to the patients, whose heart and respiratory functions have failed because of brain edema caused by severe head traumas.

II. CHARACTERISTICS OF THE COOLING SYSTEM

Any thermoelectric device or system is based on a thermoelectric module comprising thermo-elements. A thermoelectric module is made of thermo-elements electrically serial connected and thermally parallel connected.

Thermo-element

A thermo-element is done by connecting n and p type semiconductors by a conductor (copper) electrically as shown in Figure 1. Herein, n type semiconductor is characterized as negative side of the thermo-element and p type semiconductor as positive side of the thermo-element. Working principle of a thermo-element is that charge carriers flow through the semiconductor from the low-energy-level copper above when a DC current is applied to the thermo-element as shown in Figure 1. To go beyond the energy wall found between copper and the semiconductor, electrons and holes supply energy from copper's tissue. Therefore, the temperature of the copper above will reduce. Charge carriers flown from higher energy level through lower energy level transfer their excess energy through the conductor below (copper again) and thus, cause it heated. During this transfer, the temperature of the cold side decreases while heat is being absorbed from the cooling side and in the meanwhile the temperature of the hot side increases while heat is being transferred. In case that the direction of the current applied to the circuit is altered, cooling side will heat and warming surface will cool.

If temperature T_1 is kept constant by distributing the heat released from the hot side of a thermo-element in operation through the environment via any heat transfer system, temperature of the cold side will drop to a certain T_2 point depending on the current I passing through the circuit. If current applied to a thermo-element is kept constant, the value of T_2 depends on thermal change come through the cold side and absorbed. This thermal heat is caused by Joule heat coming from the environment and hot plate through cold plate via heat transfer and released because of the current flowing through the thermo-element's circuit.

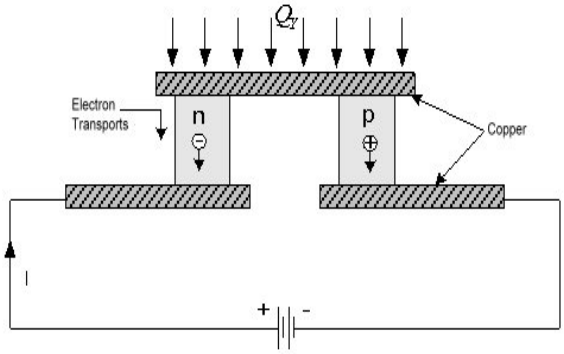

Figure 1. The structure of the thermo-element

The value of maximum current magnitude of a module made of thermo-elements varies depending on the quality, sizes and structural characteristics of thermoelectric semiconductors found in the thermo-element [10,11,12].

Thermoelectric module

Thermoelectric modules are manufactured in various sizes for various objects by connecting tens of thermo-elements electrically serial and thermally parallel. Thermo-electric modules are little heat pumps not having a mobile part. They are generally preferred for the environments in which the area is limited, safety is important and usage of hazardous cooling gases is not desired.

Although thermoelectric cooler runs by DC voltage, its cooling or heating regime may be altered easily by changing the direction of the current. Cooling is performed by moving the heat on one side of the thermo-electric module to the other side of it. Figure 3 shows a structure of a thermoelectric module [12,13].

The system is designed in the form of motorbike helmet. It is manufactured by connecting 120 of 0.1 volt thermo-elements electrically serial and thermally parallel. 12 volts and 40 Amperes in total are required for driving the system. Internal and external views of the helmet are shown in Figure 3.

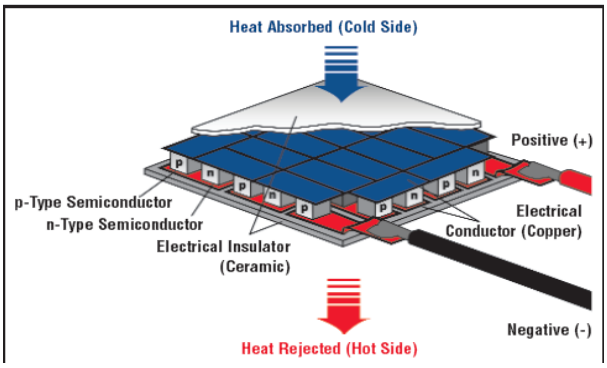

Figure 2. The structure of micro-module

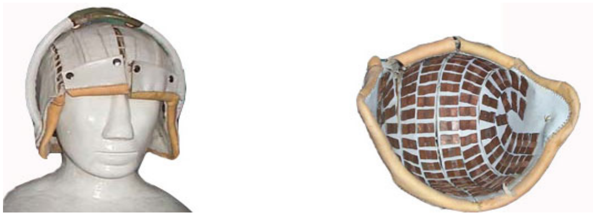
Figure 3. Thermoelectric helmet

To control the temperature of the thermoelectric helmet, the temperature on the hot side must be kept at a certain value by a heat removing system. Thus, hot side of the thermoelectric helmet is equipped with cooling water ducts. The temperature on the hot side is kept at a certain value by cycling conditioned water in the ducts by a separate water cycle system. The closed water cycling system is set at a certain value. Water is pumped into the ducts by a water pump. The heated and returned water is re-conditioned and pumped into the system again.

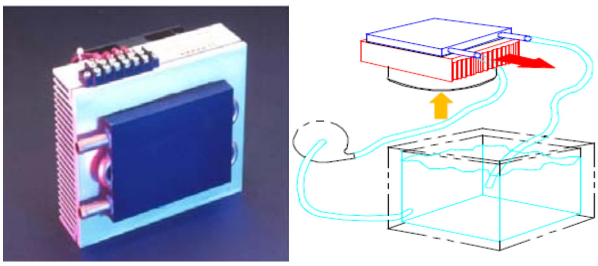
Figure 4. Recirculating system

Technical Specifications	
Capacity rating (W)	200
Voltage (VDC)	24
TE Current (A)	16.8
Fan	24 V @0.85 A
Ship Weight (kg)	9.0
Performance is based on unrestricted air flow to heat sink and fan and 1.6 l/min water flow rate.	

III. DESIGN OF THE CONTROLLER

The current of the thermoelectric cooler may be controlled in various ways. Today, especially classic control and PID control having one application is generally used. However because these linear control techniques demonstrate low performance in non-linear systems, new systems are being sought. The methods, which use logical and intuitive or objective aspects of human intelligence, were developed when artificial intelligence techniques appeared. Fuzzy logic, one of these techniques, allows controlling non-linear systems effectively as it is used in many areas. Fuzzy logic allowing programming some abilities specific to human such as making decision and subjectivity tolerates negative effects likely to be found in the system's structure by this characteristic. Another superiority of fuzzy logic is that its performance never changes even in the cases that mathematical modeling of the system is impossible to be established. It allows an easy controller design and because microprocessor technology is very developed nowadays, costs are feasible [7-9].

In the model designed for system controlling, 5 membership functions were selected for each input variable and defined by triangular type function. Linguistic variables defined and their limits are shown on Table 1. Thirteen membership functions were specified for each output variable. These variables defined and their limits are shown on Table 2. These were defined within [-30,30] range. Twenty five rules were established for five input variables.

$$T_e = T_{ref} - T_o \,,\; T_{ce} = T_e(k) - T_e(k-1)$$

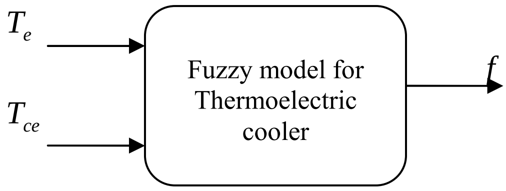

Figure-4. Fuzzy Model

For obtaining working characteristic for the helmet, the temperatures of hot and cold sides (Th and Tc) and voltage Vdc were measured by applying 5 A , 10 A, 15 A, 20 A, 25 A, 30 A respectively. These measurements were recorded once per 30 seconds and then the results were obtained (Table 3, Table 4). The neural fuzzy logic controller designed have two input variables, temperature error Te and temperature error variationTce, and an output variable to be used for setting current value to be applied to the thermoelectric cooler (f) (DGM Signal). Herein, Te is the difference between reference temperature and measured temperature and Tce is the difference between the present error and the previous error.

Table-1. Membership functions of input error and error variation

NH	Negative Higher	[-999 -0.50 -0.25]
NL	Negative Lower	[-0.50 -0.25 0.00]
Z	Zero	[-0.25 0.00 0.25]
PL	Positive Lower	[0.00 0.25 0.50]
PH	Positive Higher	[0.25 0.50 999]

Table-2. Output Membership Functions

NVH	Negative Very High	[-25 -30 -35]
NH	Negative Higher	[-20 -25 -30]
NMH	Negative Medium High	[-15 -20 -25]
NM	Negative Medium	[-10 -15 -20]
NML	Negative Medium Lower	[-5 -10 -15]
NL	Negative Lower	[0 -5 -10]
Z	Zero	[-5 0 5]
PL	Positive Lower	[0 5 10]
PML	Positive Medium Lower	[10 10 15]
PM	Positive Medium	[15 15 20]
PMH	Positive Medium High	[20 20 25]
PH	Positive Higher	[25 25 30]
PVH	Positive Very High	[30 30 35]

Fuzzy surface obtained from according to input and output error functions and the rule tables is as shown below.

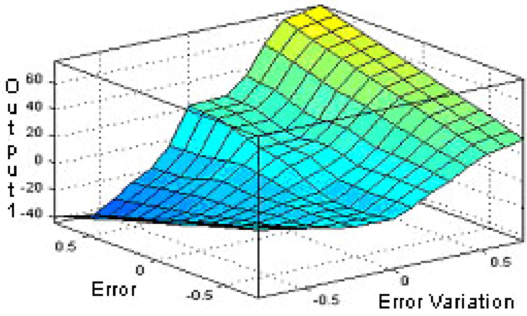

Figure-5. Fuzzy control surface

ANFIS (Adaptive Neuro-Fuzzy Inference System) model was created on MATLAB medium with the data obtained from the system designed. Optimal values of membership functions were specified by ANFIS system. Membership functions and rules given were entered into the model established on MATLAB medium. FIS was produced using grid Partition Method via testing and training data. A test was done by using 0,001 error and 100 learning age through Adaptive Feedback Learning Algorithms and the error value of 0.23704 were obtained for normalized error measurement. After 200 learning age, the error value dropped to 0.10218.

Table 3. Cold side temperature variation

Time (minutes)	**Vdc**	**5 A**	**Vdc**	**10 A**	**Vdc**	**15 A**	**Vdc**	**20 A**	**Vdc**	**25 A**	**Vdc**	**30 A**
0.00	0,00	16,99	4,46	17,09	5,63	17,05	7,16	17,23	8,34	17,20	9,70	17,19
0.50	2,66	12,06	3,65	10,22	5,35	7,67	6,96	5,60	8,46	3,79	9,82	2,44
1.00	2,67	9,94	3,64	7,43	5,34	3,62	6,95	0,70	8,66	-1,56	9,83	-3,32
1.50	2,68	9,12	3,72	6,26	5,51	2,05	7,10	-1,19	8,66	-3,82	9,84	-5,62
2.00	2,69	8,86	3,71	5,87	5,51	1,50	7,15	-1,95	8,73	-4,78	9,85	-6,39
2.50	2,68	8,68	3,71	5,76	5,51	1,15	7,15	-1,75	8,81	-4,91	9,85	-6,66
3.00	2,68	8,70	3,71	5,71	5,50	1,16	7,19	-1,09	8,79	-5,03	9,85	-6,87
3.50	2,68	8,63	3,71	5,67	5,53	-1,09	7,19	-2,13	8,77	-5,28	9,85	-6,75

Table 4. Hot side temperature variation

Time (minutes)	**Vdc**	**5 A**	**Vdc**	**10 A**	**Vdc**	**15 A**	**Vdc**	**20 A**	**Vdc**	**25 A**	**Vdc**	**30 A**
0.00	0,00	18,47	4,46	18,47	5,63	18,44	7,16	18,52	8,34	18,48	9,70	18,38
0.50	2,66	20,20	3,65	20,92	5,35	22,11	6,96	23,97	8,46	25,15	9,82	27,64
1.00	2,67	19,82	3,64	20,49	5,34	21,86	6,95	22,77	8,66	24,45	9,83	26,69
1.50	2,68	19,78	3,72	20,51	5,51	22,14	7,10	23,14	8,66	24,64	9,84	26,65
2.00	2,69	19,79	3,71	20,54	5,51	22,00	7,15	23,49	8,73	25,06	9,85	26,63
2.50	2,68	19,83	3,71	20,50	5,51	22,04	7,15	23,97	8,81	25,57	9,85	26,84
3.00	2,68	19,87	3,71	20,51	5,50	22,19	7,19	24,23	8,79	26,03	9,85	26,96
3.50	2,68	19,90	3,71	20,57	5,53	22,24	7,19	24,42	8,77	26,18	9,85	27,47

4. RESULTS

The approaches of test and education data according to the new data obtained after ANFIS analysis are as the graphics shown in Figures 6 and 7. When the system was educated according to the ANFIS method, input membership functions were reset according to the optimum values. New input membership functions were obtained as shown in Figure 8.

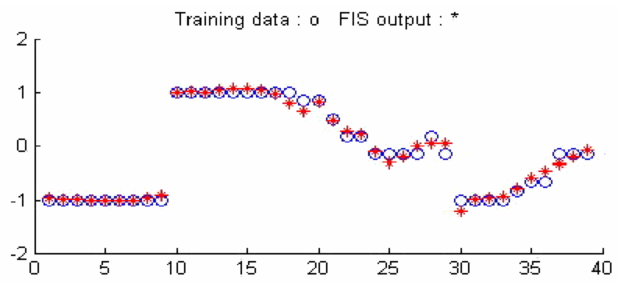

Figure 6. Education data

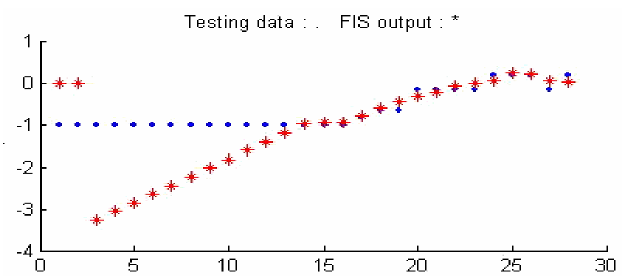

Figure 7. Test data

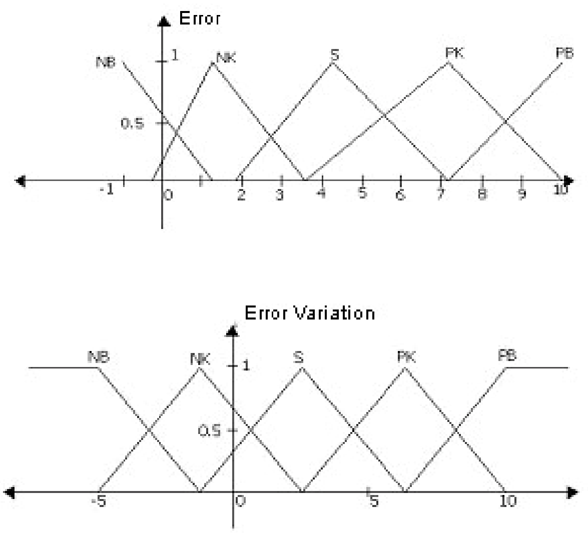

Figure 8. Membership functions after 200 education age

Today, system modeling, classifying and controlling by ANFIS is getting more important. ANFIS has both of the two advantages. These advantages are easy teaching ability of artificial nerve networks and that fuzzy logic includes knowledge and experience of human into the system.

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