Fuzzy *c*-Means Clustering Designed FLC for Air-Conditioning System

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Abstract :- A Fuzzy *c*-Means Clustering designed FLC (fuzzy logic controller) is presented in this paper and applied to air-conditioning system. In the design procedure, the auto-tuning PID controller was used to operate the plant of air-conditioning system and the plant data are collected. The fuzzy c-partition of the data are then analyzed by Fuzzy *c*-Means Clustering to use in the design to achieve optimum fuzzy sets of the FLC for temperature control in the air conditioning system. The results from the experiments show that when compared to the conventional FLC, the proposed FLC gives better temperature characteristics and can save the energy by about 11.5 percent.

Key-Words :- Fuzzy logic controller, Fuzzy *c*-means clustering, Air conditioning system.

1 Introduction

Air conditioning is connected with the comfort and health of the people and it become one of the most significant factors in natural energy consumption. In 1989, Mitsubishi Heavy Industries [13] developed the intelligent air conditioning system that used fuzzy control. Many intelligent air conditioning systems that employ fuzzy logic controller (FLC) appeared on the market in 1990s. Recently, there are several researches showing the design of the controller for air conditioning systems such as Piao Ying-Guo. [14] used fuzzy adaptive control in HVAC, Jung Ho Kim [9] designed the FLC to control the refrigerant distribution, Suriyon [3] designed FLC for air flow control in fan coil unit, and T. Iokibe [7] developed the fuzzy controlled air conditioning system. The recent researches that the controllers used are the FLCs where in the design of the FLCs, all the fuzzy sets are approximated and were defined using the designer's experiences i.e. generally used membership function is the triangular-shaped function, the ranges for each set are equally divided from the universe of discourse of the parameter, the peak points are at the mid-range points and adjacent sets overlap to the mid-range points etc. In this paper, we propose the design of FLC by using fuzzy *c*-means (FCM) clustering algorithms to find optimum fuzzy sets for each working parameter of the air conditioning system.

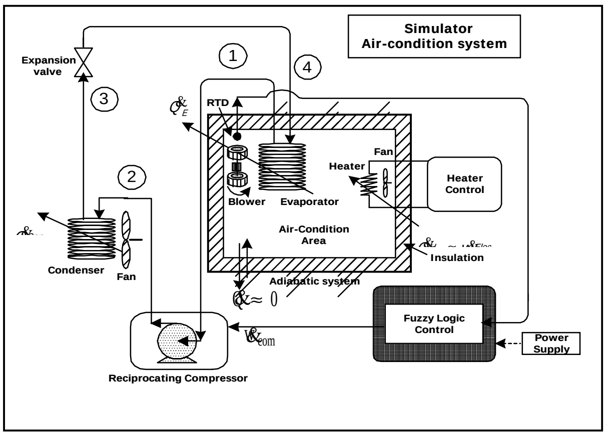
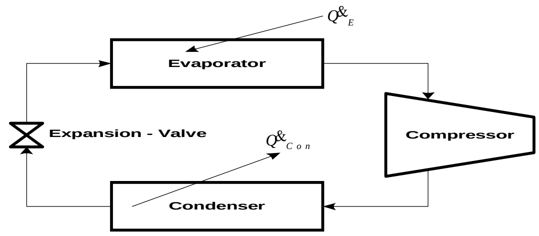


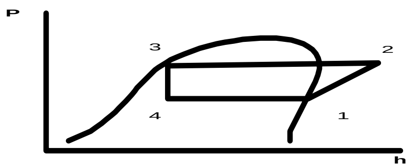
Fig. 1 Model of Air-Conditioning Control System

2 System Model of The Air Condition Control System

The control system configuration of the air conditioning system consists of three parts: an air conditioning unit, a fuzzy logic controller and a load simulator as shown in Fig. 1. In the air conditioning unit, the refrigeration processes occur during the operation of a refrigerating system and the refrigeration cycle on P-h diagram [13] as shown in Fig. 2.



(a) Schematic Diagram



(b) P-h Diagram

Fig. 2. Air-Conditioning Diagram

Fig.2b. show the refrigeration cycle on P-h diagrams [13]. The refrigerant evaporates entirely in the evaporator and produces the refrigerating effect. It is then extracted by the compressor at state point 1, compressor suction, and compressed isentropically from state point 1 to 2 as equation:

$$\dot{W}_{Com} = \dot{m}_r (h_2 - h_1) \quad (1)$$

It is then condensed into liquid in the condenser and latent heat of condensation is rejected to heat sink as equation:

$$\dot{Q}_{Con} = \dot{m}_r (h_2 - h_3) = \dot{Q}_E + \dot{W}_{Com} \quad (2)$$

The liquid refrigerant, at state point 3, flows through an expansion valve, which reduces it to the evaporating pressure. In the ideal vapor compression cycle, the throttling process at the expansion valve is the only irreversible process as equation:

$$h_3 = h_4 = \mathrm{f}(\mathrm{T}_3, \mathrm{P}_3) \quad (3)$$

Some of the liquid flashes into vapor and enters the evaporator at state point 4 as equation:

$$\dot{Q}_E = \dot{m}_r (h_1 - h_4) \quad (4)$$

The remaining liquid portion evaporates at the evapolating temperature, thus completing the cycle. where W_{com} is rate of work of compressor, h_i is enthalpy (KJ/Kg), $\dot{m}_r$ is mass flow rate of refrigerant R-134a (Kg/s), $\dot{Q}_{Con}$ is rate of heat flow of condenser (KJ/s), $\dot{Q}_E$ is rate of heat flow of evaporator (KJ/s), P is pressure (MPa) and T is temperature (°C).

3 Fuzzy *c*-Means Clustering (FCM)

The fuzzy *c*-means clustering is a data clustering algorithm [6] in which each data point belongs to a cluster to degree specified by a membership degree. Bezdek [1] proposed this algorithm as an improvement over earlier hard *c*-means (HCM) clustering be improved with use of fuzzy set method. In develop these method in classification, we classify the various data points as a fuzzy *c*-partition [2][4][10] on a universe of data points and assign membership value to it that determine from the data of each point and the data of a cluster center in each group. Hence, a single point can have partial membership in more than one class and the membership value that the *k*th data point has in the *i*th class with the following notation:

$$\mu_{ik} = \mu_{A_i}(\mathrm{x}_k) \in [0,1] \quad (5)$$

In the determination of the fuzzy *c*-partition matrix **U** for grouping a collection of *n* data sets into *c* classes, we define an objective function J_m for a fuzzy *c*-partition,

$$\mathbf{J}_m(\mathbf{U},\mathbf{v}) = \sum_{k=1}^{n} \sum_{i=1}^{c} (\mu_{ik})^{m'} (d_{ik})^2 \quad (6)$$

where

$$d_{ik} = d(\mathbf{x}_k - \mathbf{v}_i) = [\sum_{j=1}^{m} (x_{kj} - v_{ij})^2]^{1/2} \quad (7)$$

and where μ_{ik} is the membership of the *k*th data point in the *i*th class, d_{ik} is distance measure or Euclidean distance between the *i*th cluster center and the *k*th data point in m-space, m′ is a weighting parameter which has a range m′ ∈ [1,∞) and $\mathbf{v}_i$ is *i*th cluster center, which is described by m coordinates and can be arranged in vector form, $\mathbf{v}_i = \{v_{i1}, v_{i2}, \ldots, v_{im}\}$. Each of the cluster coordinates for each class can be calculated as

$$v_{ij} = \frac{\sum_{k=1}^{n} \mu_{ik}^{m'} \cdot x_{kj}}{\sum_{k=1}^{n} \mu_{ik}^{m'}} \quad (8)$$

where j is a variable on the coordinate space, i.e., j = 1, 2, …,m. The optimum fuzzy c-partition will be the smallest of the partitions described in Equation (6); that is,

$$\mathbf{J}_m^*(\mathbf{U}^*, \mathbf{v}^*) = \min_{M_{fc}} \mathbf{J}(\mathbf{u}, \mathbf{v}) \quad (9)$$

The effective algorithm for fuzzy classification is called iterative optimization [9] as follows:

1. Fix c ($2 \le c < n$) and select a value for parameter m'. Initialize the partition matrix, $\mathbf{U}^{(0)}$. Each step in this algorithm will be labeled $r = 0, 1, 2, \ldots$

2. Calculate the c centers $\{\mathbf{v}_i^{(r)}\}$ for each step.

3. Update the partition matrix for the rth step, $\mathbf{U}^{(r)}$ as follows:

$$\mu_{ik}^{(r+1)} = \left[\sum_{j=1}^{c}\left(\frac{d_{ik}^{(r)}}{d_{jk}^{(r)}}\right)^{2/(m'-1)}\right]^{-1} \quad \text{for } \mathbf{I}_k = \phi \qquad (10)$$

or

$$\mu_{ik}^{(r+1)} = 0 \ \text{ for all classes } i \text{ where } i \in \tilde{\mathbf{I}}_k \qquad (11)$$

where

$$I_k = \{i \mid 2 \le c < n;\, d_{ik}^{(r)} = 0\} \qquad (12)$$

and

$$\tilde{\mathbf{I}}_k = \{1, 2, \ldots, c\} - \mathbf{I}_k \qquad (13)$$

and

$$\sum_{i \in \mathbf{I}_k} \mu_{ik}^{(r+1)} = 1 \qquad (14)$$

4. If $\| \mathbf{U}^{(r+1)} - \mathbf{U}^{(r)} \| \le \varepsilon_L$, stop; otherwise set $r = r+1$ and return to step 2.

4 Fuzzy Logic Controller Design

In the design process of the FLC, fuzzy rules are defined for two input variables, the error (ER) and the change of error (DE), and single output variable, the control signal (CS) which are used as the input

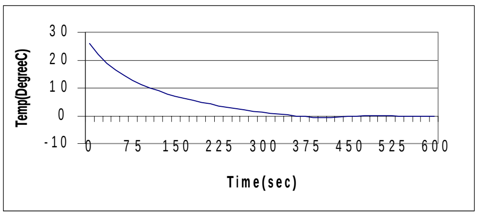


Fig. 3. The Recorded Values of The Error

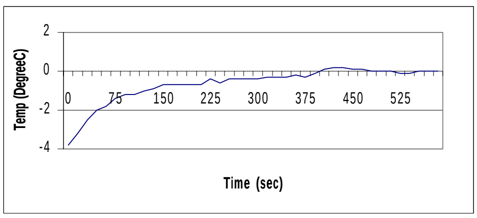


Fig. 4. The Recorded Values of The Change of Error

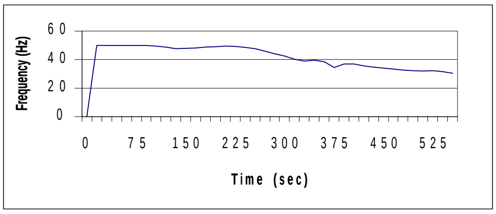


Fig. 5. The Recorded Values of The Control Signal

and output variables of the plant. The design were carried on using the plant of air-conditioning system with the procedures:

4.1 With the auto-tuning PID controller operate the plant in steps over its full range of operation and at each step, record the values of the input and output variables of the plant which can be shown in Fig. 3. , 4. and 5. for setpoint at 19 °C.

4.2 The fuzzy c-partition from 4.1 are then analyzed by fuzzy c-means clustering algorithms for 7 clusters of data for the input variables and 5 clusters of data for the output variable as shown in Fig. 6. The obtained clusters were then normalized to get the fuzzy sets as shown in Fig. 7., 8., and 9.

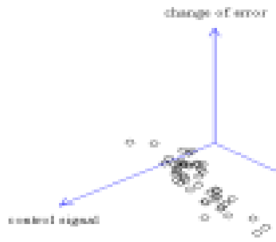


Fig. 6. The Converged Fuzzy Partition for Temperature Control in the Air-Conditioning System

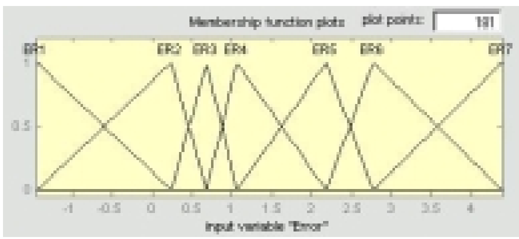


Fig. 7. Fuzzy Sets of Error

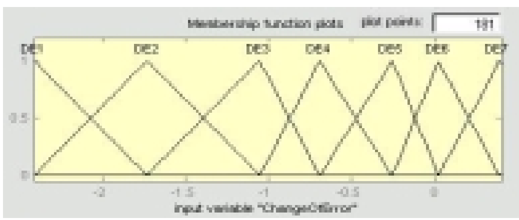


Fig. 8. Fuzzy Sets of Change of Error

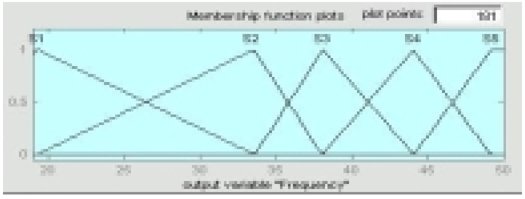


Fig. 9. Fuzzy Sets of Control Signal

4.3 Implement the fuzzy c-means clustering designed FLC with the fuzzy sets obtained in 4.2, design a set of fuzzy control rules to reduce the overshoot and the rise time. The fuzzy control rule can be formulated as shown in Fig. 10., and operate the fuzzy logic controller with sup-product operator for compositional rule of inference (CRI) and center of gravity (COG) for defuzzification process.

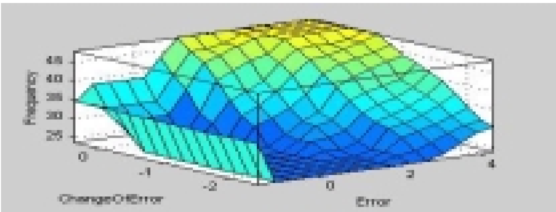


Fig. 10. Output Surface of Mamdani FIS for Air-Conditioning System

5 Experimental Results

The fuzzy *c*-means clustering designed FLC was tested on the setpoint of 25 °C for a simulator of 1.8 m. in wide, 2 m. in long and 1.5 m. in high and the results were compared to the results by conventional designed FLC on the same setpoint, the system were able to give the output response and energy saving as following:

5.1 Operating characteristics temperature (°C) vs time (sec.) of the air-conditioning controlled by the conventional designed FLC is shown in Fig. 11.

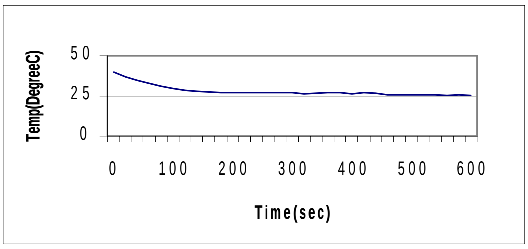


Fig. 11. Temperature Characteristics of The Conventional Designed FLC

5.2 Operating characteristics temperature (°C) vs time (sec.) of the air-conditioning controlled by the fuzzy *c*-means clustering designed FLC is shown in Fig.12.

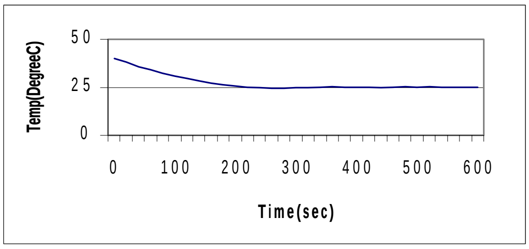


Fig. 12. Temperature Characteristics of The Fuzzy *c*-Means Clustering Designed FLC

5.3 Operating characteristics energy (WattsHours) vs time (sec.) of the air-conditioning system controlled by the conventional designed FLC is shown in Fig. 13.

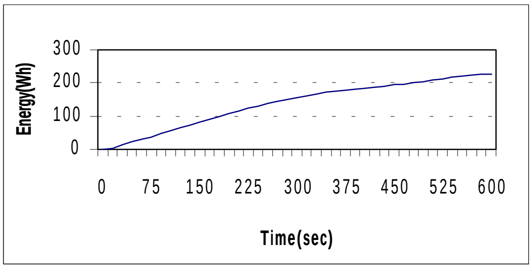


Fig. 13. Energy Characteristics of The Conventional Designed FLC

5.2 Operating characteristics energy (WattsHours) vs time (sec.) of the air-conditioning system controlled by the fuzzy *c*-means clustering designed FLC is shown in Fig.14.

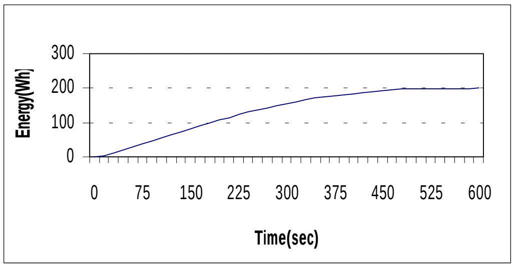


Fig. 14. Energy Characteristics of The Fuzzy *c*-Means Clustering Designed FLC

6 Conclusion

In this paper, we have investigated an application of fuzzy *c*-means algorithms in the design of the fuzzy sets for the fuzzy logic controller of the temperature control in air conditioning system. The results from the experiments show that the fuzzy *c*-means clustering designed FLC gives the temperature characteristics that is better than the conventional designed FLC. Moreover it was able to save the energy by about 11.5 percent when compared with the conventionally designed one on the same setpoint.

References:

[1] Bezdek, Jim C. *Fuzzy Mathematics in Pattern Classification.* PhD. Thesis, Applied Math. Center, Cornell University, Ithaca, 1973.

[2] Bezdek, J. C. ;and Pal, N.R. *On Cluster Validity for the Fuzzy c-means Model*, IEEE Transactions on Fuzzy Systems, Vol.3 No.3 August , p370-p372, 1995.

[3] Chomdee, Suriyon and P., Suttichai. *Fuzzy Logic Control of Fan Coil Unit.*, Proceedings of 14th Mechanical Engineering Conference in Thailand, Chiang Mai, p479-p490., 2000.

[4] EI-Sonbaty, Yyasser and Ismail, M.A. *Fuzzy Clustering for Symbolic Data*, IEEE Transactions on Fuzzy Systems, Vol.6 No.2, p195-p204, May, 1998.

[5] Ismail, M.A. and Selim, S.Z. *Fuzzy C-Means : Optimality of Solutions and Effective Termination of the Algorithms,* Pattern Recognition, vol.19, No.6, p481-p485, 1986.

[6] Jang, Jyh-Shing Roger. ; Sun, Chuen-Tsai. ; and Mizutani, Eiji. *Neuro-Fuzzy and Soft Computing : A Computational Approach to Learning and Machine Intelligence,* Prentice Hall, 1997.

[7] Jain, Lakhmi C. and Silva, Clarence W,de *Intelligent Adaptive Control : Industrial Applications,* New York : CRC Press, 1999.

[8] Jovcicc, D. ; Pahalawaththa, N. and Zavahir, M. *Stability Analysis of HVAC Control Loops,* IEE Proc.-Gener. Transm. Distrib., Vol.146, No.2, p143-p148, March 1999.

[9] Kim, Jung Ho. et al. *An Application of Fuzzy Logic to Control the Refrigerant Distribution for The Multi Type Air Conditioner,* IEEE International Fuzzy Systems Conference Proceedings, Seoul, Korea, p1350-1354, August 1999.

[10] Ross, Timothy J. *Fuzzy Logic with Engineering Applications.* Singapore : McGraw-Hill, Inc., 1995.

[11] Tobi, T. and Hanafusa, T. *A Practical Application of Fuzzy Control for an Air-Conditioning System,* Int'l. Journal of Approximate Reasoning, Vol.5, No.3, p331-p348, 1991.

[12] Wakami, N. ; Araki, S. and Nomura, H. *Recent Application of Fuzzy Logic to home appliances, Proceedings of the International Conference on Industrial Electronics, Control and Instrumentation, p155-p160, 1993.*

[13] Wang, Shan K. *Handbook of Air Conditioning and Refrigeration,* New York : McGraw-Hill, Inc., 1994.

[14] Ying-Guo, Piao; Hua-Guang, Zhang ;and Bien, Zeungnam *A Simple Fuzzy Adaptive Control Method and Application in HVAC.* Fuzzy Systems Proceedings of IEEE World Congress on Computational Intelligence., Vol. 1., p528 – p532, 1998.

[15] Zuojun, Lin.; Wenlong, Xie and Yalou, Huang. *The Energy Saving Control of Air Condition System in Intelligent Building,* Proceedings of The 4th World Congress on Intelligent Control And Automation, China, p2240-2243, 2002.