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Energy-Efficient Three-Variables Unsupervised Fuzzy Control Model of Wind Strength for Ceiling type Air-conditioning System

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Abstract

There is a growing need for intelligent energy-efficient control of air conditioning systems. Traditional PID controlling structure is not appropriate for modern energy efficiency requirements and we need some intelligent procedure to compensate such control. Among many intelligent algorithms available, we propose an unsupervised fuzzy control of wind speed for ceiling type air conditioning systems with three variables - the temperature of the space, the humidity of the space, and the temperature of the walls that is affected by outside radiation heat. Temperature variables are represented as the form of color distribution images. The simulation result verifies that the proposed system shows only 47% consumption of electronic energy compared with two-variable control model without considering wall temperature.

Keywords*: Fuzzy Control, Radiation Heat, Wind Strength, Air Conditioning System, Energy Efficiency*

1. Introduction

The systems for heating, ventilation, and air-conditioning (HVAC) are very important in ensuring the quality of living. The need for efficient control of such systems has been continuously increasing. The traditional PID (proportional, integration, differentiation) controller that has nearly a hundred years of history of practice is simple to understand and still the most widely used controller in many engineering applications [1]. However, the classic control technique using the basis of on-off or linear PID, PI, and P based controllers cannot satisfactory deal with the problem of energy-efficient stabilization of the basic interacting microclimate parameters [2]. Recently, many intelligent control models and algorithms are introduced especially to meet the recent requirements of energy efficiency and green house environment. While there has been a general intelligent approach to make PID control structures more adaptive by using fuzzy logic [3], many new approaches are introduced just for air conditioning systems in the last decade. When we use fuzzy control, one of the important issues is to reduce the dimension of the uncertainties, e.g. the number of variables to be controlled. Thus, one may use a supervised neural network approach [4], or a supervised auto-tuning of parameters with two-variable fuzzy control [2], or a genetic algorithm for dynamic tuning of rule weighing of an expert system [5]. However, such supervised learning approaches depend on the expertise' knowledge thus it can be environment sensitive or the quality of the expertise.

If we focus on a single optimizing goal like unsupervised temperature control, the problem might be a simple localized optimization problem with fuzzy logic [6] but very often the situation is more serious than that. One might design the cooling process of the HVAC systems and decide what to optimize. The model of such unsupervised intelligent HVACs varies system to system with respect to the optimizing goals (e.g. time to be

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stabilized to the target temperature, energy consumption etc.) and it may become quite complex [7, 8].

In this paper, we are interested in developing an unsupervised fuzzy dynamic control structure of wind speed, direction, and timing for energy efficient ceiling type air conditioning system with minimal fuzzy control variables. In such a fuzzy control system, it is important to define the fuzzy membership functions and corresponding decision rules [9]. Especially in this paper, we extend our fuzzy control variables from (temperature, humidity) [10] to (temperature, humidity, temperature of the wall) according to the thermal environment defined in [11]. Temperature of the wall is important in our case because the radiation heat outside affects the temperature of the wall and its distribution is quite different from that of the space in consideration.

2. Simulation Model and Fuzzy Control Variables

The input of our simulation model of the ceiling type air conditioning system consists of three variables - the temperature distribution of the given space represented as the color distribution image shown in Figure 1 with colors defined in Table 1, the temperature distribution image of the wall and the humidity. The color distribution image is obtained from the thermal image with region labeling method [12].

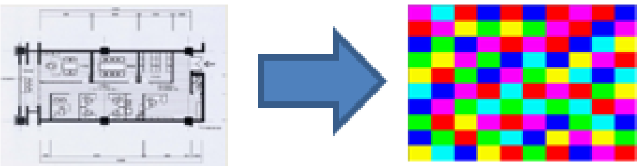


Figure 1. Color Distribution Image of a Given Space

Table 1. Color Representation W.R.T the Temperature

Color	Temperature	Color	Temperature
Red	26.6℃~27.0℃	Green	25.1℃~25.5℃
Magenta	26.1℃~26.5℃	Sky	24.6℃~25.0℃
Yellow	25.6℃~26.0℃	Blue	24.0℃~24.5℃

The input thermal image of the target space is of 400 x 300 sizes and it is divided by one hundred (10 x 10) 40 x 30 sizes subregions that are represented with colors defined in Table 1 with respect to the average temperature of the region. Table 1 is based on the government report for proper cooling temperature [13].

For each 40 x 30 size subregion, we compute the average temperature E_t of the region with equation (1)

$$E_t = \sum \frac{C \cdot C_t}{S_p} \tag{1}$$

where C, C_t, S_p denote the color value based on the histogram shown in Figure 2, the number of pixel of that color, and total number of pixels in that sub-region.

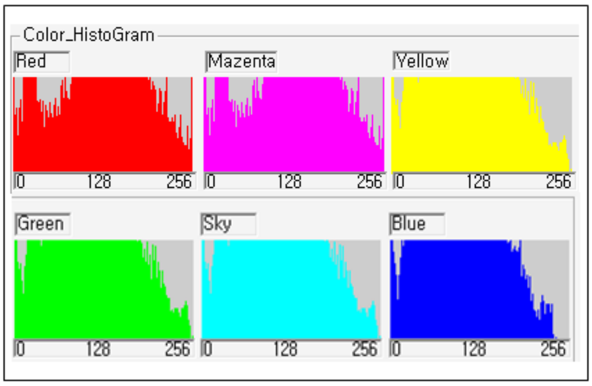


Figure 2. Histograms in Color Distribution Image

Our second input is the thermal image of the wall of size 400 x 200 and similarly, we divide it into one hundred 40 x 20 size sub-regions as the image of the target space.

Then three fuzzy membership functions are defined as follows;

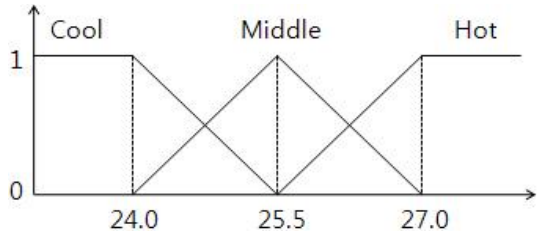


Figure 3. Membership Function of Temperature Of The Given Target Space

Figure 3 Shows the membership function of the given target space for cooling. Based on the national standard [13], the membership degrees of three symbolic intervals are defined as following;

1) Interval Cool

$$if\ (X \geq 25.5)\ then\ \mu(X) = 0$$

$$elseif\ (24 \leq X \leq 25.5)\ then\ \mu(X) = \frac{-(X-25.5)}{25.5-24.0}$$

$$else\ \mu(X) = 1$$

2) Interval Normal

$$if\ (24.0 < X \leq 25.5)\ then\ \mu(X) = \frac{(X-24.0)}{25.5}$$

$$elseif\ (25.5 \leq X \leq 27.0)\ then\ \mu(X) = \frac{-(X-27.0)}{27.0-25.5}$$

$$else\ \mu(X) = 0$$

3) Interval Hot

$$if\ (25.5 < X < 27.0)\ then\ \mu(X) = \frac{(X-25.5)}{27.0-25.5}$$

$$elseif\ (X \leq 25.5)\ then\ \mu(X) = 0$$

$$else\ \mu(X) = 1$$

Similarly, the membership function of the wall temperature and corresponding membership degrees are computed as follows;

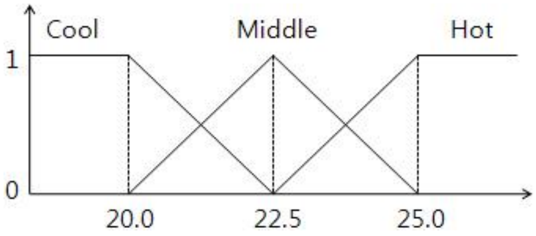


Figure 4. Membership Function of the Temperature of the Wall

1) Interval Cool

$$\begin{aligned}
&if\ (X \geq 22.5)\ then\ \mu(X) = 0\\
&elseif\ (20.0 \leq X \leq 22.5)\ then\ \mu(X) = \frac{-(X-22.5)}{22.5-20.0}\\
&else\ \mu(X) = 1
\end{aligned}$$

2) Interval Normal

$$\begin{aligned}
&if\ (20.0 < X \leq 22.5)\ then\ \mu(X) = \frac{(X-20.0)}{22.5}\\
&elseif\ (22.5 \leq X \leq 25.0)\ then\ \mu(X) = \frac{-(X-25.0)}{25.0-22.5}\\
&else\ \mu(X) = 0
\end{aligned}$$

3) Interval Hot

$$\begin{aligned}
&if\ (22.5 < X < 25.0)\ then\ \mu(X) = \frac{(X-22.5)}{25.0-22.5}\\
&elseif\ (X \leq 22.5)\ then\ \mu(X) = 0\\
&else\ \mu(X) = 1
\end{aligned}$$

Values on X-axis in Figure 3 and Figure 4 denote the temperature. Figure 5 shows the membership function of the humidity. In Korea, usually the comfortable humidity is known to 50% but it may increase to 90% during hot summer thus we design the membership function as Figure 5.

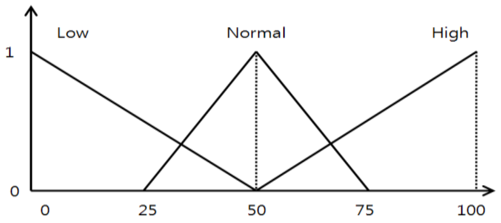


Figure 5. Membership Function of Humidity

Again, the membership degree is computed as follows with respect to the symbolic interval – Low, Normal, and High.

1) Interval Low

$$\begin{aligned}
&if\ (Y \geq 50)\ then\ \mu(Y) = 0\\
&elseif\ (Y \geq 0)\ then\ \mu(Y) = \frac{-(Y-50)}{50.0}\\
&else\ \mu(Y) = 1
\end{aligned}$$

2) Interval Normal

$$\begin{aligned}
&if\ (Y \leq 25\ or\ Y \geq 75)\ then\ \mu(Y) = 0\\
&elseif\ (Y \leq 50)\ then\ \mu(Y) = \frac{(Y-25)}{50-25}\\
&else\ \mu(Y > 50)\ then\ \mu(Y) = \frac{-(Y-75)}{75-50}
\end{aligned}$$

3) Interval High

$$\begin{aligned}
&if\ (Y \leq 50)\ then\ \mu(Y) = 0\\
&elseif\ (Y \leq 100)\ then\ \mu(Y) = \frac{(Y-50)}{100-50}\\
&else\ \mu(Y) = 1
\end{aligned}$$

From these three membership degrees, we compute the membership degree of our target control variable wind speed strength. First, we apply fuzzy inferences based on the rules defined in Table 2.

Table 2. Fuzzy Inference Rules

Humidity Temperature /W	Low	Normal	High
Cool	VW	VW	W
Middle	VW	W	M
Hot	W	M	M

(a) Target Space Temperature: Cool

Humidity Temperature /W	Low	Normal	High
Cool	VW	W	M
Middle	W	M	S
Hot	M	S	VS

(b) Target Space Temperature: Middle

Humidity Temperature /W	Low	Normal	High
Cool	M	M	S

Middle	M	S	VS
Hot	S	VS	VS

(c) Target Space Temperature: High

where Temperature/W denote the Wall temperature.

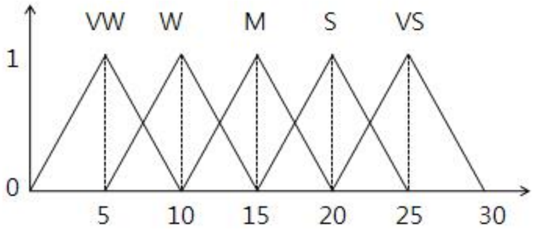


Figure 6. Membership Function of Output Variable Wind Strength

Then the membership function of Wind Strength is given as Figure 6 and its interval is given as Table 3.

Our model follows the standard fuzzy control model such that the fuzzy inference is based on Max-Min method and the defuzzification is done by the center of the gravity rule [14].

Table 3. Wind Speed and Energy Consumption

Interval(x)	Code	Wind	Energy
<= 7.5	VW	Very Weak	80%
7.5~12.5	W	Weak	90%
12.5 ~ 17.5	M	Middle	Standard
17.5 ~ 22.5	S	Strong	110%
>= 22.5	VS	Very Strong	120%

In our model, we can derive the duration of wind blowing and electricity usage estimation. First, we assume that we need to blow the wind one minute in order to decrease 0.1 degree (Centigrade) of the temperature of the target space. However, the radiation heat transferred by the wall also influences the cooling effect thus we assume that wind supplying duration T is a linear combination of 80% of space temperature effect and 20% of wall temperature effect as shown in equation (3) and (4).

$$D_t = 0.8 TempSpace + 0.2 TempWall \qquad (3)$$

$$T = \frac{10y}{50}(D_t - T_t) \qquad (4)$$

where *TempSpace* denote the temperature of the space and *TempWall* is the temperature of the wall and y is the humidity and Tt. is the goal temperature of the cooling.

D_t is measured by 5 separate vertical levels and the strength of the wind are controlled with respect to the average D_t of each level.

The required electricity amount *W* can be computed as equation (5).

$$W = \frac{PT}{60} \tag{5}$$

Where P is the electricity energy consumption represented in Table 3 with respect to the wind strength and T is the duration of wind supplying computed from equation (4).

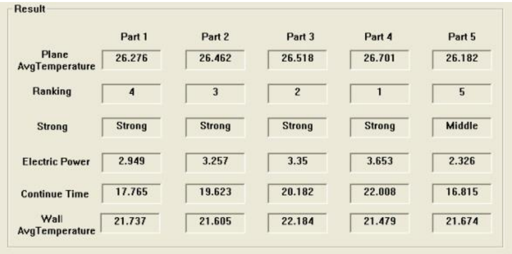
3. Simulation Result

In simulation, we provide 50 virtual 400x300 space temperature color distribution images and 400x200 wall temperature color distribution images. The software is implemented with Microsoft VC++ 2008 tool and experiments were performed on an IBM-compatible PC with Intel Pentium-IV 3.0 GHz CPU and 2GB RAM. In our simulation, the standard energy consumption is set to 8.3 Kw.

(A) Space Color Distribution (B) Wall Color Distribution

Figure 7. Example Input Color Distribution from Thermal Image

The input of the system is shown as Fig. 7. Two color distribution array from thermal images of the target space (Fig. 7(a)) and the wall (Fig. 7(b)) are given. Then, the fuzzy control logic explained in section 2 computes three control variables based on three fuzzy membership functions and corresponding fuzzy inference engine decides the strength of the wind and the duration of wind supplying. As a result, we can compute the energy consumption for that environment with our assumptions explained in the previous section. A snapshot of the implemented software is shown as Fig. 8.



Result

	Part 1	Part 2	Part 3	Part 4	Part 5
Plane AvgTemperature	26.276	26.462	26.518	26.701	26.182
Ranking	4	3	2	1	5
Strong	Strong	Strong	Strong	Strong	Middle
Electric Power	2.949	3.257	3.35	3.653	2.326
Continue Time	17.765	19.623	20.182	22.008	16.815
Wall AvgTemperature	21.737	21.605	22.184	21.479	21.674

Figure 8. Example Snapshot of the Implemented Software

Comparing our model with other existing models is a difficult task since all models have different assumptions and control variables and environments. However, we can compare our own previous models [10] with just two control variables – the space temperature and the humidity. As one can see the result in Table 4, the proposed system that considers wall temperature consumes only 47% of previous two-variable model (space temperature and humidity) thus the role of “wall temperature control” is the key of success in energy efficient air conditioning system design.

Table 4. Energy Consumption Comparison in Simulation (Unit: Kw)

Energy	Previous[10]	Proposed
Level 1	2.35	1.13
Level 2	2.92	1.36
Level 3	2.71	1.45
Level 4	3.05	1.64
Level 5	3.05	1.14

4. Conclusion

Designing energy efficient HVAC is an important task in recent days and many intelligent algorithms are applied in part or in the full device design. When the design scale is general and large, one may need to have the ground truths or correct models from field experts and should pay for the subjectivity instead. In this paper, we take an approach to propose an unsupervised fuzzy controller for ceiling type air conditioning system with satisfying reasonable energy consuming efficiency. Since we take only three control variables in our fuzzy logic, the computational burden is not that much of an issue. The great gain of our approach is that we consider radiation heat effect in the cooling control structure by having wall temperature as one of the three fuzzy control variables. By doing that, our simulation supports our design philosophy as reducing energy consumption to only 47% of the previous model without the wall temperature control.

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