Reducing Air-Conditioning System Energy Using a PMV Index

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Abstract: The control system of central air-conditioning, based on PMV, not only improves thermal comfort but also reduces system energy consumption. A new thermal comfort degree softsensor model is built via use of the CMAC neural network nonlinear calibration function. It can realize on-line detection of thermal comfort. At the same time it can also realize real-time control of central air-conditioning system based on PMV. Simulation results demonstrate the simplicity and effectiveness of the presented method.

Key words：PMV；CMAC neural network；Thermal comfort degree

1. INTRDUCTION

Air-conditioning systems of intellect architecture usually adopt central air-conditioning systems. At present, there are basically two control methods in summer condition. The first, the control index only selects the single parameter of indoor temperature. This method would not meet the need of thermal comfort degree of people. For example, In summer, the same temperature of 27℃ , 40% of relative humidity can make people feel comfortable while 70% of relative humidity can make people feel stuffy. The second, the valve's position of cooler is controlled by Max-selector which selects the higher difference of temperature and humidity. This method would lead to improving energy consumption and the cost of attendance. In Air-conditioning systems, the ideal control index should be thermal comfort degree .PMV[1] index is most representative in all the method of thermal comfort degree. This paper will present a new control method. The control index of it is PMV. This method not only improves the hot comfortable indoor but also reduces the energy consumption of air conditioning. Winter condition usually needs to add moisture due to lower relative humidity while summer condition usually needs to reduce moisture due to higher relative humidity especially the city near sea. So this paper only discusses the control of thermal comfort degree in summer condition.

2．PMV THERMAL COMFORT DEGREE INDEX

Professor Fanger of Danish first proposed PMV thermal comfort degree index which presented thermal comfort degree feeling of most people. The PMV index is showed in table one.

Tab.1 PMV index

Feeling of hot	hot	warmer	warm	comfort	cool	cooler	cold
PMV	3	2	1	0	-1	-2	-3

Thermal comfort degree index of body relates with six variables, which are the motion of body, clothing, temperature, humidity, wind speed and average radiation temperature. But the six variables could not be full measured in practice. Especially on-line measurement of some of them is very difficult. So some variables can be hypothesized on the basis of practice.[1.2]

①The people indoor usually sit or do some lighter physical labor. The metabolic rate of sitting is 58.15 W/m^2 and The metabolic rate of lighter physical labor is 69.78 W/m^2. In general we select 69.78 W/m^2.

②Hot resistance of clothing is 0.094 m^2•℃/W.

③Mechanical work of body is zero.

④ Average radiation temperature of indoor surface equals temperature of indoor.

⑤Air conditioning design standard provide that wind speed in Summer is lower than 0.25m/s. So make wind speed equal 0.2m/s in summer.

Through hypotheses, the left variables are temperature and steam pressure in door. The temperature can be measured by temperature sensor. The steam pressure can be calculate by relative humidity measured by humidity sensor and temperature.

3. PMV INDEX SOFTSENSOR

As PMV index is nonlinear relation with variables and The outsurface temperature of clothing needs iteration calculation. So the general method cannot realize on-line measurement of Thermal comfort degree index and cannot meet the need of on-line control of central air-conditioning systems [2]. CMAC (Cerebellar Model Articulation Controller) neural network specially fits in with softsensor because it has the feature of algorithm simply, learn speed quickly [3,4]. So the paper adopts soft measurement method to measure PMV by temperature and humidity measured. Softsensor model is showed in figure 1.

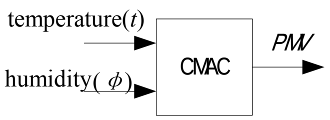

Fig 1 Softsensor model

3.1 Hyperball CMAC Structures and Learning Algorithms [5]

$\overline{U}$ is input space of limits, $\overline{x}$ is arbitrary input , $\overline{x} \in \overline{U} = \overline{A}_1 \times \overline{A}_2 \times \cdots \times \overline{A}_n$, $\overline{A}_i = \left[\overline{x}_{\min i}, \overline{x}_{\max i}\right]$. $\overline{x}$ is normalized for the purpose of selecting basis functions and CMAC no depending on $\overline{x}$.

$$x_i = \frac{Max - Min}{\overline{x}_{\max i} - \overline{x}_{\min i}}\left(\overline{x}_i - \overline{x}_{\min i}\right) + Min \qquad (1)$$

where $A_i = [Min, Max]$, $x \in A_1 \times A_2 \times \cdots \times A_n$ 。

The quantification degree of every dimension is *QL*. The span is Δ.

$$QL = (Max - Min)/\Delta \qquad (2)$$

The intersecting points of quantification mesh are numbered as P_j ($j = 1,2,\cdots,L$) . The corresponding weight ratio is q_j. The hyperball CMAC centered with P_j is given by

$$C_j = \{x \mid \|x - p_j\| \le R_b, \quad x \in U \qquad (3)$$

The basic function $b_j(\cdot)$ is defined in C_j.

$$b_j(x_k) = \begin{cases} \exp - \left(\dfrac{\|x_k - p_j\|^2}{\sigma^2} \right), x_k \in C_j \\ 0, x_k \notin C_j \end{cases} \qquad (4)$$

Where $S_{\text{amp}} = \{(x_k, y_k)\}(k = 1,2,\cdots,N_s)$ is learning sample. $\forall x_k \in S_{\text{amp}}$, N_L hyperballs include x_k in U. The output of CMAC is defined as basic function linear combination of hyperballs centered with active intersection. S_k is weight ratio selecting vector. S_{k_j} is 1 as C_j include x_k and S_{k_j} is 0 as C_j don't include x_k.

$$\hat{y}_k = S_k^{\mathrm{T}} B(x_k) q \qquad (5)$$

Where $B(x_k) = \mathrm{diag}[b_1(x_k), b_2(x_k) \cdots, b_l(x_k)]$, $q = [q_1, q_2, \cdots, q_L]^{\mathrm{T}}$ is weight ratio vector. $S_k = [S_{k,l}]_{L \times 1}$ is weight ratio selecting vector.

Learning algorithm adopts C-L algorithm.

$$\Delta q_{k-1} = \frac{\alpha e_{k-1} B(x_{k-1})\ S_{k-1}}{\beta + S_{k-1}^{T} B(x_{k-1}) B^{T}(x_{k-1}) S_{k-1}} \qquad (6)$$

Where α 、β are constants. Let $0 < \alpha < 2$, $\beta > 0$. Weight ratios only need to be regulated locally to every sample.

3.2 Building Softsensor Model

In essence, softsensor model realizes static mapping from input to output. Actually building softsensor model is a learning sample process of CMAC. The collecting sample data for building softsensor model include learning sample data and calibrating sample data. At first, acquiring input-output data with 2 dimensions input and 1 dimension output via PMV hot equilibrium equation[1]. Softsensor model structure is showed in figure 2. In learning time, closing the switch K1 and K3 and opening the switch K2, the softsensor would off-line learn sample data. The weight ratios of CMAC would be acquired after learning. In calibrating or detecting time, opening switch K1 and K3 and closing switch K2, the softsensor model would calibrate or detect on-line. The learning steps include the following:

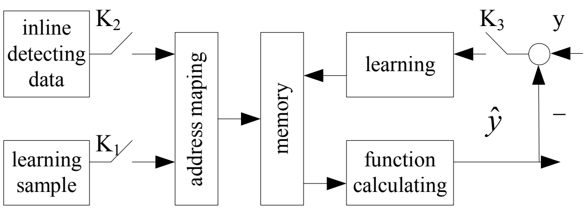

Fig. 2 Softsensor model structure

① Determining input space $\overline{U}$, $\overline{U} = [0,40] \times [0,1]$. It means that the variation of temperature indoor is 0～40℃ and the variation of relative humidity is 0～100%. Normalizing product space $U = [0,100] \times [0,100]$;

②Let quantification degree *QL*=10，determining intersecting points of space U and selecting weight ratio initial value $q^0 = [0,0,\cdots,0,0]^{\mathrm{T}}$;

③Selecting parameters σ and active radius R_b of basis functions. Selecting $\sigma = 4$，$R_b = 12$ according to document[5] and determining hyperballs centered with active intersection.

④ Determining the hyperballs including the point according to sample point $\{x_t, y_t\}$，determining selecting matrix S_t;

⑤Calculating estimated value $\hat{y}_t$ according to formula (5). Estimated error is $e_t = y_t - \hat{y}_t$. Weight ratios are corrected by formula （6）. Let $\alpha = 0.6$、$\beta = 0.2$;

⑥Repeating steps 4 to 5 until the error meets the

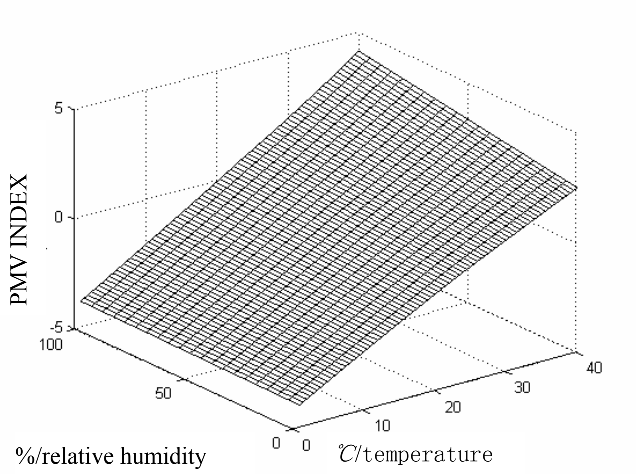

Fig.3.1 PMV expecting output

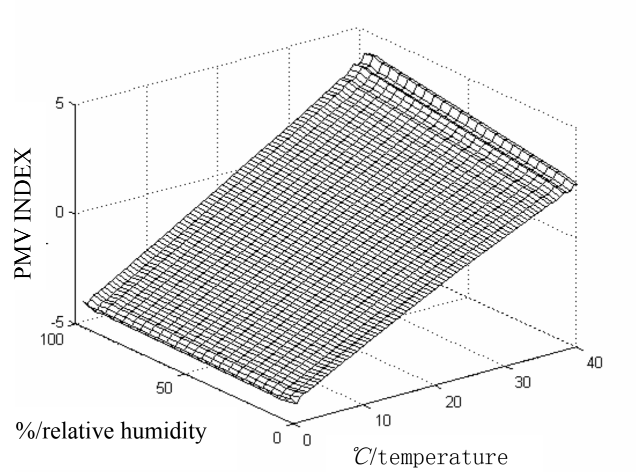

Fig.3.2 PMV soft sensor output

The simulation results are showed in figure 3.1 and figure 3.2. Figure 3.1 is expecting output while figure 3.2 is simulating output of CMAC neural network. The LMSE(learning mean squared error) is 0.0019 via simulation results calculation. The measuring error of actual temperature sensor usually is 0.1 ℃ .The measuring precision of humidity sensor usually is more lower than others and it precision degree often is 5%. So the simulation precision completely meets the detecting demand.

4. AIR-CONDITIONING SYSTEM REAL -TIME CONTROL BASED ON PMV

Air-conditioning system control block diagram based on PMV is showed in figure 4. In summer condition, coolers have two functions of cooling and reducing humidity. PMV expecting index adopt 0 for most people comfortable need. Which means balance of heat production and heat loss of body and the best comfortable state. PMV index can be realized on-line detection by neural network softsensor according to temperature and humidity indoor. Controller adopts fuzzy neural network controller[6]. According to error and change-in-error of PMV, controller operates the electrical valve of the cooling to realize comfortable control. This method not only meets most people comfortable needs but also saves energy.

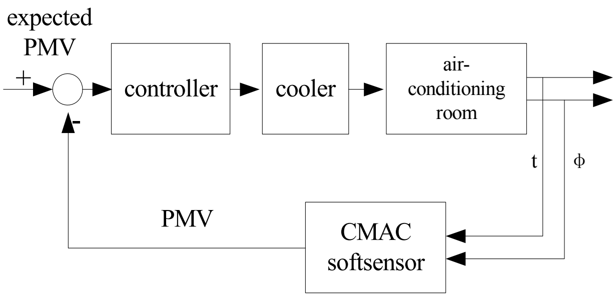

Fig. 4 Air-conditioning system control block diagram based on PMV

5. SUMMARY

This paper builds indoor hot comfortable softsensor model adopting CMAC neural network and realizes on-line detection of PMV index. It is very hard to measure PMV on-line in general methods. The simulation results show that CMAC softsensor is effective and accurate. The softsensor associated with intelligent control technology realizes real time control of center air-conditioning system based on PMV index. This method not only provides a comfortable environment to people but also saves energy. So this method has broad prospects in comfortable air-conditioning system. The key factor of the technology is accuracy of sample in practical. Especially in some special condition, when practical conditions deviate from the design conditions, the softsensor must learn on-line anew according to new learning sample of practical condition(for example, in gymnasium the people’s metabolic rate is higher than general building.).

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