MVA2011 IAPR Conference on Machine Vision Applications, June 13-15, 2011, Nara, JAPAN

Estimation of Thermal Comfort by Measuring Clo Value without Contact

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Abstract

In order to create more comfortable and energy saving living spaces, we have to investigate what is comfortable and how to measure comfort of users in a living space. Some measures of thermal comfort have been defined as Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) as an international standard. However, complex and high cost equipments are required to measure PMV by conventional methods. In this paper, we propose a method for PMV estimation more easily and cheaper than conventional methods by using a camera. PMV is calculated from temperature, humidity, air velocity and clo value estimated by sensors and clothes database.

1 Introduction

The growth of broadband network brings a large amount of information to us. Home appliances such as TV, PC, and game consoles are connected to the broadband network today and other home appliances will also be connected to the broadband network in the near future. The home plays a key role in such a situation, because every generation of people lives in home, and performs everyday life activities by obtaining information from home appliances.

In recent years, many researches have been proposed for services in the home. Ubiquitous Home[1] at NICT provides a TV recommendation system from user history and a lost object indication system by using RFID tags. The Aware Home at Georgia Institute of Technology is constructed in order to address the fundamental technical, design and social challenges for people in a home setting[2]. In addition, various researches such as Sensing Room[3] and Easy Living[4] have been performed in order to apply the technologies to the home.

The above researches aim for creating a comfortable space in the home. It is necessary to construct a “comfort index” to measure the comfort of a living space. Thermal comfort is one of important “comfort index” because people directly feel hot or cold according to the air temperature and the humidity in the home. PMV and PPD are proposed by Prof. Ole Fanger for measure the thermal comfort and are become international standard as ISO 7730[5]. PMV is calculated from 6 main parameters: metabolic rate, clothing insulation, air temperature, mean radiant temperature, air velocity and air humidity. The PPD is an index that establishes a quantitative prediction of the percentage of thermally dissatisfied people who feel too cold or too hot. The clothing insulation is measured by using the thermal mannequin which is very high cost, and it is difficult to use the thermal mannequin in conventional houses. It is, therefore, to measure the PMV values correctly without thermal mannequins, we have to estimate human factors such as clothing insulation and metabolic rate accurately without any discomfort. Thermography is one of sensors that can measure temperature without contact, however thermography is still expensive and is not suitable for daily use in the home.

In this paper, we propose a method for estimation of clothing insulation by using a camera and a clothes database. We apply object recognition technique[9, 10] for clothes recognition. We show the effectiveness of the proposed method through the experimental results.

Table 1. Seven-point thermal sensation scale[5]

+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

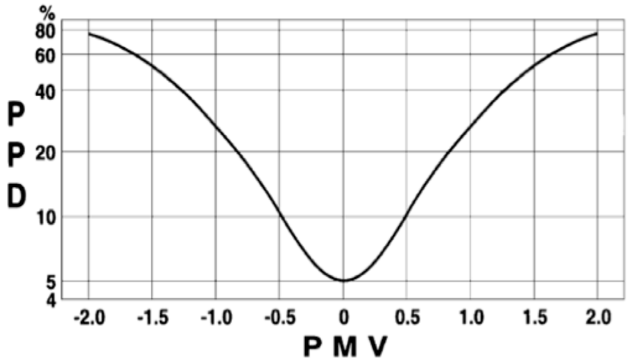

Figure 1. PPD as function of PMV[5]

2 Thermal Comfort and PMV index

The PMV is an index that predicts the mean value of the votes of a large group of persons on the 7-point thermal sensation scale (Table 1), based on the heat balance of the human body. The PMV is calculated by the following equations[5]:

$$
\begin{aligned}
PMV \;=\; & (0.303\exp(-0.036M)+0.028)\cdot \\
& \{(M-W)-3.05\cdot 10^{-3}\cdot[5733-6.99(M-W)-p_a] \\
& -0.42\,[(M-W)-58.15] \\
& -1.7\cdot 10^{-5}M(5867-p_a)-0.0014M(34-t_a) \\
& -3.96\cdot 10^{-8}f_{cl}\left[(t_{cl}+273)^4-(\bar{t}_r+273)^4\right] \\
& -f_{cl}h_c(t_{cl}-t_a)\},
\end{aligned}
$$

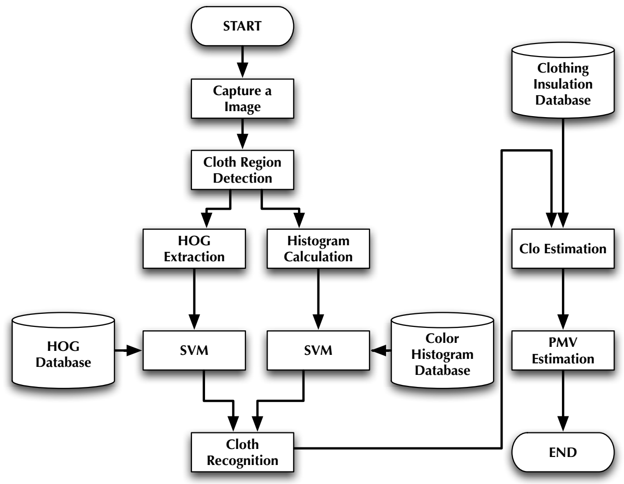

Figure 2. Process flow of the proposed method

Figure 3. Example of upper clothes detection

Figure 4. Example of lower clothes detection

$$
\begin{aligned}
t_{cl} &= 35.7 - 0.028(M - W) - \\
&I_{cl}\left\{3.96 \cdot 10^{-8}\left[(t_{cl}+273)^4 - (\bar{t}_r+273)^4\right] + f_{cl}h_c(t_{cl}-t_a)\right\}, \\
hc &= \max(2.38\,|t_{cl}-t_a|^{0.25}, 12.1\sqrt{v_{ar}}), \\
f_{cl} &\begin{cases} 1.00 + 1.290 I_{cl} & \text{for } I_{cl} \leqq 0.078 m^2K/W \\ 1.05 + 0.0645 I_{cl} & \text{for } I_{cl} > 0.078 m^2k/W \end{cases},
\end{aligned} \tag{1}
$$

where M is the metabolic rate, W is the effective mechanical power, I_{cl} is the clothing insulation, f_{cl} is the clothing surface area factor, p_a is the water vapour partial pressure, t_a is the air temperature, $\bar{t}_r$ is the mean radiant temperature, and v_{ar} is the relative air velocity. Here, pressure p_a can be calculated from relative humidity. In this paper, we assume that W is zero because the effective mechanical power is much smaller than the metabolic rate.

The PPD is an index that establishes a quantitative prediction of the percentage of thermally dissatisfied people who feel too cool or too warm. The relation between PMV and PPD is shown in Fig. 1.

2.1 Clothing Unit and Clothing Weight

The clo value expresses the clothing insulation (thermal conductivity resistance). Conventionally, the clothing insulation is measured by using the thermal mannequin which is very high cost, and it is difficult to use the thermal mannequin in the home. Therefore, we use the approximation equation for calculation of the clo value proposed by Hanada et al.[6]:

$$y = 0.000558W + 0.062, \tag{2}$$

where W is the total sum of weights of wearing clothes and y is the clothing insulation (clo). From this equation, we can obtain the clothing insulation from the total sum of weights of wearing clothes.

3 PMV Estimation System

The process flow of the proposed method is shown in Fig. 2. Clothes regions are relatively determined from the position of a face detected by OKAO Vision[7]. The user of the proposed system is also identified by

Figure 5. Examples of upper clothes in the clothes database

Table 2. Simulation conditions for PMV calculation

Condition	Relative humidity (%)	Clothing insulation (clo)	Air speed (m/s)	Metabolic rate (met)	Air temperature (°C)	Radial temperature (°C)
1	30	1.2	0.1	1.5	15	15
2	30	1.2	0.1	1.0	20	20
3	30	0.7	0.1	1.0	25	25
4	30	0.7	0.1	1.0	30	30

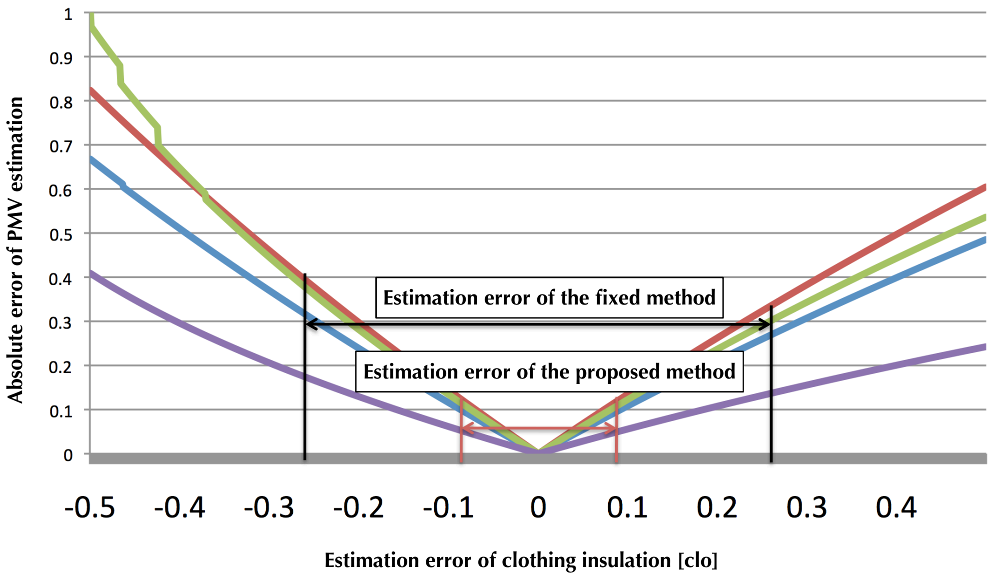

Figure 7. Estimation error of PMV values and clothing insulation

Figure 6. Examples of lower clothes in the clothes database

Table 3. The number of clothes of examinees

Examinees	# of upper clothes	# of lower clothes
1	7	5
2	7	7
3	7	5
4	7	5
5	7	5

OKAO Vision and the identification information is used to reduce the candidate of clothes. Figures 3 and 4 show examples of upper and lower clothes detection, respectively. Detected cloth regions are resized by 40×40 pixels for feature extraction. HOG[8] and color histograms are used for clothes recognition. The cell size of HOG calculation is 5 by 5 pixels. Each feature is classified into clothes by multi-class SVM, and then the final decision is made from recognition results by SVMs. The total weight of cloths, w is estimated from the final decision by using the following equation:

$$w = w_u + w_l + w_i, \tag{3}$$

where w_u is the weight of the recognized upper clothes, w_l is the weight of the recognized lower clothes, and w_i is the average weight of the inner cloths. In this experiment, we use $83[g]$ as w_i which is used in [6].

4 Experimental Results

We conducted evaluation experiments to verify the efficiency of the proposed method in the view point of

Table 4. Examples of weights of clothes (upper body): the average is 283.7 and the standard deviation is 111.4

Clothes	1	2	3	4	5	6	7
weight (g)	182	466	278	270	210	178	402

Table 5. Examples of weights of clothes (lower body): the average is 447.4 and the standard deviation is 208.8

Clothes	1	2	3	4	5	6	7
weight (g)	684	242	304	224	550	730	398

the accuracy of clothes recognition and PMV estimation.

The size of images in the clothes database is 1024×768 and 10 images per clothes per person are stored in the database. The number of examinees is 5 for this experiment. The number of clothes of each person is shown in Table. 3. Examples of weights of clothes are shown in Tables 4 and 5. By using this database, the experimental results of clothes recognition are shown in Table 6.

The recognition rates of the clothes of upper body are highly accurate, but the recognition rates of the clothes of lower body are not so accurate. This is because textures of upper clothes are different with each other, but texture of lower clothes are the almost same. We compare the PMV calculated from this recognition results and the true PMV under the various conditions shown in Table 2. The results are shown in Fig. 7. As shown in Fig. 7, the error of PMV values estimated by the proposed method is smaller than the conventional fixed method.

Table 6. Recognition rates of clothes

Examinees	Recognition rate (upper clothes)	Recognition rate (lower clothes)
1	0.931	0.387
2	0.997	0.849
3	0.988	0.433
4	0.838	0.660
5	0.813	0.411

5 Conclusion

In this paper, we have proposed a method for clo estimation by using a camera and clothes database. Clo value is used for PMV calculation, which is a measure of thermal comfort. We also show the effectiveness of our method through the experimental results. In future work, we will improve the recognition rate of wearing clothes which affects the estimation accuracy of PMV. Moreover, our method requires the clothes database registered in advance. We will investigate the relation between weight and appearance of clothes in order to remove clothes database. In this experiment, we have conduct experiments with fix met values. We will also develop a method for metabolic rate estimation for more accurate estimation.

Acknowledgement

This work is partially supported by cooperative research with Daiwa House Industry Co., Ltd.

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