The Effect of Multi-media Contents in Reducing Sensible Temperature

Shuhei Yamamoto[1], Akira Tomono[1] and Hajime Katsuyama[2]
[1]Department of Information Media Technology, School of Information and Telecommunication Engineering, Tokai University, 2-3-23 Takanawa, Minato-ku, Tokyo 108-8619, Japan
[2]Graduate school of Engineering, Tokai University, 4-1-1 Kitakaname, Hiratsuka-shi, Kanagawa, 259-1292, Japan

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Abstract: In this paper, the effect of multi-media contents such as visual images, scent, and their combinations on sensible temperature is investigated. For this purpose, a new definition of sensible temperature which takes into account the effect of visual images and scent is proposed. Using this definition, the effectiveness of multi-media contents in reducing sensible temperature was quantitatively measured. It turned out that visual images with lemon aroma is more effective in reducing sensible temperature than visual images alone.

1 INTRODUCTION

In Japan, nuclear accident at Fukushima, which took place on the 11th of March, 2011, has been causing a severe shortage in electric supply, especially in the Kanto region, which includes Tokyo. As a result, companies and households are required to raise the room temperature during the summer and lower it during the winter in order to save electricity. The top energy consuming equipment in the house is the air-conditioner, followed by the refrigerator and then lighting equipment. Although it is difficult to significantly cut down energy consumption by the refrigerator and lighting equipments, effective reduction of energy usage can be attained through adjustment of the room temperature because the electric energy consumption of the air conditioner is said to be lowered by 10% by changing the control temperature of the air conditioner by 1 °C. Due to its high effectiveness in energy saving, the Ministry of Economy, Trade, and Industry of Japan has encouraged companies and households to set the room temperature to 28°C.

However, 28°C is really high, and although it depends on humidity as well, such an environment is actually very uncomfortable. This is problematic, as the productivity of workers will generally decrease with decreasing amenity of the working place. On the other hand, it is known that performance level can be increased by changing the working environment with presentation of aroma (Yasuda et al., 2010). Also, the level of discomfort is reported to decrease in the presence of aroma, according to an experiment (Kimura et al., 2001).

Thus, our proposal of a method to manipulate sensible temperature by presenting multi-media stimuli will contribute to energy saving at this time of this energy shortage. In Japan, multi-media, which can express sensation and feeling by adding olfactory and tactile information to visual and audio information that traditional multi-media have presented to the user, is called KANSEI multi-media (Nakamoto et al., 2008). In this paper, a new definition of sensible temperature, which is adapted in the paper, will be presented first, and the effect of KANSEI multi-media, such visual images along with aroma, will be investigated.

2 RELATED WORK

Among many definitions of sensible temperature, the definition proposed by Missenard is well-known (Missenard, 1931). The definition takes into account the influences of humidity as well as temperature and is given by:

$$M = t - 2.3^{-1}(t - 10)(0.8 - H/100) \quad (1)$$

where t denotes the temperature in Celsius, and H the relative humidity in %. In the late 1960s, Fanger

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proposed Predictive Mean Vote and the PMV-model that takes into account the effect of clothing and activity (Fanger, 1972). This is a static heat balance model and predicts the percentage of people in a given group experiencing thermal comfort.

There are also other factors that affect sensible temperature. In addition to tactile stimuli, such as temperature and humidity, it is affected by visual, audio, and olfactory stimuli. For example, scent is known to have psychological and physiological impacts on humans. A research showed that refreshing scents such as mint flavour reduces apparent temperature (Shoji, 2005).

However, not many researches have been done on the methods to measure sensible temperature that take into account the effect of visual images and scent and how much these factors change sensible temperature.

3 THEORY OF SENSIBLE TEMPERATURE

3.1 Definition of Sensible Temperature

In this section, we propose a new definition of sensible temperature, which will be adapted in the rest of this paper. The key idea is to focus on similarity in psychological reaction. To explain this idea, imagine two environments, $\mathbf{e}_1$, with a temperature of 26°C and humidity of 80%, and $\mathbf{e}_2$, with a temperature of 28°C and humidity of 30%. Suppose that environment $\mathbf{e}_1$ feels as warm as environment $\mathbf{e}_2$. This is entirely conceivable as we know from experience that increased humidity leads to increased sensible temperature, just like many formulae for sensible temperature, such as the heat index equation, indicate (Steadman, 1979).

Then, the sensible temperature in the two environments is the same. In other words, the subjective evaluation of the environments is equal, at least in respect to the temperature. Also, when one is initially in environment $\mathbf{e}_0$, with a physical temperature of 26°C and humidity of 30%, that gradually changes into $\mathbf{e}_1$, one would feel as if the temperature of the environment increased by 2°C. This means the effect of increasing humidity by 50% is equivalent to that of increasing physical temperature by 2°C. These considerations suggest that apparent change in temperature can be gauged by making use of the similarity of psychological reaction to the apparent heat of the environments.

To formalize these ideas, first let $x_1, x_2, \ldots, x_n$ be environmental factors that affect sensible temperature, such as physical temperature and humidity, and form an environment space, E, by collecting the ordered tuples comprising of these factors, i.e. $\mathrm{E} = \{\mathbf{e} \equiv (x_1, x_2, \ldots, x_n) | x_i \in \mathbb{R}\} = \mathbb{R}^n$, where x_1 denotes physical temperature, and x_2 humidity. Then, sensible temperature can be expressed as a function over E. Call this function $T_s^i: \mathrm{E} \to \mathbb{R}$ a sensible temperature function. Here, the subscript i indicates individual dependence of the function. Hereafter, the existence and uniqueness of the sensible temperature function is assumed.

Then, we divide E into equivalent sets based on similarity in psychological reaction related to apparent temperature. For this purpose, we introduce a function $\mathrm{S}: \mathrm{E} \times \mathrm{E} \to \mathbb{R}_0^+$ called the similarity function. Given two environments, $\mathbf{e}_1$ and $\mathbf{e}_2$, $\mathrm{S}(\mathbf{e}_1, \mathbf{e}_2)$ indicates similarity in psychological reaction to these two environments. The smaller the value of this function, the more similar the reactions are. The precise definition of this function is given later. With this function, we partition E into the following equivalent sets:

$$\mathcal{E}_t = \{\mathbf{e} \in \mathrm{E} | (\forall k \in \mathbb{N}) \mathrm{S}((t, c_2, \ldots, c_n), \mathbf{e}) \leq \mathrm{S}((k, c_2, \ldots, c_n), \mathbf{e}))\}$$

where $c_2, c_3, \ldots, c_n$ are arbitrary constants. Note that these equivalent sets are formed first by picking up discrete points on the line $\mathrm{L} = \{(x, c_2, c_3, \ldots, c_n) | x \in \mathbb{R}\}$, and then by making an environment belongs to the equivalent set represented by the point closest to it among those picked up points. Although it might seem appropriate to form an equivalent set for each value of sensible temperature, for the following two reasons, our equivalent sets are countable and not continuous.

1) Sensible temperature is a fuzzy quantity

2) E is partitioned into equivalent sets using a similarity function, which gives a relative measure of similarity in psychological reaction, and due to the fuzziness coming from psychological evaluation and fuzziness of sensible temperature itself, cannot confirm identicalness of psychological reactions in the two environments.

Now, since one feels as hot in any environment belonging to the same equivalent set by definition, the following approximation holds:

$$T_s^i|_{\mathcal{E}_t} \approx const. \tag{3}$$

Thus, we can reduce the problem of defining T_s^i into that of defining $\overline{T}_s^i: \Omega \to \mathbb{R}$, where $\Omega = \{\mathcal{E}_t | t \in \mathbb{N}\}$. There are several possible ways to define $\overline{T}_s^i$, and below are the examples:

1) Standard Sensible Temperature

Let c_1, c_2, ..., c_n be arbitrary constants in the definition of $\mathcal{E}_t$ and call an environment $\mathbf{e}$ = (x_1, x_2,...,x_n) s.t. (c_2,c_3,...,c_n) = (x_2,x_3,...,x_n) a standard environment. Then:

$$T_s^i(\mathbf{e}) = t \; s.t. \mathbf{e} \in \mathcal{E}_t \quad (4)$$

2) Heat Index Definition

The use of physical temperature as sensible temperature suffers from an issue that it is not clear as to whether one feels hot or not, because different people react differently to the same environment. For instance, a person coming from a warmer area might think that a room at 18°C and humidity of 50% is cold, while another person coming from a colder area might think the other way around. Thus, it is desirable to introduce an index that expresses thermal comfort so that we can speak of universal measure of apparent heat. For example, if the value of the index is +2 for the two persons, then their sensed hotness is the same.

The actual definition is as follows. Let $\overline{x_1}, \overline{x_2}, \dots, \overline{x_n}$ be the average values of the environmental factors of the area from which one comes, $(\overline{x_1}, \overline{x_2}, \dots, \overline{x_n}) \in \mathcal{E}_t$, **e**' the environment in which we try to find the value of the index, $\mathbf{e}' \in \mathcal{E}_{t'}$, and C the constant for sensitivity to temperature change. Then, the index can be defined as:

$$C[\overline{T_s^i}(\mathcal{E}_{t'}) - \overline{T_s^i}(\mathcal{E}_t)] \quad (5)$$

where $\overline{T_s^i}(\mathcal{E}_t) = t$ s.t. (c_2,c_3,...,c_n) = $(\overline{x_2}, \overline{x_3}, \dots, \overline{x_n})$.

These definitions enable us to express change in sensible temperature quantitatively. Definition (2) is used in this paper with the values of the constants being those of the reference environments.

3.2 Similarity Function and Information Extraction Analysis

The definition of the similarity function, S, is detailed in this section. As is stated in the above, the function is an indicator of similarity of psychological reaction to apparent heat in two environments. To evaluate the similarity, the reaction needs to be measured in some way before any numerical comparison can be made. Let y_1, y_2,…, y_m be the measurements of this reaction such as skin conductance and answers to a questionnaire. Define the Kansei space, K, by K = $\{\mathbf{k} = (y_1, y_2, \dots, y_m) | y_i \in \mathbb{R}\} = \mathbb{R}^m$. Taking the measurements in the environments naturally defines:

$$\mathrm{R}^i\colon \mathrm{E} \to \mathrm{K} \text{ by } \mathrm{R}(\mathbf{e}) = \mathbf{k} \quad (6)$$

where **k** is comprised of the measurements in the environment **e**. We call R^i the reaction function. Here, the subscript *i* indicates individual dependence of the function.

Based on the distribution of $R^i(E)$, we assess similarity in psychological reaction in different environments. Before carrying this out, note that some measurements might correlate not only with sensible temperature but also with different psychological quantities such as a sense of beauty. For instance, a score for a pair of adjectives, Lively ⇔ Dull, could be an indicator of sensible temperature, but at the same time, it might also respond to music. Thus, in order to extract only important information and form new measures from the old ones, we apply Information Extraction Analysis (IEA), which combines Principal Component Analysis (PCA) with an information extraction procedure. First, we introduce new useful measures and reveal their sensitivity by applying PCA to $\bigcup_i \mathrm{R}^i(\mathrm{E})$. The reason why we apply PCA to $\bigcup_i \mathrm{R}^i(\mathrm{E})$ and not to $R^i(E)$, is to take into account the tendency of the entire group. In actual practice, instead of $\bigcup_i \mathrm{R}^i(E)$, $\bigcup_i \mathrm{R}^i(\{(t, c_2, c_3, \dots, c_n) | T_l \leq t \leq T_u \wedge t \in \mathbb{N}\})$ is considered, where (t,c_2,c_3,...,c_n) is called a reference environment, which is a point on the line L. Also, T_u and T_l are upper and lower bounds of the range of temperature employed in the experiment, respectively. Application of PCA brings in a new coordinate axes, called principal coordinate axes, and origin to Kansei space, K. Among these principal components, we keep only the components that satisfy the following criteria:

1) Contribution to contribution factors to accumulated contribution factor is significant

2) Coefficient of correlation of the component with physical temperature is relatively large

3) The principal component has strong relation to sensible temperature

Using these criteria, only the information strongly related to sensible temperature is extracted. Some justification on the criteria is as follows. In the process of PCA, the components that do not contribute to the accumulated contribution factor are disregarded. Generally speaking, by reordering the principal components in increasing order if necessary, the first several components whose sum of contribution factors exceeds 70% are used. This is what is meant in criterion (1). Criterion (3) is based on a technique commonly practiced by people who use PCA. One task in PCA is to interpret what the newly obtained principal components stand for. There are several procedures that one can adapt. If a principal component turns out to be irrelevant to sensible temperature after this interpretation, the component will be excluded from consideration. Mathematically speaking, these operations correspond to first rotating orthonormal basis, then translating the origin to the center of mass of $\bigcup_i \mathrm{R}^i(\{(t, c_2, c_3, \ldots, c_n) | T_l \le t \le T_u \wedge t \in \mathbb{N}\})$, and finally doing orthogonal projection onto the subspace spanned by the principal components left. If we denote the function that does these operations by $\mathrm{Ext}: \mathrm{K} \to \mathrm{K}'$, where we call K' the extracted space and its components extracted components. Here, the extracted components are subscribed from 1 to m' in the order of increasing contribution factor.

Similarity in psychological reaction is evaluated using the extracted information. The measure of this psychological quantity is a metric $\mathrm{d}: \mathrm{K}' \times \mathrm{K}' \to \mathbb{R}$, which is defined as follows:

$$\mathrm{d}(\mathbf{p}, \mathbf{q}) = \sqrt{\sum_{i=1}^{p} w_i{}^2 (p_i - q_i)^2} \quad (7)$$

where w_i is a correlation coefficient of the i^{th} extracted component with physical temperature, taking into account sensitivity to change in sensible temperature. Therefore, the similarity function is defined as

$$\mathrm{S}(\mathbf{e}_1, \mathbf{e}_2) = \mathrm{d}(\mathrm{Ext} \circ \mathrm{R}(\mathbf{e}_1), \mathrm{Ext} \circ \mathrm{R}(\mathbf{e}_2)) \quad (8)$$

4 EXPERIMENT

4.1 The Method of the Experiment

The purpose of the experiment was to investigate into the effect of visual stimuli and olfactory stimuli on apparent heat. In particular, we researched how much reduction in sensible temperature could be attained by presenting a movie of scuba diving from the diver viewpoint alone and the movie along with lemon aroma. The movie is slow and relaxing, full of blue color. The data were analysed using IEA. In total, 18 individuals participated in the experiment.

First, the reference environments used in this experiment were prepared. Each reference environment was realized in a room, shown in Figure 4.1.1, where temperature and humidity were adjustable. The detailed specifications of the room are shown in Figure 4.2.1. It can be seen from the figures that the room was empty except for several apparatuses in order to minimize the influence of the environmental factors other than temperature and humidity on sensible temperature and control the condition of the room. The factors whose effects on sensible temperature were not analyzed were kept constant in this room. Humidity of the room was fixed at 70% during the entire experiment. Physical temperature was changed by 1°C from 26 to 30°C each time the subject moved to the next environment. The environments under these conditions were chosen as the reference environments for this experiment. Call these reference environments $\mathbf{e}_T$ where T indicates the temperature of the reference environment. The subjects were asked to stay for 5 min inside of the room under the condition of a reference environment and then take a 10 min break in a separate room where the temperature was 23°C and humidity was 60%. This process was repeated for each reference environment.

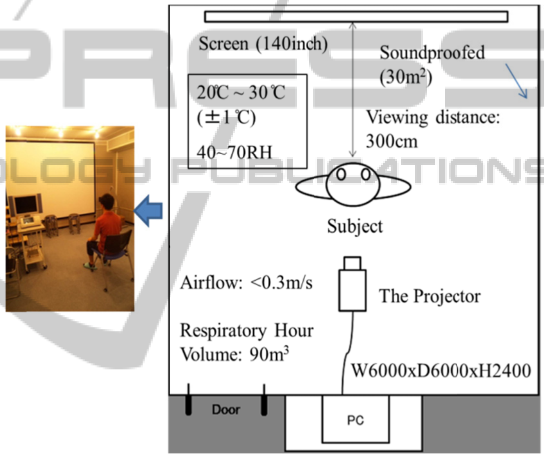

Figure 4.1.1: The thermostat room and the schematic diagram of the experimental set up with specification of the room.

The psychological reaction of each subject was measured during the break, using a questionnaire consisting of 26 pairs of opposite adjectives, shown in Table 4.2.2, to be scored from -3 to 3 scales indicating in which way a taker felt in the given environment. After the measurements in the reference environments were taken, the subjects were presented with control stimuli, namely the movie with and without lemon aroma. The aroma was presented at short intervals in order to avoid olfactory exhaustion. They spent another five minutes in the room in which the temperature was 28°C, humidity is 70%, and the movie of scuba diving was displayed first with lemon aroma, and after a 10 minutes break, without aroma. During the breaks, the subjects were asked to fill in the same questionnaire.

4.2 The Results of the Experiment

The data of these measurements were analyzed using IEA. We first applied PCA to the data and found the contribution factor and corresponding accumulated contribution factor for each principal component, which are listed in Table 4.2.1. Although there are as many principal components as the questions in the questionnaire, only ten principal components are shown in the figure. This is because those principal components that are not listed had small contribution factors so that they did not contribute to the accumulated contribution factor notably. It can be seen from the figure that the accumulated contribution factor of the 7th principal component was more than 80%. Thus, we disregard all the components beyond the 7th components and analyzed the data using only the first seven components.

Then, from the value of each component of the eigenvectors in the original space, which is shown in Table 4.2.2, we could interpret what the new components expressed. The columns correspond to the eigenvectors, and the rows correspond to each question in the questionnaire. The questions are grouped together based on the values of the components. We also computed the linear correlation coefficients between each principal component score and physical temperature. The computational results are summarized in Table 4.2.3. It was concluded from these two tables that the 2nd, 4th, and 5th principal components were not related to sensible temperature, and thus excluded from the analysis. The 2nd principal component was excluded because Table 4.2.2 indicates that it did not respond to changes in sensible temperature. For the 4th and 5th principal components, not only does Table 4.2.2 indicate that they are unrelated to sensible temperature change, but also the corresponding correlation coefficients were extremely low.

Table 4.2.1: The eigenvalues for principal components.

Principal Component	Eigenvalue	Contribution Factor (%)	Accumulated Contribution Factor (%)
1	8.93	40.60	40.60
2	2.67	12.15	52.76
3	1.88	8.53	61.29
4	1.61	7.31	68.59
5	1.41	6.42	75.01
6	1.02	4.62	79.63
7	0.87	3.94	83.57
8	0.66	2.99	86.56
9	0.65	2.95	89.51
10	0.43	1.95	91.46

Table 4.2.2: The eigenvectors for principal components.

Adjective Pair	1st Principal Component	2nd Principal Component	3rd Principal Component	4th Principal Component	5th Principal Component	6th Principal Component	7th Principal Component
Warm ↔ Cold	0.2195	-0.2168	0.0935	0.0472	0.0161	0.3255	-0.2167
Fun ↔ Bothersome	-0.2773	-0.0105	-0.1173	0.0473	0.0393	-0.1664	-0.1095
Happy ↔ Unhappy	-0.2610	-0.0381	-0.1185	0.0410	-0.2523	-0.0904	-0.1720
Sensitive ↔ Insensitive	-0.2219	-0.1509	-0.1093	-0.1104	0.0047	-0.0535	-0.3490
Comfortable↔ Unpleasant	-0.2954	-0.0004	-0.0659	-0.1345	0.2295	0.0651	-0.1820
Kind ↔ Unkind	-0.2917	-0.0712	-0.1424	0.0322	0.1859	-0.0416	-0.0674
Damp ↔ Dry	0.2732	0.1050	-0.0445	-0.0100	-0.2210	0.2458	0.1160
Rich ↔ Poor	-0.0114	0.4212	0.0946	0.0834	0.1027	-0.2292	0.0633
Complex ↔ Simple	-0.0485	0.3544	-0.2584	0.1823	-0.1934	0.1989	0.0168
Massed ↔Scattered	-0.0610	0.4261	0.2032	-0.2452	-0.1090	0.1916	-0.1766
Rough ↔ Smooth	0.0939	0.3826	-0.3562	-0.1899	-0.0919	-0.3164	-0.0408
Fulfilling ↔ Nihilistic	-0.0602	0.3403	0.0054	-0.4669	-0.3112	0.1820	-0.0272
Calm ↔ Restless	-0.0740	0.2196	0.5018	0.0189	0.2621	0.1384	0.1958
Enthusiastic ↔ Tepid	-0.2453	-0.0193	0.3077	0.1174	0.0980	0.1096	0.1115
Rational ↔ Emotional	-0.1466	0.1998	0.0470	0.5267	-0.0169	0.0778	-0.2907
Beautiful ↔ Ugly	-0.0326	0.2224	-0.1404	0.5412	-0.2367	-0.1980	-0.0527
Sharp ↔ Blunt	-0.2190	-0.1150	-0.1918	-0.0072	-0.2332	0.2236	-0.1225
Lively ↔ Dull	-0.1929	-0.0473	0.4780	-0.0207	0.5128	0.0849	0.1054
Pleasing ↔ Unpleasing	-0.2657	-0.0533	-0.0886	-0.0605	-0.1960	0.4433	0.0596
Preferable ↔ Unpreferable	-0.3035	0.0582	-0.1134	-0.0832	-0.2246	-0.2593	0.3712
Clear ↔ Unclear	-0.2741	0.0529	0.1410	0.0250	0.2582	0.0977	-0.4738
Good ↔ Bad	-0.2840	-0.0563	-0.0825	-0.1090	0.1608	0.3464	0.4131

Table 4.2.3: The table of correlation coefficients between principal components and physical temperature.

Correlation Coefficient	1st Principal Component	2nd Principal Component	3rd Principal Component	4th Principal Component	5th Principal Component	6th Principal Component	7th Principal Component
Physical Temperature	-0.687	0.215	-0.126	-0.076	0.065	-0.319	0.117

Then, we transformed the raw data of psychological measurements in the control environments to obtain the corresponding results expressed in principal components and computed the distance from each of these two data points in K' to each point corresponding to one of the reference environments in order to find the closest reference environment to each control environment. The computational results are illustrated in Figure4.2.1. It can be observed from the figure that in both of the control environments sensible temperature of each subject decreased. Also, presentation of the aroma increased the percentage of the subjects experiencing reduction of sensible temperature by 2°C from 75% to 100%. The average reduction in the control environment with only the movie was 1.75°C, and that in the control environment with the movie along with lemon aroma was 2°C. This result is consistent with the research result that mint flavour caused to feel colder (Shoji, 2005).

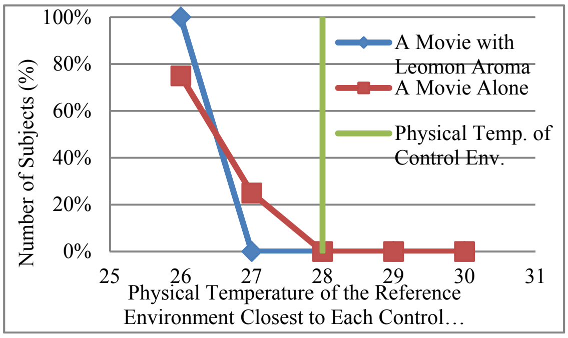

Figure 4.2.1: The graph illustrating the effect of control stimuli to reduce the sensible temperature.

5 CONCLUSIONS

As a summary, in this study:

1) A new definition of sensible temperature that takes into account the factors not traditionally considered such as scent and visual images is introduced, thereby allowing quantitative estimation of change in the sensible temperature by these factors.

2) The experimental results support the conclusion that lemon aroma can enhance the effect.

In the future, we would like to investigate the effect on apparent heat of other types of aromas and make compassions to determine which aromas have the strongest effects in lessening apparent heat. The effects of other types of stimuli are also subject to future investigation. We are convinced that the results of these investigations will contribute to energy saving. For practical application, we would also like to devise customized scent delivery method in office space. Furthermore, we would like to reveal the ethnic, gender, and regional variation in response to change in environmental factors by accumulating the data of psychological reaction for various groups under specified reference environments and reveal the trend of its distribution $\bigcup_i R^i(E)$. With enough data, it would also be possible to estimate one's sensible temperature in a given environment simply by taking some standard measurements of psychological reaction in an environment together with one's personal information such as one's ethnic group and place of residence.

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