

# Modeling of Human Texture Perception for Tactile Displays and Sensors

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## Abstract

*It is necessary to ascertain texture perception of humans in developing tactile devices that create or detect lifelike texture. In this paper, the relationship between object surface physical properties and texture perception is discussed through multivariate analysis. We quantified the tactile sensation and texture perception through sensory evaluation. From the results, we built a model of the relationship.*

## 1. Introduction

“Texture perception”, a type of perception to recognize fine surface conditions, has recently attracted much attention. A lot of tactile sensors and displays for detecting or creating object surface conditions have been developed. However, a device that creates or detects lifelike texture has not been developed yet. The fact that stimulating factors of texture and the perceptual mechanism are still uncertain is believed the biggest reason for this. Therefore, we clarified the relationship between surface properties and texture perception through factor analysis and multiple linear regression analysis from the measurement result. In addition, we made a model as an index for detecting or creating texture.

## 2. Analysis about object surface properties and tactile sensation

### 2.1 Object surface properties

We measured and analyzed surface roughness, friction property, thermal property and elasticity of 20 samples shown in Table 1.

Average roughness was calculated from the measurements of the height of sample surface, and regarded as the property of surface roughness.

Density  $\rho$ , specific heat  $c$  and thermal conductivity  $k$  are the thermal properties that are based on reference.

In addition, from the heat equation, the surface temperature  $T_s$  human perceive is represented as

$$T_s = \frac{(k\rho c)_A^{1/2} T_{Ai} + (k\rho c)_B^{1/2} T_{Bi}}{(k\rho c)_A^{1/2} + (k\rho c)_B^{1/2}}, \quad (1)$$

where  $T_{Ai}$  is the initial temperature of the finger,  $T_{Bi}$  is the initial temperature of the object material[1]. In this research, we call the calculated physical value  $(k\rho c)^{1/2}$  the heat transfer property, a type of thermal property.

The modulus of elasticity was obtained from references for metal and polymer, from tension tests for fabric and leather.

### 2.2 Tactile sensation

We quantified texture perception by semantic differential method (SD method) in the sensory evaluation experiment. We selected 30 panelists in their early twenties. The panelists evaluated texture perception by running their finger along the 20 samples shown in Table 1. In addition, we had the 30 panelists judge material with 9 alternatives materials. We extracted 4 potential factors of texture perception through factor analysis of the normalized values. We named each factors “Rough factor”, ”Cold factor”, ”Moist factor” and “Hard factor”. Then, we calculated factor scores of each sample with the extracted factors.

**Table 1 Object samples**

Texture	Object
Fabric	Silk, Polyester, Denim, Felt
Leather	Velour, Nubuck, Sheep
Paper	Plain Paper, Tissue Paper
Wood	Cypress, Balsa
Metal	Copper, Alminum, Stainless, Albata
Plastic	Acrylic, Chloroethene
Coolite	Coolite
Rubber	Butyl-rubber
Sponge	Polyurethane

### 3. Modeling of texture perception

First, we calculated the correlation coefficients between physical values and tactile factor scores to ascertain the relationship. Fechner stated that magnitude of a subjective sensation increases proportionally to the logarithm of the stimulus intensity, not the stimulus itself [2]. Based on this idea, physical properties, ratios excluded, were transformed into common logarithms, and correlation improvement was confirmed. Therefore, humans can be considered to perceive texture through logarithmic transformation of the physical values.

Secondly, we conducted multiple linear regression analysis to ascertain the effect of physical property on each tactile factor. Then, all multiple linear formulas were assessed meaningful within the confident interval of 95.0%. We also conducted multivariate analysis of every sample to clarify the relationship between tactile factor scores and the rates of material determination. Multiple linear formulas of material, except for leather, coolite and rubber were considered meaningful within the confident interval of 95.0%. We formulated the effect of each tactile factor on material determination based on this multiple linear regression analysis.

We built a model of texture perception shown by Fig. 1 from the analysis results as stated above. Fig.1 indicates that human recognizes various materials by tactile sensation obtained from surface physical values.

Based on the model shown in Fig. 1 a relationship between physical properties and material determination can be represented as;

$$\begin{pmatrix} Z_{fabric} \\ Z_{paper} \\ Z_{wood} \\ Z_{metal} \\ Z_{plastic} \\ Z_{sponge} \end{pmatrix} = \begin{pmatrix} 0.019 & -0.095 & 0.071 \\ 0.006 & -0.086 & 0.030 \\ 0.022 & -0.132 & 0.056 \\ -0.129 & 0.213 & 0.015 \\ -0.212 & 0.008 & -0.016 \\ 0.007 & 0.001 & -0.037 \end{pmatrix} \begin{pmatrix} \log_{10} x_1 \\ \log_{10} x_2 \\ \log_{10} x_3 \end{pmatrix} + \begin{pmatrix} 0.080 \\ 0.111 \\ 0.046 \\ 0.234 \\ 0.748 \\ 0.126 \end{pmatrix}, \quad (2)$$

where  $x_1$  is average roughness ( $\mu\text{m}$ ),  $x_2$  is heat transfer property ( $\text{kJ/m}^2/(\text{KS})^{1/2}$ ), and  $x_3$  is modulus of elasticity (MPa). Z-value in formula (2) indicates ease of recognizing the material, based on the rate of material determination. Fig. 2 illustrates the relationship between Z-values calculated from the obtained physical properties and formula (2) and the result of the material judgment test stated in section 2.2. Fig. 2 shows the rate of material determination helped improve the Z-value by approximately over 0. Consequently, this Z-value can be indicator in developing devices to create or detect particular material texture.

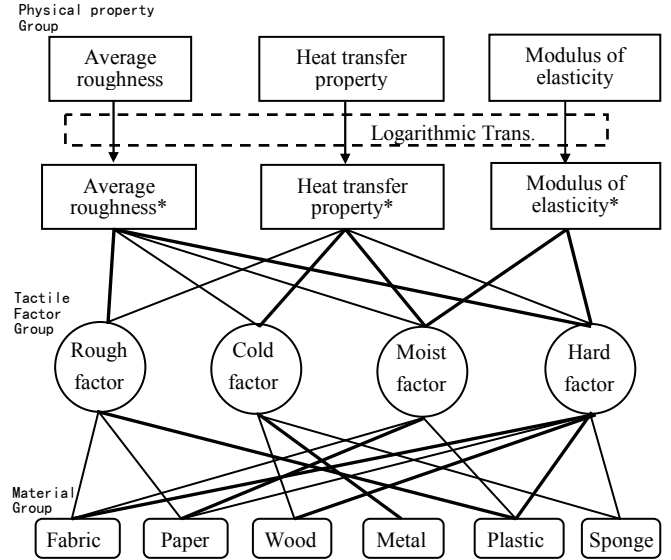


Fig. 1 Texture perception model

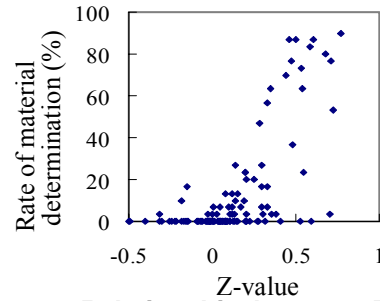


Fig. 2 Relationship between Z-value and rate of material determination

### 4. Conclusions

In this research, we analyzed human texture perception in recognizing fine surface conditions. In other words, we conducted multivariate analysis between tactile factor scores and physical values of object surface or rates of material determination. From the results, we built a total model of texture perception.

### References

- [1] P. I. Frank, and P. D. W. David, Fundamentals of heat and mass transfer, John Wiley & Sons, 3<sup>rd</sup> ed., pp. 259-262, 1990
- [2] G. T. Fechner, Elemente der Psychophysik, Aufl. Leipzig, Breitkopf u. Hartel, 1907.