Realization of Human Skin-like Texture by Emulating Surface Shape Pattern and Elastic Structure

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ABSTRACT

Artificial skin having human skin-like texture is necessary for the development of tactile evaluation systems and for robots that have physical contact with humans. This paper describes a novel type of artificial skin having human skin-like texture and a model of human texture perception. The artificial skin is designed by emulating the surface shape pattern and elastic structure of the human skin. Appropriate wettability and friction property of the artificial skin was achieved by designing the surface shape. Through sensory evaluation, we confirmed the artificial skin has human skin-like texture due to its surface shape pattern and elastic structure. In addition, we built a model of skin-like texture perception through multivariate analysis between physical parameters and tactile factor scores. This model can indicate what factor is important for human skin-like texture. From the results, artificial skin having optional skin-like texture can be developed.

Keywords: texture, artificial skin, cognitive model

1 INTRODUCTION

Recently, there has been an increase in demand for evaluating tactile texture as data since dealing with tactile texture is important for developing products having physical contact with humans [1]. To meet this demand, some tactile sensor systems for evaluating tactile texture have been developed [2]-[4]. However in spite of large demand, existing sensor systems still have not been able to evaluate the tactile texture of fine skin surfaces like the smoothness of cream. This can be attributed to under-development of artificial skin for evaluating skin texture. When evaluating texture, if actual human skin is used, experimental parameters differ among individuals and areas of the body. To use artificial object whose design variable can be set solves this problem. However, existing sensor systems have not considered the tactile texture of such artificial objects. Evaluation may completely differ when an object without human skin-like texture is used. If a sensor system evaluating tactile texture on human skin as data is developed, it is absolutely essential that artificial skin having human skin-like texture is developed.

In developing artificial skin having optional texture, it is important to ascertain the relationship between physical parameters and tactile texture in order to design its surface shape and material constant meeting its purpose. The purpose of this research is to develop artificial skin with human skin-like texture and ascertaining the relationship between its physical parameters and tactile texture by design and fabrication of samples based on a human skin model and sensory evaluation.

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2 DESIGN OF ARTIFITIAL SKIN

Human skin is composed of multiple layers of elastic tissue where highly elastic tissue like the dermis and hypodermis is interior of very thin less elastic tissue like the corneum [5]. This structure allows skin surface to maintain the contact condition with low friction coefficient, despite large deformation. Therefore layer-structured artificial skin was designed emulating the human skin. The surface layer is made of polyurethane rubber with Young's modulus of 900kPa, the inner layer silicone rubber with Young's modulus of 40kPa. We confirmed through sensory evaluation that the artificial skin exhibited similar hardness as human skin due to this material composition.

Given we can also assume that surface shape affects contact condition, surface shape pattern of skin also influences tactile texture other than roughness. Parameters of surface shape are width of convex area, depth of groove, width of groove and curvature of groove. We calculated average roughness, Rate of convex area and groove shape property $G \equiv d/(a+l)\rho$, derived from the rate between flow volume and phase boundary force of groove, as evaluated values. First, we simplified the human skin surface pattern to obtain a design standard for surface shape of the artificial skin. Human skin surface has grooves with several depth and length [5]. Figure 1 is a view showing a frame format of sample A designed based on such human skin surfaces. The pattern is composed of regular hexagons and the size of sample A is 30 x 80 x 10mm. We next designed six kinds of surface shapes; samples B-G. The design variables for these samples were based on the three evaluated values of sample A.

3 EVALUATION OF SKIN-LIKE TEXTURE

Figure 2 shows the result of similarity of each sample texture to skin texture of a human forearm. Figure 2 indicates that the evaluation of sample A is in the range from 0 (no opinion) to 2 (fairly similar), whereas all the evaluations of samples B-G are in the range from -2 (fairly different) to 0 (no opinion). Consequently, results suggest sample A, emulating human skin surface based on the three evaluated values, can exhibit human skin texture. In other words, tactile texture of human skin can be displayed by this design, but the design parameter region is very restricted because other samples designed by minor differences in parameter from sample A could not display skin-like texture.

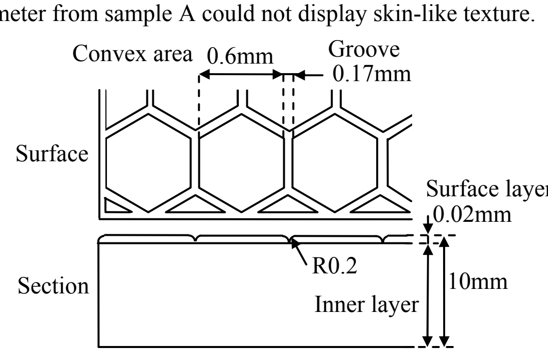

Figure 1: Frame format of sample A

4 COGNITION MODELING OF SKIN-LIKE TEXTURE

We next attempted to ascertain the relationship between the physical parameters and skin-like texture through multivariate analysis to realize of various skin-like textures.

First, we measured two physical properties of contact condition, wettability and friction coefficient. Wettabilty was measured using the droplet method where we named cosine of the 5 mm^3 droplet contact angle *wettability rate* in this research. There is a strong correlation between wettability rate and groove shape property from surface shape. Friction coefficient was measured using a self-made strain gage device. We selected twelve examinees and had them rub each sample with their forefinger; their rubbing velocity and pushing depth was not restricted so that examinees could move their fingers at will. We measured rubbing force concurrently with the evaluation of tactile texture. We calculated coefficient of dynamic friction from the rate between normal and tangential force. There were many ways of rubbing among individuals when evaluating tactile texture. Therefore, we grouped the examinees into three groups according to the size of coefficient. We conducted multivariate analysis, with each calculated coefficient of dynamic friction as the induced variable and the rates of convex area and the wettability rates as the independent variable, after normalizing each variable. All multiple linear formulas were meaningful within the confident interval of 85.0%.

Second, we extracted factors explaining tactile texture of human skin. We evaluated tactile texture by using semantic differential method for sensory evaluation experiment with eight evaluation items; smooth-roughness, coarse-fine, slippy-sticky, clammy-creamy, moist-dry, soft-hard, plump-slim and supple and sagging. Through factor analysis of the normalized values of the result, we extracted three potential factors of texture perception. We named each factors "Smoothness factor", "Moistness factor" and "Softness factor". Then, we calculated factor scores of human skin and each sample with the extracted factors.

Then, we conducted multivariate analysis whose induced variable is the similarity to the human skin and independent variables are the difference of the factor scores between each sample and human skin. The formula of material was considered meaningful within the confident interval of 95.0%. In addition, we calculated the correlation coefficients between the physical parameters and tactile factor scores of the samples. From the analysis results, we built a cognitive model of skin-like texture as shown in Figure 3. Figure 3 indicates that each evaluation value of surface shape influences wettability and friction property. We observed correlations between physical parameters of a surface and smoothness / moistness factors. Gathering these evaluation results, we can conclude that humans can recognize skin-like texture.

5 CONCLUSION

In this research, we developed artificial skin with human skin-like texture by emulating the surface shape pattern and elastic structure of human skin. We ascertained the relationship between its physical parameters and skin-like texture. In other words, we confirmed that the artificial skin can have the most similar texture to human skin when it is composed of multilayer rubber pieces with surface shape pattern convex width of approximately 0.6mm, groove depth of approximately 0.02mm and groove width of approximately 0.2mm. From the results, we will be able to develop artificial skin having optional skin-like texture in the future. It can be used to evaluate texture of products and to construct robot skin.

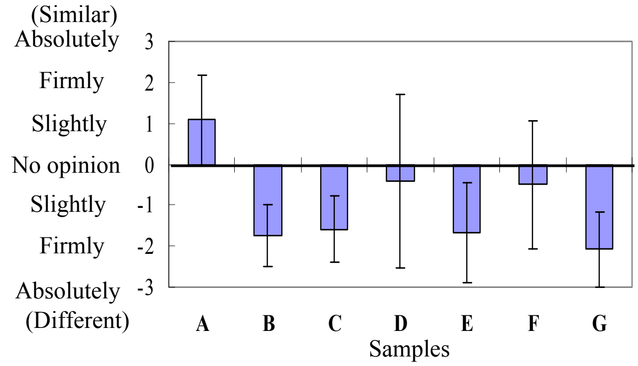

Figure 2: Similarity of each sample texture to skin texture of a human forearm

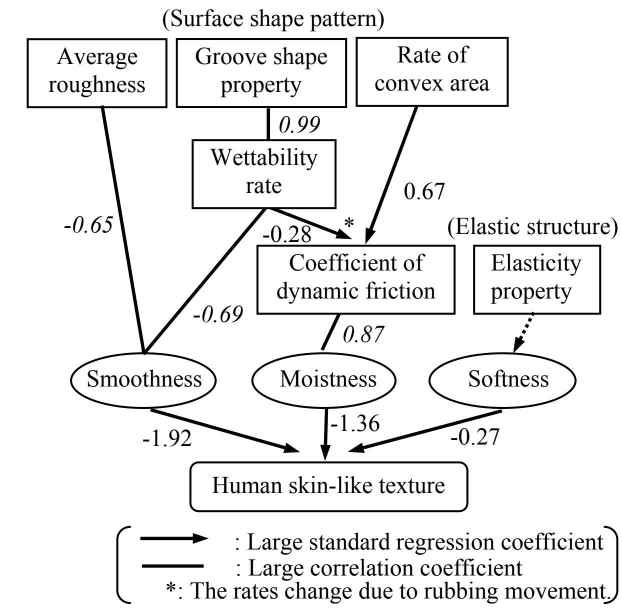

Figure 3. Cognitive model of skin-like texture

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