

Quantification of Stickiness Using a Pressure Distribution Sensor

Takayuki Kameoka, Akifumi Takahashi, YemVibol, Hiroyuki Kajimoto

Abstract — We developed and evaluated a device aiming at quantifying stickiness. A typical pressure distribution sensor can measure a pressing force but cannot measure a tensile force. We therefore installed a pin array on a sensor, with the pin array applying an offset pressure to the sensor through its weight. Furthermore, a subjective stickiness evaluation and measurement of the adhesive force were performed for an actual sample, and the correlation between evaluations and measurements was preliminarily investigated.

I. INTRODUCTION

There have been many studies on the presentation of the human skin sensation. In reproducing a realistic feeling, it is effective to measure the change in the skin condition in the real situation of tactile sensation according to, for example, the skin deformation distribution and contact area and to reproduce this information. Levesque et al. [1], for example, measured the horizontal displacement of finger skin tracing a glass surface in detail to capture how the skin deforms on an irregular shape. Bicchi et al. [2] captured changes in the skin contact area when a finger touches a flexible object. These measurements are closely related to the technique used in tactile presentation. The measurement of the horizontal displacement of skin is related to the development of devices that present horizontal displacement [3], and the measurement of the contact area has led to the development of a device that presents a flexible feeling by changing the contact area [4]

The present study focuses on the distribution of skin deformation when one feels stickiness. The sense of stickiness defined in this research refers to the adsorptive feeling when touching natto (which is a traditional Japanese food made from soybeans) or honey. The feeling of frictional resistance on the display surface is sometimes expressed as a sticky sensation [5], but we deal with stickiness that is related to vertical motion of the finger; i.e., that felt when one releases a finger after pressing that finger to a material. Such stickiness affects the impression of daily goods, such as lotion. Moreover, stickiness is known as one of the factors responsible for the wet feeling (i.e., wetness) in fabric perception [6] [7]. The application range of stickiness is thus considered large.

It is thought that both proprioceptive and cutaneous sensations contribute to stickiness, but here we mainly focus on cutaneous sensation.

Yamaoka et al. [8] observed the relationship between the contact area of an adhesive surface and the temporal change in the pressing force, and found that there is large hysteresis in the contact area. They created a stickiness display based on this finding. However, because the observation was limited to the change in contact area, the detailed force distribution during the period that the stickiness was felt remained unclear.

In a previous report, we described the basic principle of a system that measures the force distribution between adhesive substances and finger skin and preliminary experimental results [9]. In this paper, we present a measurement method having higher accuracy and a preliminary investigation of the correlation between the subjective evaluation of stickiness and measurement results.

II. MEASURING DEVICE

We first describe the equipment used in our previous report [9]. To measure the adhesive force as a pressure distribution, it is necessary to measure the negative pressure distribution when lifting the skin. However, general pressure distribution sensors measure only the positive force (in the pushing direction). Therefore, in the previous paper, we devised a method of inserting a pin matrix between the skin and pressure distribution sensor and applying a preload using the weight of the pins. The device is shown in Fig. 1 and comprises an acrylic pin insertion plate, spacers, a 10×10 stainless-steel pin array, and a pressure distribution sensor (I-SCAN100, Nitta Co., Ltd.). The pin insertion plate has a thickness of 1 mm, which is thin enough not to influence the measurement by friction. Pins are arranged one-to-one at sensing points of the pressure distribution sensor, and preload the sensor. Using this configuration, the adhesive force can be observed as the decrease in the offset force when the finger is raised.

The sensor elements and pins are spaced at intervals of 2.54 mm. Each pin is made of stainless steel and has a diameter of 2 mm, height of 30 mm, and weight of 0.8 g.

In the experiments of the previous report, time-dependent changes in the pressure distribution were measured by applying adhesive substances to the fingertips in advance, pressing the fingertips against the upper surface of the pin array installed on the pressure distribution sensor, and lifting the fingers vertically. Measurement made using this device, revealed that the tensile force generated strongly at the edge of the contact portion tends to move to the center as the finger is released, and fuse to one.

However, this device has few measurement points and only grasps the nature of the change in force, and it was not possible to measure details of the force change. In addition, since the force and speed of pushing and separating from the finger pad in the vertical direction are different from experiment to experiment, it was impossible to perform the measurement under the same condition and thus strictly compare different samples.

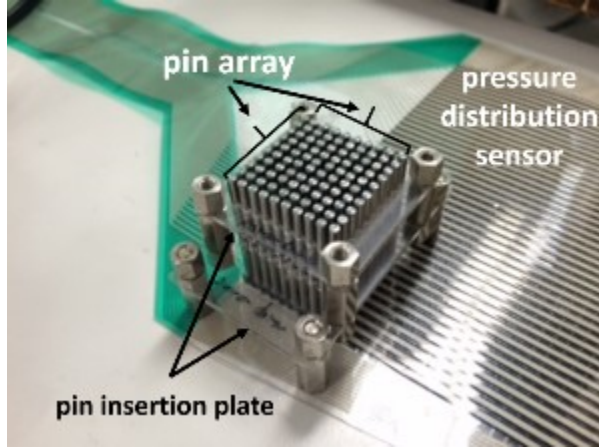


Fig. 1 Previous experimental apparatus (10 × 10 pin array) [9]

To overcome the problems described above, we created a new stickiness measurement device as follows.

For the new device, the number of measurement points was increased by changing the number of measurement points from the 10 × 10 pin array to a 20 × 20 pin array. Additionally, using a hemispherical artificial human skin gel (having a diameter of 5 cm, manufactured by BEAULUX Corporation) having elasticity equivalent to that of human skin as a contactor and a single-axis robot (T4L manufactured by YAMAHA), the forces of pressing and separation in the vertical direction are the same, making it possible to measure stickiness.

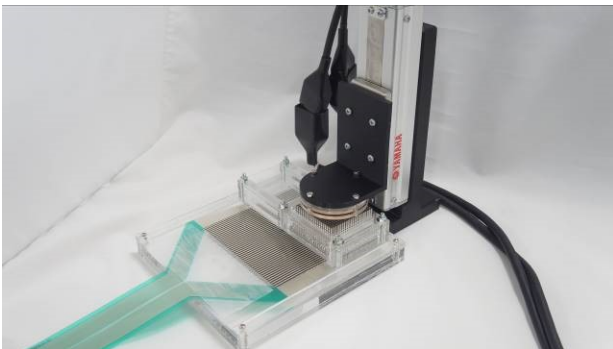


Fig. 2 Experimental apparatus (overall scene)

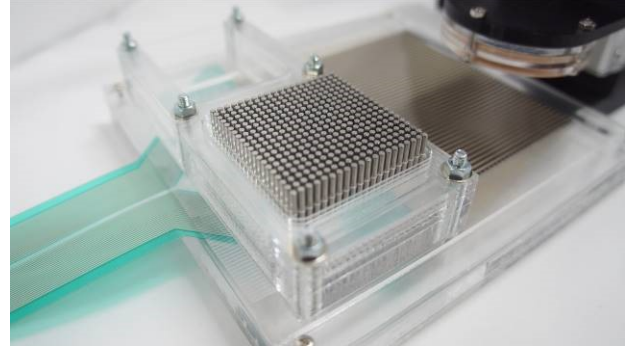


Fig. 3 Experimental equipment (20 × 20 pin array)

III. EXPERIMENT

3.1 Measurement experiment

Adhesive substances were uniformly applied to the upper part of the pin array beforehand, and the contactor was pushed against the upper surface of the pin array placed on the pressure distribution sensor. The temporal change in the pressure distribution was measured when pulling apart the contactor. A single-axis robot was used for pressing and separating, and the pushing distance of the contactor was set to 2 mm vertically downward from the state in contact with the pin array, while the pulling-off distance was set to 2 mm vertically upward from the state in contact with the pin array. The moving speed of the contactor was 1 mm/s. The measurement data were saved as a csv video file. Honey, toothpaste, shaving gel, and shampoo were prepared as adhesive substances. For measurement, sticky substance attached to contactor and pin arrays was removed each time.

3.1.1 Experimental Results and Discussion

From the measurement data obtained using the measuring device, it was possible to observe the temporal pressure change in each pin array. Fig. 4 and Fig. 5 show the measurement results when honey was used as a sample.

Fig. 4 is a three-dimensional graph of the experimental results, in which a depressed region expresses pressure in a vertically downward direction (i.e., a pushing force) while a green high region expresses pressure in a vertically upward direction (i.e., a tensile (adhesive) force). Fig. 5 shows a cross section of the three-dimensional graph of Fig. 4.

In the figures, only the pressing force is observed until 3.33 seconds, while the tensile force is observed after 4.00 seconds. In particular, referring to Fig. 5, two peaks are observed from 4.00 to 5.00 seconds, and it is seen that a strong adhesive force is generated at the edge of the contact surface.

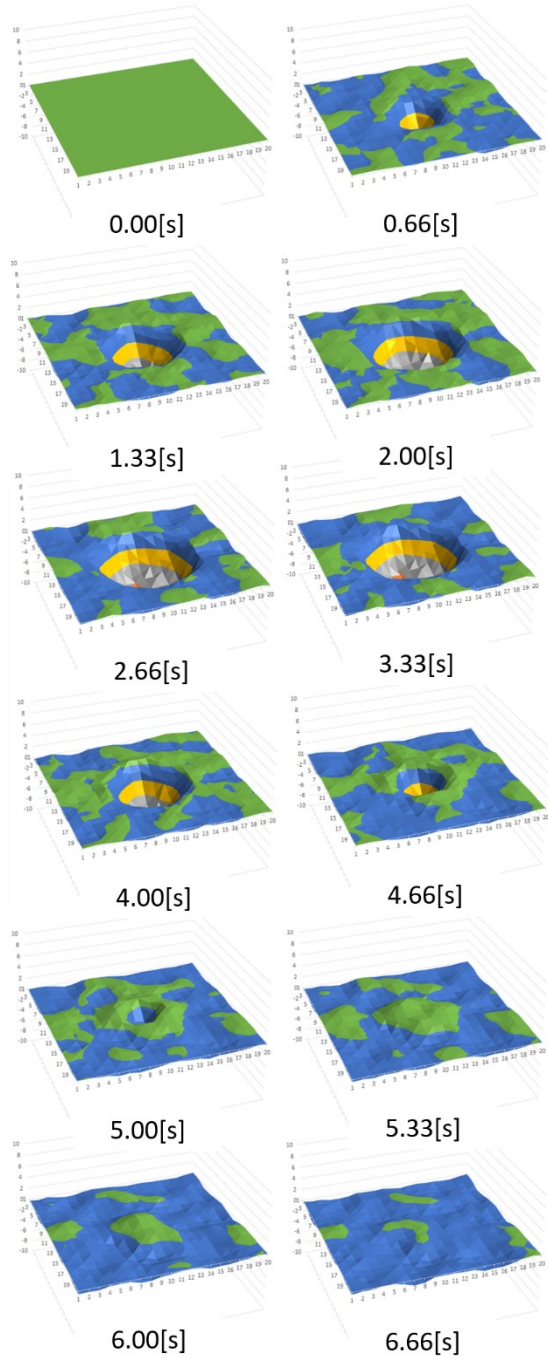


Fig. 4 Change in the pressure distribution for honey (three dimensions)

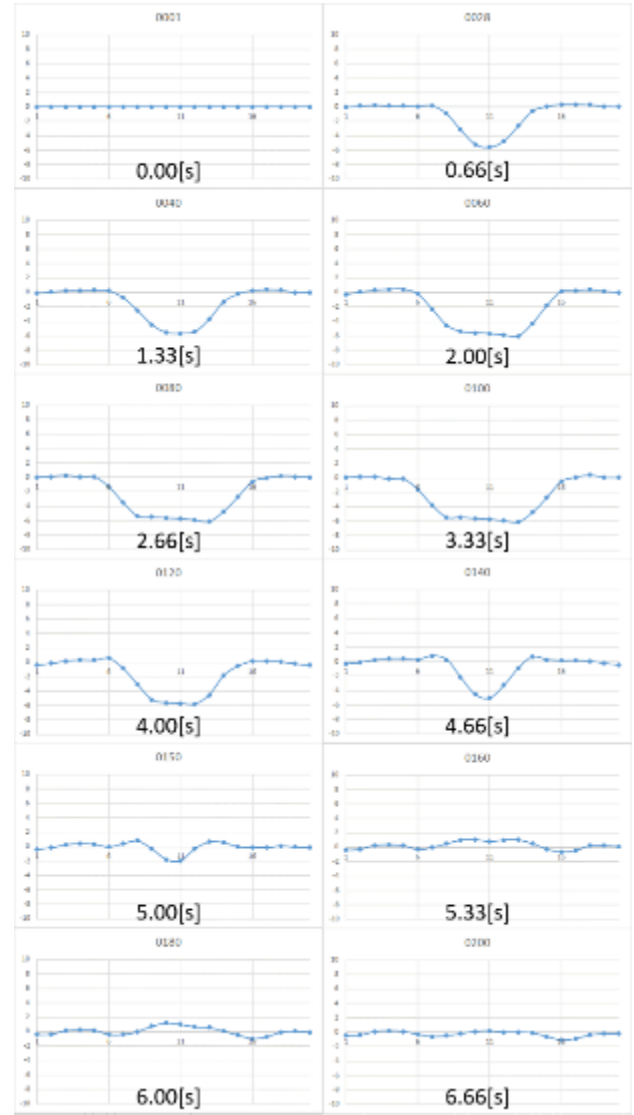


Fig. 5 Change in the pressure distribution for honey (two dimensions)

Features were extracted from the measurement data to compare with subsequent subjective evaluation. The parameters used were the peak value of the adhesive force, the maximum value of the area in which the adhesive force was generated, the maximum volume value of adhesive force, the change rate of the adhesive force area, and the change rate of the volume value of adhesive force.

The peak value of the adhesive force (f_p) is the highest pressure among the adhesive strengths observed at each sensing point. The area in which the adhesive force is generated is the area of the region in which the adhesive force is generated in Fig. 4 (shown as a green region).

$$S=na$$

(S : area of the adhesive force, n : number of points that detected adhesive force, a : one point area)

This calculation was performed for all times, and the maximum

area (S_p) was taken. Similarly, the volume value of the adhesive force was obtained by extracting values at the sensing points at which the adhesive force was observed, and summing the values. (Note that this is not a simple integral of the force distribution because we extract sensing points at which the adhesive force was observed beforehand.)

$$V = a \sum_{k=1}^n f_k$$

(V : volume value of the adhesive force, f_k : adhesive force at point k)

This was also done for all time and the maximum volume value (V_p) was taken. The rates of change of the area and volume value were obtained by taking the 10 points preceding the maximum values and making a linear approximation (v_s , v_v). In addition, the product of the peak value of the adhesive force and the maximum adhesive force was used as another compound feature.

$$f_p \times V_p$$

Fig. 6 shows the time change of the volume value of the adhesive force. The horizontal axis shows the measurement frame number. The contactor was pushed between frame 0 and 100, and it was raised from around frame 100. Note again that this measurement result is an integrated value at the measurement point where the force in the adhesive direction (the upward force of the contact surface) is detected, and it thus has a meaning different from that of the overall lifting force.

Figure 6 shows that the change in the volume value of the

adhesive force has a sharp maximum, and there is a possibility that we can use this parameter to subjectively judge stickiness. Additionally, there are differences in the slope leading to the maximum value in each graph. The slope is straight in the case of (a) honey whereas there are steps for other substances. Particularly remarkable is the case of (d) shampoo.

3.2 Subjective evaluation experiment

Ten participants (seven female, three male, aged 20–52 years) were recruited for the subjective evaluation. They were asked to evaluate the degree of stickiness of the sample by answering a questionnaire. Evaluation items were "sticky feeling", "length (duration of adhesive strength)", "softness" and "viscosity", which were scored on visual analog scales.

In this experiment, a 1-mm-thick dish was prepared so that the sample had a thickness of 1 mm, and the participants were instructed to touch the sample from above and to pull the sample up. The experimental scene is shown in Fig. 7. The results of the experiment are shown in Fig. 8. One-way analysis of variance confirmed a difference in averages of responses regarding the "sticky feeling", "length" and "viscosity" among the different substances (respectively $p=0.0026<0.01$, $p=0.000040<0.01$, $p=0.000041<0.01$), while there was no difference in the average of responses for "softness" ($p=0.81$). This suggests that it was difficult to evaluate softness.

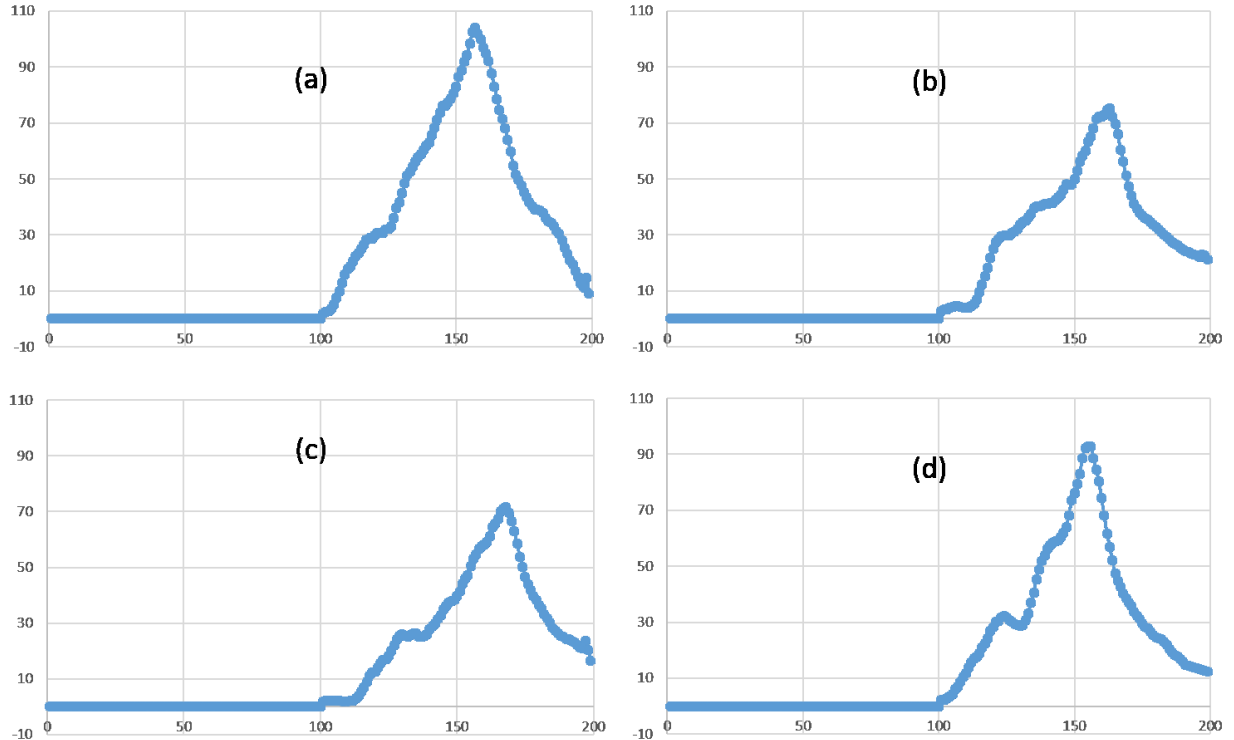


Fig. 6 Temporal change in the volume value of the adhesive force for (a) honey, (b) shaving gel, (c) toothpaste, and (d) shampoo



Fig. 7 Subjective evaluation experiment

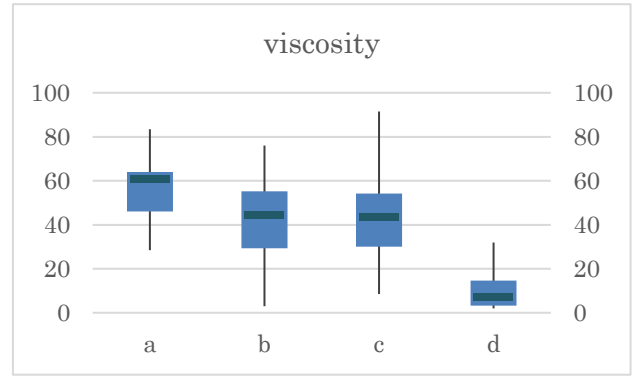
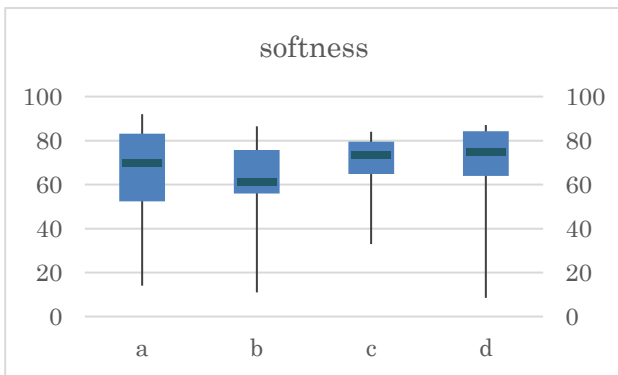
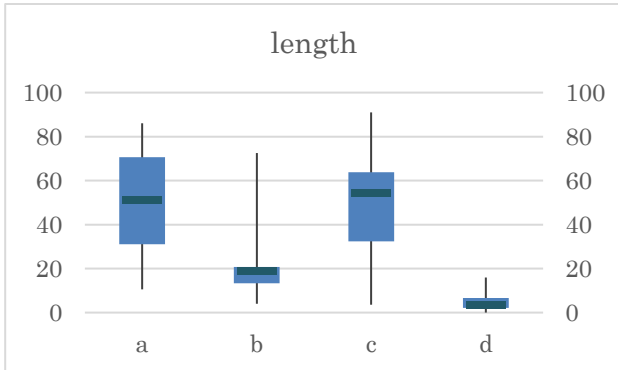
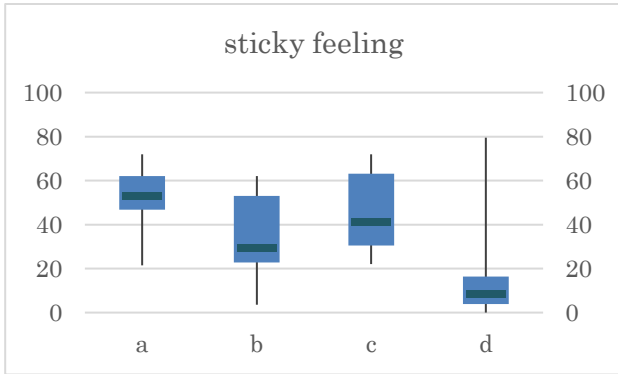


Fig. 8 Results of the subjective evaluation experiment
(a) honey, (b) shaving gel, (c) toothpaste, and (d) shampoo



3.3. Comparison of results obtained in the measurement experiment and subjective evaluation experiment

We observed the relation between the results of the measurement experiment obtained in section 3.1 and the results of the subjective evaluation obtained in section 3.2. We did not perform statistical analysis because there were few samples, and we only report results showing tendencies. Median values obtained in the participants' evaluation are used.

Fig. 9 shows the relationship between the rate of volume change and the subjective answer for "length". We instructed participants that "length" is the duration of the adhesive force when they lifted their fingers. The figure shows a monotonically increasing tendency. However, physically, the duration shortens as the rate of change increases. Therefore, when a participant judged the "length" of an adhesive substance, it seems that they did not necessarily determine the "length" by the duration of the adhesive force despite being instructed to do so.

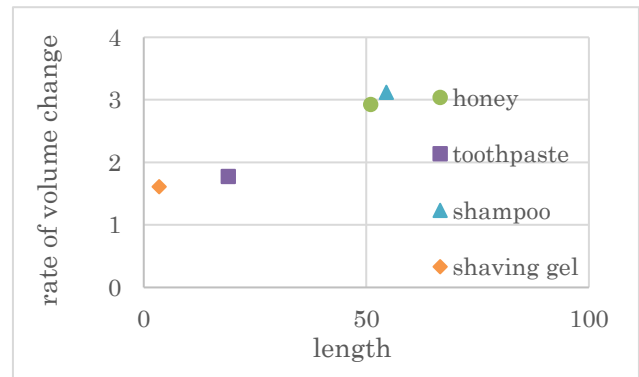


Fig. 9 Relationship between the rate of volume change and a subjective evaluation (length)

Fig. 10 shows the relationship between the peak value of the adhesive force and the maximum product of the volume value of adhesive force and the subjective evaluation of the "sticky feeling". The figure again shows a clear monotonically increasing tendency.

Such a clear relationship was not observed for only the peak value of the adhesive force or only the maximum volume value of adhesive force.

This result suggests the possibility that we evaluate a sticky feeling according to both the instantaneous strength of the adhesive force applied to a certain point of the contact surface and the overall adhesive force applied to the entire contact surface.

Regarding other subjective evaluation items, "viscosity" had almost the same tendency as "sticky feeling", while "softness" was not correlated with the features examined.

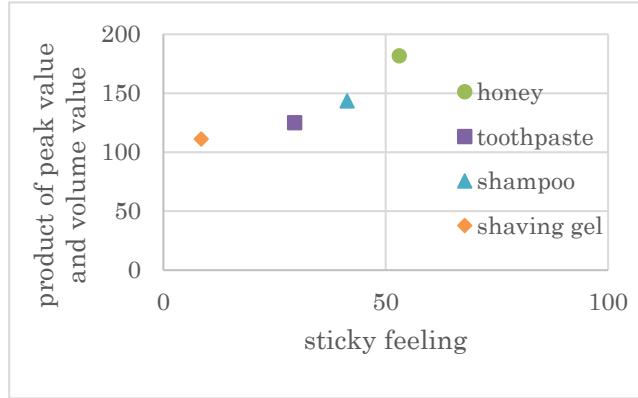


Fig. 10 Relationship between the product of the peak value and volume value of adhesion and a subjective evaluation (sticky feeling)

IV. CONCLUSION

We aimed to make a quantitative measurement of stickiness on the surface of an object, and observed the temporal change in the pressure distribution on the contact surface between an adhesive material and the fingertip. In addition, we examined the correlation between survey results of the subjective feeling and measurement data.

A pressure distribution sensor was used to observe the temporal change in the pressure distribution. A typical pressure distribution sensor can measure the pressing force but not the tensile force, and we thus proposed and implemented a method of measuring the tensile force by applying an offset pressure in advance to the sensor and measuring the difference.

We prepared several items for the subjective stickiness survey and investigated the correlation with feature quantities extracted from the measurement data. Results revealed that the subjective "length" tends to correlate with rate of change of the adhesive volume value, while a "sticky feeling" tends to correlate with the product of the peak value of the adhesive force of the adhesive

substance and the maximum volume value of adhesive force.

In this experiment, in the case of substances with high adhesive force, the pins may float, so we will construct a system that can apply stronger preload in the future. The experiment was conducted for four types of adhesive substances, namely honey, toothpaste, shaving gel, and shampoo. Because there are few data points for the analysis of correlation, we will use a variety of adhesive samples in future work. In addition, we will extract features not used in the present study and select the survey items of subjective stickiness, aiming to construct relational expression to quantify the stickiness. We will also develop a display for presenting stickiness based on the obtained findings.

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