Friction Evaluation System with a Human Finger Model

Keitaro Kuramitsu,[1] Toshio Nomura,[2] Shyuhei Nomura,[2] Takashi Maeno,[3] and Yoshimune Nonomura*[1]
[1]*Department of Biochemical Engineering, Graduate School of Science and Engineering, Yamagata University, 4-3-16 Jonan, Yonezawa, Yamagata 992-8510*
[2]*Trinity Lab Inc., 3-4-8 Daita, Setagaya-ku, Tokyo 155-0033*
[3]*Graduate School of System Design and Management, Keio University, Yokohama, Kanagawa 223-8526*

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Many industrial products such as automobiles, information appliances, cosmetics, and furniture are prepared from synthetic resin with attractive tactile texture. Information on the characteristics of their tactile impressions is useful in the design of these products. There are many reports on the effects of friction on our tactile sense[1–3] because tactile texture is caused by factors such as roughness, hardness, and friction.[4–6] Previous studies showed that the frictional properties vary with the surface structure of objects. For example, according to the Hertz contact theory, the area of real contact depends on the curvature, elastic modulus, and Poisson ratio.[7] Wang et al. reported that the friction on a rough surface is determined by the slope angle between the convex part of object's surface and the other substrate.[8] The authors developed an artificial skin having human-skin-like texture and confirmed the effects of surface shape.[9] These findings show that objects should be rubbed with contact probes that reflect the geometric properties of human skin to find the origin of their tactile texture. In this study, we developed a new evaluation system containing a polyurethane finger model that imitates real human fingers. The evaluation system containing the finger model is shown in Figure 1. As shown in Figures 1a and 1b, fine grooves were carved at regular intervals to mimic the geometry of fingerprints.[10] Two three-axis accelerometers were mounted in the finger model to detect vibration during sliding processes.

Here, the effects of the vertical force and sliding velocity on friction were examined when a polypropylene plate was rubbed against the finger model.[11] The plate was also rubbed with a probe having a flat contact surface to show the effect of fingerprints. When the polypropylene surface was rubbed with a contact probe, we observed three types of friction profiles. Their features are as follows.

(a) *Stick-slip pattern*: When the polypropylene surface was rubbed with a sliding velocity of 100 mm s^{-1} and a vertical force of 1.96 N, the frictional resistance changed periodically every several tens of milliseconds. Figure 2 shows the temporal changes in the frictional coefficient and the acceleration in the x and z directions. Just after the sliding began, the frictional coefficient increased to 0.49, and it changed periodically with fluctuations of 0.4 in magnitude and 50 Hz in frequency. With reciprocal sliding, the periodic change was attenuated in 0.3 s. The acceleration in the x direction also exhibited fluctuations

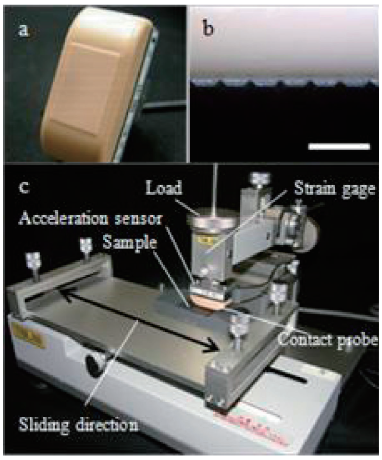

Figure 1. Images of friction evaluation system: (a) human finger model; (b) surface grooves, bar: 1 mm; (c) whole image.

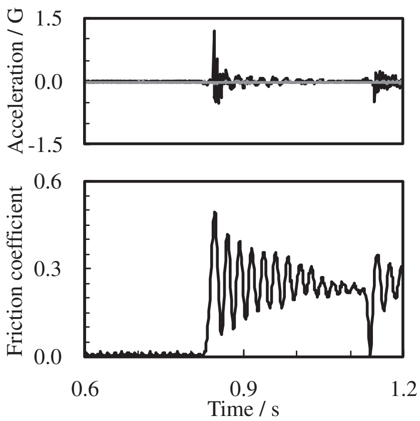

Figure 2. Friction pattern when the polypropylene surface was rubbed by probe: acceleration along the x axis (black), z axis (gray), friction coefficient.

with a magnitude of 1.6 G. These characteristic friction behaviors are caused by stick-slip phenomena at interfaces between the contact probe and polypropylene.

(b) *Stable pattern*: When the polypropylene surface was rubbed with a sliding velocity of 1 mm s^{-1} and a vertical force of 0.196 N, the frictional coefficient was almost constant, as shown in Figure S1.[13] The acceleration in the x and z directions was almost zero. These results indicate that the probe moved smoothly with approximately constant frictional resistance.

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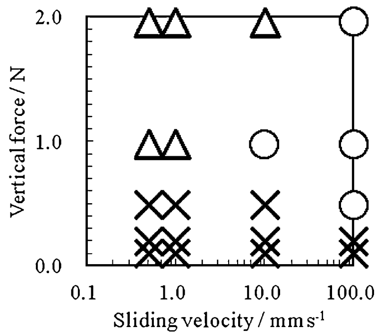

Figure 3. Effect of sliding velocity and vertical force on friction profile: stick-slip pattern (○), stable pattern (×), unstable pattern (△).

(c) *Unstable pattern*: When the polypropylene surface was rubbed with a sliding velocity of 1 mm s^{-1} and a vertical force of 0.98 N, the frictional coefficient changed irregularly. At 1.2 s after friction appeared, the friction coefficient reached 0.42 and then exhibited fluctuations with a magnitude of 0.30, as shown in Figure S2.[13] During the sliding process, acceleration in the x direction fluctuated by 0.40 G in magnitude. These results show that the probe accelerates because of disruption of the adhesion between the probe and the polypropylene surface when sliding begins.

The effects of the sliding velocity and vertical force were examined in order to clarify the factor governing the friction at the finger model surface (Figure 3). The stick-slip pattern was observed when the sliding velocity was the highest (100 mm s^{-1}) and the vertical force was more than 0.49 N and when the sliding velocity was 10 mm s^{-1} and the vertical force was 0.98 N. The stable pattern appeared when the vertical force was small, whereas the unstable pattern appeared when the vertical force was large. These results predict that the friction profiles are determined by the sliding velocity and vertical force. When we performed the experiment using a flat surface without grooves as a reference, the stick-slip pattern was not observed. Instead, the stable pattern was observed in almost all conditions: the unstable pattern appeared only at a vertical force of 1.96 N and sliding velocity of ≥10 mm s^{-1}. These results show that the mechanical stimuli change dramatically depending on whether rough structure exists on the human fingertip.

The stick-slip phenomenon on the skin surface is important because it can induce the characteristic tactile feel. In this study, we observed this friction pattern when the plate was rubbed with the contact probe under high sliding velocity and a large vertical force. When the vertical force is small, the contact probe can be moved smoothly because its deformation is vanishingly small. When the vertical force is large, the adhesion force between the contact probe and the polypropylene surface is large because the contact area is increased by the deformation of the probe. This large adhesive force can induce the stick-slip phenomenon. The stick-slip friction appears at suitable sliding velocity. We expect that the stick-slip phenomenon is inhibited when the plate is rubbed at extremely fast velocity. On the other hand, the stick-slip phenomenon was observed only when the plate was rubbed by the finger model with fine grooves on the contact surface. We guess that this stick-slip phenomenon is caused by a specific oscillation on the convex parts of the model surface. Scheibert et al. showed that the rough pattern of fingerprints enhanced frictional vibration with a specific frequency.[12] This enhancement system causes one of the mechanoreceptors, the Pacinian corpuscle, and supports the recognition of fine texture on solid surfaces. These results show that a friction system that mimics the geometric and mechanical conditions on the skin surface is important for understanding the physical origin of tactile texture.

In this study, we evaluated the friction between the polypropylene surface and the finger model and found that the friction profile depends on the vertical force, sliding velocity, and roughness of the model finger surface. These findings are important for understanding the governing factors and physical origins of tactile texture and design synthetic resin. This work was supported by a Grant-in-Aid for Scientific Research (C) (No. 22540417) from the Ministry of Education, Culture, Sports, Science and Technology, Japan (MEXT).

References and Notes

1 Y. Nonomura, T. Fujii, Y. Arashi, T. Miura, T. Maeno, K. Tashiro, Y. Kamikawa, R. Monchi, *Colloids Surf., B* **2009**, *69*, 264.
2 Y. Nonomura, Y. Arashi, T. Maeno, *Colloids Surf., B* **2009**, *73*, 80.
3 Y. Nonomura, T. Miura, T. Miyashita, Y. Asao, H. Shirado, Y. Makino, T. Maeno, *J. R. Soc., Interface* **2012**, *9*, 1216.
4 M. Hollins, S. Bensmaïa, K. Karlof, F. Young, *Percept. Psychophys.* **2000**, *62*, 1534.
5 T. Yoshioka, S. J. Bensamaïa, J. C. Craig, S. S. Hsiao, *Somatosens. Mot. Res.* **2007**, *24*, 53.
6 S. Okamoto, H. Nagano, Y. Yamada, *IEEE Trans. Haptics*, Preprint. doi:10.1109/TOH.2012.32.
7 B. N. J. Persson, *Sliding Friction*, Springer, Berlin, **1998**, Chap. 2.
8 L. G. Wang, X. P. Sun, Y. Huang, *J. Mater. Process. Technol.* **2007**, *187–188*, 631.
9 H. Shirado, Y. Nonomura, T. Maeno, *Trans. Jpn. Soc. Mech. Eng., Ser. C* **2007**, *73*, 541.
10 T. Maeno, K. Kobayashi, N. Yamazaki, *Trans. Jpn. Soc. Mech. Eng., Ser. C* **1997**, *63*, 881.
11 Friction measurements were conducted using a friction evaluation meter (Tribo Master TL201Ts, Trinity Lab Inc., Tokyo, Japan). The meter's specifications were as follows: measurement range: 0.098–19.6 N, vertical load: 0.098–4.9 N, sliding velocity: 0.1–100 mm s^{-1}, measurement distance: 1–100 mm, driving motor: AC servomotor. We evaluated the frictional force when a polypropylene plate 30 mm square and 0.75 mm thick was rubbed with a polyurethane contact probe that reflects the geometric properties of real human fingers. On the probe surface, 29 grooves 0.15 mm in depth were carved at intervals of 0.5 mm, as shown in Figures 1a and 1b. The hardness evaluated based on JIS K6253 was E30 ± 5. The friction conditions were as follows: width of sliding: 10 mm, sliding velocity: 0.5, 1, 10, and 100 mm s^{-1}, vertical force: 0.098, 0.196, 0.49, 0.98, and 1.96 N, sampling velocity: 1 (when sliding velocity was 100 mm s^{-1}), 10 (10 mm s^{-1}), 100 (1 mm s^{-1}), and 200 ms (0.5 mm s^{-1}). Here, width of sliding was the distance when the plate was rubbed at setting values: actual distance was longer than 10 mm because acceleration process for 0.1 s was set at start or returning point. Two three-axis low-g micromachined accelerometers (MMA7361LC, Freescale Semiconductor, Inc., Arizona, USA) were mounted in the contact probe to evaluate the acceleration on the probe.
12 J. Scheibert, S. Leurent, A. Prevost, G. Debrégeas, *Science* **2009**, *323*, 1503.
13 Supporting Information is available electronically on the CSJ-Journal Web site, http://www.csj.jp/journals/chem-lett/index.html.

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