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ScienceDirect
Journal of Bionic Engineering 11 (2014) 98–108

Artificial Sweat for Humanoid Finger

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Abstract

To achieve favorable Frictional Tactile Sensation (FTS) for robot and humanoid fingers, this report investigated the effects of human finger sweat on Friction Coefficient (FC) and verified the effectiveness of artificial sweat on FTS for a humanoid finger. The results show that the model sweat (salt and urea water faked real sweat) increases the FC of the real finger sliding on the high hygroscopic and rough surface (paper), whereas on the low hygroscopic and smooth surface (PMMA), the sweat forms a fluid film and decreases FC, restricting severe finger adhesion. Further, the film formation and capillary adhesion force of sweat were discussed. The experimental results with the artificial sweats (ethanol and water) and humanoid finger (silicone rubber skin with tactile sensors) verifies the effectiveness. The artificial sweat restricts severe adhesion (stick-slip vibration), and enhances cognitive capability of FTS.

Keywords: humanoid finger, artificial sweat, tactile sensation, adhesion, friction coefficient,

doi: 10.1016/S1672-6529(14)60024-X

Nomenclature

a	radius of a droplet on a solid plane surface
D_c	distance between solid surfaces (sweat film thickness)
F	raw data of finger friction force
$\bar{F}$	average of finger friction forces at the constant finger load force
f_c	Capillary Adhesion Force (CAF)
f_p	capillary pressure force
f_s	surface tension force
g	acceleration of gravity
h	film thickness (= $a \tan\theta_d$)
h_{min}	minimum film thickness (sweat)
i, k	integer variable for sigma
L	finger load force (normal force)
m	total count number of sampled-data at the constant finger load force
n	total count number of friction tests under individual conditions
Ra	calculated average roughness (JIS B 0601, 2001, in Japanese)
r_K	radius of meniscus curvature (equal to the Kelvin's radius)
r_w	radius in water-solid contact
S_f	contact area of a finger
S_w	water contact area of a finger
γ_L	surface tension of water
θ	equilibrium contact angle that the liquid makes with both solid surfaces
θ_d	droplet contact angle on a solid plane surface
σ	equivalent surface roughness
λ	the film parameter (= h / σ)
μ	Friction Coefficient (FC)
$\bar{\mu}$	average of friction coefficients at the constant finger load force
ρ	density of a droplet

1 Introduction

A simple question "Is artificial sweat in humanoid fingers useful for artificial tactile sensations?" motivated and led to the author's interests in this study on Frictional Tactile Sensation (FTS)[1,2] that is defined as tactile recognition or sensation given by frictional properties of contacting materials. Human sweat secreted from the hands and fingers consists of primarily water, salt (NaCl), urea (CH_4N_2O) *etc.*[3,4]. However, we do not know well how human sweat affects finger friction and tactile sensations, or how these individual compositions and concentrations of sweat affect finger friction.

Refs. [1,2] pointed out the difference between human and general robot fingers in shape and hardness. The shape and hardness of real fingers are individual and non-uniform, but most artificial products including

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robot fingers[5,6] are uniform. This is because we pursue simplicity and uniformity in manufacturing design and process for mass production and low costs. Refs. [1,2] investigated finger friction to elucidate functions of these complexities (or unpredictable complexity and ambiguity) and the effects of the non-uniform shape and hardness in a human finger. The experimental results show that individual non-uniformities change the Friction Coefficient (FC) with varying the apparent contact area of the human finger, *i.e.*, FC increases with the contact area. Ref. [7] concluded that the rougher paper induces lower FC than the smoother one, because of the smaller contact area. Further, Refs. [1,2] showed that the humanoid finger (slid on paper) due to faking the shape and hardness of the human finger, is able to reproduce frictional behavior of the human finger. Further, the humanoid finger could induce particular friction force signals (waveform, frequency, and amplitude) with different contact situation of the finger, *e.g.*, contact locations, sliding directions, contact materials, *etc.*), and generate individual FTS signals. Furthermore, the finger could detect the slight roughness difference between the front and back of a piece of paper, whereas on the smooth plastic surface (PMMA), the humanoid finger without sweat and fingerprint causes high FC and severe adhesion giving tactile noise and damages of the finger and sensors.

The friction of skin in the interface between skin and a contacting surface strongly depends on the presence of sweat, water and moisture[8,9,10–12,14–17] more than fingerprints[13]. The moisture of human fingerpad during object manipulation is modulated in such a way that the forces to grip an object are minimized[16]. The *in vivo* frictions of wet human skin[10,11] and fingers[1,2,8,9,12] against smooth and dry surfaces exhibit stick-slip phenomena. Further, enough sweat volume for a full fluid film reduces the phenomena and decreases FCs on smooth surfaces[11,12]. Furthermore, differences in contact area and occlusion time of the wet fingerpad associated with different finger frictions[14,15].

Refs. [1,2] proposed FTS for robot and humanoid fingers. Further, Refs. [8,9] introduced the artificial sweat (ethanol and water) of humanoid fingers for tactile sensations. They experimentally demonstrated that the artificial sweat could restrict stick-slip phenomena as well as the human sweat did.

This report aims to verify the effectiveness of artificial sweat for tactile sensations used in robot and humanoid fingers. First, the effect of the human sweat (using the model sweats) on FC of the human finger is evaluated. Second, the main factors (fluid film formation and Capillary Adhesion Force (CAF)) of human sweat are investigated. Third, artificial sweat for tactile sensations is studied. Finally, the effectiveness of the artificial sweat on FTS for the humanoid finger is verified.

2 Experiments

2.1 Experimental method

Table 1 shows test conditions to measure finger friction. The fingerpads and substrates before testing were cleaned with ethanol (KENEI Pharmaceutical, $C_2H_6O \geq 99.5$ vol%) to remove contaminants (*e.g.*, moisture, lipid material, used sweat samples, *etc.*). To repeat using the fingerpad after the test, the fingerpad surface was dehydrated with ethanol after exposing to the model or artificial sweats, which reduced hydration effects of the prior test. All frictional measurements with a normal finger used the same finger (forefinger of the right hand of the same person; gender male; age 45). The model or artificial sweats were injected onto the substrate before testing (Fig. 1). The human or humanoid fingerpad slid on the plane substrates (Poly(methyl methacrylate) (PMMA) and plain paper, Table 1). In triboelectric series[18], the property of acrylic resin, *i.e.* PMMA, is closer to that of plain paper. (The acrylic plate is not polyacrylonitrile as acrylic fibers) The close surface electric charges of these substrates may lead to a

Table 1 Conditions of finger friction tests

Atmosphere	298 K (25 ˚C), 60% RH
Finger	The human finger: male, age 45, surface temp. 303 K to 305 K The humanoid finger: SR (a)
Substrate	Acrylic plate (PMMA): thick 2 mm, *Ra* 0.01 μm Plain paper: thick 95 μm, *Ra* 2.38 μm, water absorptiveness 22 mm Klemm method (b).
Model sweat	NaCl and/or urea (CH_4N_2O) dissolved in water (c); sweat volume 0.03 mL, 0.06 mL (d); NaCl ≥ 99.5 wt%, $C_2H_6O \geq$ 99.5 vol%, $CH_4N_2O \geq 99.0$ wt%.99.5 vol%
Artificial sweat	0.03 mL and 0.06 mL ethanol (CH_4N_2O, 99.5 vol%) and/or water
Load force	Finger loading 0 to 0.29 N Filtering data at 0.15 N (15 gf) and 0.25 N (25 gf)
Sliding velocity and time	0 to 3 $cm \cdot s^{-1}$, 5 s (total sliding length ≈ 15 cm)
Sliding motion	Reciprocal sliding
Sensing and monitoring	Sensing load and friction force by strain gauges; monitoring by a PC

Note: (a) silicone rubber (hardness, Shore00); (b) ISO 8787, 1986; (c) ion-exchanged purified water; (d) the model sweats were used after adding salt and urea in water and stored 24 h.