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Measurement of sound, vibration and friction between soft materials under light loads☆

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ABSTRACT

Tactile perception of materials and surface texture involves friction under light normal loads and is fundamental to further advancing areas such as tactile sensing, haptic systems used in robotic gripping of sensitive objects, and characterization of products that range from fabrics to personal care products, such as lotions, on skin. This paper describes a new apparatus to measure friction simultaneously with dynamic quantities such as accelerations, forces, and sound pressures resulting from light sliding contact over a soft material, much like a finger lightly touching a soft material. The paper also introduces a novel friction and adhesion measurement method that can be particularly useful for soft materials and light normal loads.

1. Introduction

In recent years, haptic perception, one of the fundamental areas of cognitive engineering, has advanced with significant contributions from research in biology, engineering, and psychology. Although less well understood than audition and vision, the touch, or somatic sensation, continues to have an increasing significance in engineering and medical fields alike. For example, in the development of robotic grips or virtual reality hardware, tactile feedback is an essential element. In medicine, tactile sensitivity at fingertips is thought to have a role in diagnosis of and monitoring during rehabilitation for diabetes.

Haptic perception of materials and surfaces relies largely on touch, or tactile sensing, but also benefits from visual and auditory cues and, in some cases, from olfactory and even gustatory senses. Investigations have shown that visual or auditory cues can have a significant role in discriminating surface characteristics [viz., 1–4]. Studies on the role of multisensory integration of these signals on perception of surface finish or texture suggest that vision and touch act as independent sources [4] although in some cases vision can improve perception based on somatic sensation [5].

Multiple sensory inputs are utilized not only in judging or characterizing surface finish or its texture, as for fabrics and cosmetics, but also in identifying shape and weight of an object. In applications of haptic technologies to grasp and lift or to move very light-weight or fragile objects mechanically, tactile sensing has a primary role in the regulation of the applied power. In all such applications, there is a need to relate the physical characteristics of surface qualities and texture to somatic sensation and perception. However, the question remains open whether or not the subjective evaluations such as rough/smooth, sticky/slippery, and hard/soft can be identified reliably using objective measures. The extreme surface characteristics, of course, can be identified using a number of different methods. For surfaces with mixed or less pronounced physical characteristics, however, objective measures have not yet replaced human perceptions, and there continues to be a need to develop measurement techniques to emulate somatic sensation that also correlate well with perception.

The purpose of this paper is to describe a method to measure signals similar to the tactile signals that a finger senses when it lightly touches a soft surface while simultaneously capturing the air-borne acoustic signals generated due to the friction forces that develop between them. The method also includes a unique approach to measuring friction and adhesion between two surfaces that can pave the way to discern between each pair of the subjective qualities described above.

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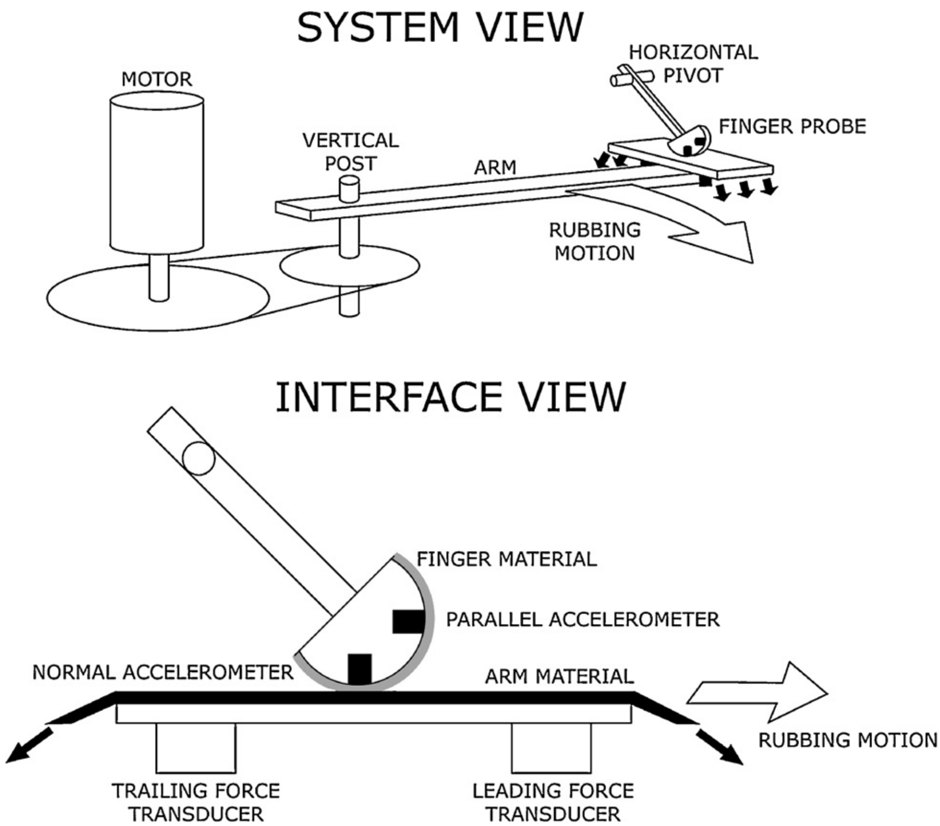

Fig. 1. Schematic description of apparatus to measure tribological and acoustic signals from friction between soft materials with the cross sectional view of contact between finger probe and arm during contact indicating the positions of accelerometers inside the finger probe and force transducers in the arm.

2. Contact parameters between soft surfaces and their measurement

The mechanical stimuli that form the basis of somatic sensory perception originate from contact forces that develop during the rubbing process, which contains information about smoothness, roughness, stickiness, slipperiness, hardness, and softness of the surfaces.

At room temperature, the physical parameters that are closely related to and influence subjective measures are the material properties, surface texture and shape, and adhesion between the surfaces. The sliding speed and contact pressure define the dynamic effects of these parameters. As a by-product of light rubbing, structure- and air-borne sounds provide additional signals that can be used in evaluating the surface characteristics and correlating the measurements with perception [6]. Effects of some of these material and texture properties can also be measured by mounting accelerometers on a finger to detect surface roughness and slipperiness.

Similarly, accelerometers placed on a probe can provide information regarding surface roughness/smoothness and even hardness/softness of a surface through the transient oscillatory response of the probe tip when they first come into contact as discussed below. For example, surfaces that are often described as sticky correlate with the tangential force [viz., 7–9], which on an otherwise smooth surface stems from adhesive forces that are known to be dissipative and, consequently, those described as smooth and silky produce a low tangential dissipative force. The magnitudes and time (or frequency) dependence of these signals influence the perception about a surface. In addition, third bodies such as lubricants between the surfaces also affect the magnitude of the tangential dissipative force [10].

The apparatus described in this paper can measure tribological and dynamical parameters that result from friction between soft materials under very light loads, such that they can be used to relate dynamical output to material and texture properties. The simple apparatus described here mimics very light passive touch of a finger over another surface. The device has the capability to measure air- and structure-borne acoustic signals as well as the tangential contact forces and normal loads during the contact process.

3. Test apparatus

3.1. Design criteria

The functional requirements on which the design criteria are based include: (i) a finger-like mechanism that can lightly touch a moving surface, (ii) signals generated during its operation largely result from the contact of the “finger probe” with a sample, with negligible contributions of ancillary signals from other sources, and (iii) the apparatus allows access to sensors and accessories for measurements during its operation. In addition to these functional requirements, further design rules were developed for ease of operation and measurements with the apparatus.

Like a finger, the probe should be able to retract from or press on a moving surface, with a desired normal contact load similar to a light touch that an actual finger can exert. As a finger does while probing a surface, the relative motion between the probe and sample should be steady, controlled, and preferably with constant velocity. Also, the device should enable easy change of materials on either surface in order to be able to test different material combinations.

Signals generated by a light contact are normally localized and can be detected by collocated sensors. However, they are often