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Texture design for light touch perception

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Abstract

This study focused on active light touch with predefined textures specially-designed for tactile perception. The counter-body material is stainless steel sheet. Three geometric structures (grid, crater and groove) were fabricated by pulsed laser surface texturing. A total number of twenty volunteers participated in the research which contains two parts: perception tests and skin friction measurements. The perception tests focused mainly on the participants' perceptual attributes: perceived roughness and perceived stickiness. For the skin friction measurements, a multi-axis force/torque transducer was used to measure the normal force and friction force between skin and counter-surface along with the fingertip position. The results of the predefined textures showed the ability to reduce skin friction due to the reduction of contact area. Moreover, the participants' perceptual attributes were greatly influenced by the predefined micro-structures in the light touch regime.

Keywords: Skin tribology; Skin friction; Surface texture; Light touch; Texture design

1. Introduction

Tactile perception of surfaces is an essential aspect of our daily life and has a profound importance for our well–being [7]. The introduction of haptic interfaces that rely on texture discrimination tasks might enhance this importance greatly. From the work of Jean-Louis Thonnard's group, the just noticeable difference (JND) threshold for roughness discrimination under moving conditions is discussed and perceptual dimension of roughness is highly prominent [13]. Other related studies on textural perception of deterministic surfaces are focusing on the perception of form, size, spatial period and spacing of the textures, as for example shown in [4,30]. Recently, experimental research was presented on the effect of the sliding direction and applied normal force of the finger [38]. As such, it is highly relevant to develop the knowledge for designing the surface textures that we like to touch [7], give pleasure [18] and that e.g. enables us to perform touch based control tasks in reliable way [21].

The human hand for example, is innervated by more than 600 nerve fibers per mm^2, [17] in [20], conveying cutaneous stimuli that are represented and processed in the spinal cord and brain to touch perceptions [37]. The main part of the nerve fibers consists of low threshold mechanoreceptive Aβ-fibers with sensory axon terminals, associated non-neuronal components and contacts between them and the surrounding cells of the skin [37,10]. The underlying principles that govern transduction at axon terminals in the skin have only recently been revealed and show

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that Merkel cells – a non-neuronal component – are essential in texture discrimination [19]. Future research on specific deletion of subclasses of cutaneous mechanoreceptors might clarify which functional assignment is to be associated with which specific parts of the cutaneous somatosensory system [20].

From a mechanistic point of view, the frictional interactions between the human skin and objects affect the tactile and haptic experiences with counter-surface. Based on the work of Derler, the new insights of surface topographical modifications of both skin (abraded) and counter-surfaces are analyzed due to friction [6]. One form of tactile perception that is of particular relevance, is the light [19] or gentle [37] regime of touch, which is essential for the discrimination of surface structures without skin abrading. Light touch perception of the hands and feet of most mammals is associated with sliding of the glabrous in contact with surface at a certain normal load [37]. The mechanism of light touch is characterized by dynamic skin deformations or static skin indentations in the micro- to nano- meter range [19] and typically involves normal loads between 0.1 N to 1.0 N with respect to the exploratory procedure for an human fingertip [5,9]. The required relevant detail of surface roughness for texture discrimination under light touch conditions, can only be reached in a deterministic way based on modern fabrication techniques, of which pulsed laser surface texturing [12,30] is selected in this work.

This research focusses on enhancing tactile perception in the sense of sliding regarding to the relationship between surface roughness and dynamic friction under light touch conditions. An experimental approach was adopted in this work based on two perspectives: 1) a panel test with a questionnaire that subjectively rates touch perception of roughness and of slipperiness, and 2) in vivo friction measurements and area roughness measurements as objective ratings of the touch system. The correlation of the two is expected to provide design principles that enhance tactile perception of the counter-surface.

2. Subjects and objects

2.1. Texture design

Besides the surface texture, tactile perception can be influenced by other perceptual stimuli such as the cold/warm and the hard/soft, rough/smooth and sticky/slippery dimensions [16,31]. To avoid cross over from these perceptual stimuli, all textures were fabricated on one material which is stainless steel EN-1.4301. The textural stimulus of hard/soft remains the same, because all samples were made from the same stainless steel sheet material. Also, the textural stimulus of warm/cold is considered constant, given the minimum amount of frictional heat that is produced during sliding at low velocity and at low normal load [32] and given the constant thermal properties of the interacting surfaces. As such, the perceptions including rough/smooth and sticky/slippery are two subjective dimensions which are expected to be modified by the texture design. The surface roughness has the ability of modifying the perceived roughness and perceived stickiness. Moreover, study shows that the friction force generated between metals and skin decreases when surface roughness increases [8].

Surface roughness parameter *Ra*, related to the center line average of the local surface heights, is a well-defined and frequently used parameter to evaluate the surface quality. Yet, line measurements conducted on deterministic surfaces are influenced by the length of the measurement and by the angle relative to the texture. The areal form of this parameter (*Sa*) is able to evaluate the surface quality with less dependence on the actual location at the surface see e.g. Wang et al. [34]. The surface roughness *Sa* of the texture designs can be calculated by Eq. (1).

$$S_a = \frac{1}{MN}\sum_{k=0}^{M-1}\sum_{l=0}^{N-1}\left[\left|Z\left(x_k, y_l\right)\right|\right] \tag{1}$$

where variable $z\left(x_k, y_l\right)$ denotes the vertical deviation of the surface at location $\left(x_k, y_l\right)$

The surface roughness *Sa* of these patterns are greater when the structures have proportionately deeper depth (refer to Fig 2a and b). However, to avoid negative influences like interlocking effects, the depth cannot be too large to reach a threshold level [29]. Since the criteria of texture design is focused on the surface roughness, therefore, the leading parameter is the depth (or height) based on the geometric shape of surface features. Three geometric shapes were designed, referred to as crater (concave), groove (concave) and grid (convex) structures with different parameters including width, depth and spacing (see Fig. 1a, b and c, respectively). These patterns can be fabricated by pulsed laser surface texturing with the purpose of changing the surface roughness in a deterministic manner [14,24,30]. For the crater structure, the overlapping spots need to be considered due to the fabrication process (refer to Fig. 2c).

2.2. Fabrication of textures

In this work, six textured and one non-textured samples of each dimension of 35 mm × 35 mm × 1 mm were used. The same stainless steel sheet material EN-1.4301 was used for all samples. Two grid structures (picosecond laser), two crater structures (nanosecond laser) and two groove structures (nanosecond laser) were fabricated by pulsed laser surface texturing (LST) (refer to Fig. 3) with different surface parameters. The power of the picosecond laser is 0.151 W with frequency of 250 kHz. The speed was set at 750 mm/s with 20 tracks. For the nanosecond laser, the power is 9.5 W with 41 kHz as frequency. The speed was 3280 mm/s with 10 tracks (refer to Fig. 3b). The surface parameters of the samples are listed in Table 1 and examined by SEM and confocal microscopy as shown in Fig. 4. In addition, one conventionally finished sample (2G finish) produced by cold rolling was conducted in the same experiments as a reference for comparison.