The role of vibrations in tactile perception

Marco Barbieri and Ramona Fagiani
Department of Engineering "Enzo Ferrari", University of Modena and Reggio Emilia, Italy

Summary. In the present paper, the role of vibrations in tactile perception is investigated. It is well established in the physiological literature that tactile perception of a rough surface occurs either by sensing pressure or by perceiving vibrations generated by the interaction of the rough surface and the fingerprints. A dynamical model of such interaction in the case of periodical rough surface is able to explain why largely spaced textures cannot be perceived by vibrations: for a coarse texture, the nonlinear response generated at the contact will contain a large number of superharmonic components which can mask the periodicity of the perceived surface. The proposed model is useful for a clear understanding of the mechanism of tactile perception, as well as for designing prostheses and haptic interfaces.

Introduction

Perception of a surface pattern is obtained thanks to a combination of the different senses that supplies the global information. For example, sight furnishes information on object localization and shape, while touch provides information about physical properties like texture and compliance. Tactile perception is allowed by the activity of the cutaneous sensory neurons located in the skin, joints and muscles. The aim of the present paper is to approach the haptic sense directly investigating the vibrations induced by finger/surface scanning, which are the direct cause of the tactile perception coded by the brain. When the hand moves to scan a surface, the interaction between the finger skin and the surface roughness produces a vibration that propagates into the skin causing a space time variation of the skin stress state that induces the response of the mechanoreceptors, allowing the brain to perceive information about object surfaces [1]. At the same time, contact pressure is perceived by mechanoreceptors.

In 2000, Hollins and Risner [2] showed by means of physiological experiments that tactile perception of rough surfaces occurs by sensing pressure if the spatial period of the perceived surface is larger than the period of the fingerprint, while it is mainly due to sensing vibrations when the spatial period is finer. This behavior is known as the duplex theory of tactile texture perception.

In 2014, Fagiani and Barbieri [3] developed a dynamic model for describing the tactile perception of a sinusoidal surface; the model was validated by comparisons with experiments present in the literature, see references [4] and [5]. More recently, the same authors developed a parametrical investigation to clarify the role of geometrical and load parameters on the tactile perception of a periodical rough surface [6].

In the present work, it will be shown that largely spaced rough patterns cannot be perceived by sensing vibrations, due to the nonlinear vibrations induced in the finger-surface contact.

Numerical model

In the present paper, the model proposed in Ref. [3] is considered: the equations are put in non dimensional formulation, and solved for different values of the dimensionless parameters. Vibration between a finger and a periodical rough surface sample is described as follows:

$$\frac{k}{L}\int_0^L \bar{\delta}(\mathrm{x},\mathrm{z},\mathrm{t})\,\mathrm{d}x = \mathrm{w} \tag{1}$$

where k is the equivalent contact stiffness, L is the contact length along the fingertip, w is the external load. Figure 1 proposes a graphical representation of eq. (1).

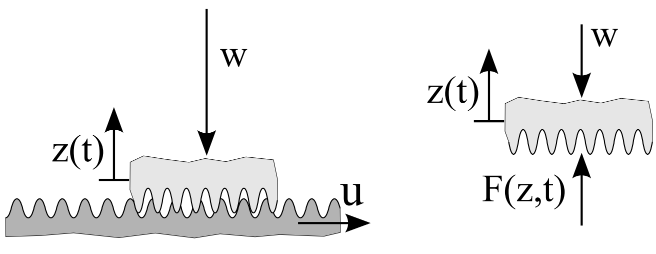
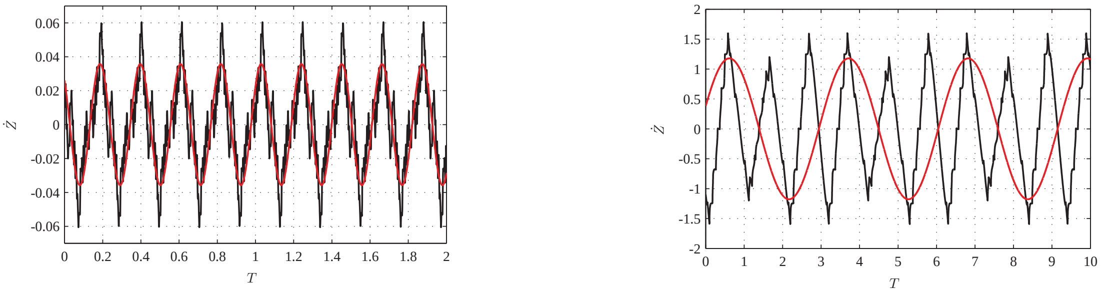


Figure 1: Quasi-static model of the contact with asperities, Ref. [3].

$\bar{\delta}$ is the punctual approach of the mating surfaces, in the no adhesion hypothesis; δ is the corresponding geometrical approach defined as in the following:

$$\bar{\delta}(x,z,t) = \begin{cases} \delta(x,z,t) & if \quad \delta(x,z,t) \geq 0 \\ 0 & otherwise \end{cases} \quad ; \quad \delta(x,z,t) = a_2\cos\left(\frac{2\pi(x-ut)}{\lambda_2}+\phi\right) - a_1\cos\left(\frac{2\pi x}{\lambda_1}\right) - z \tag{2}$$



(a) (b)

Figure 2: Case 1 ($\eta < 1$): (a) velocity (black curve), expected surface sample pattern (red curve); (b) Case 2 ($\eta > 1$): velocity (black curve), expected surface sample pattern (red curve).

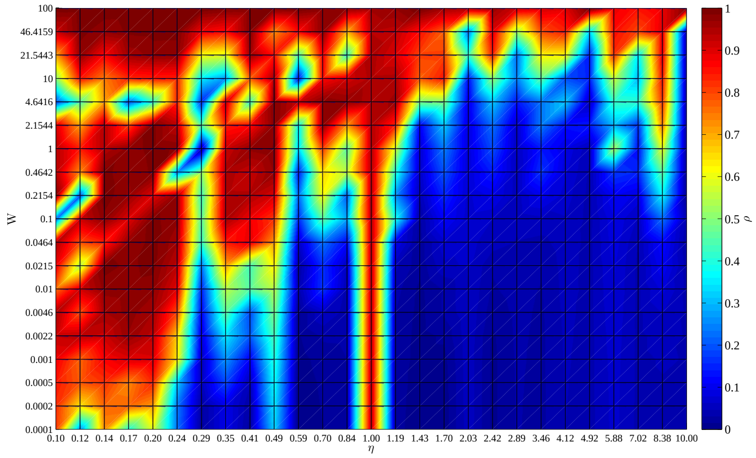


Figure 3: surface sample perception ratio ρ for varying η and W, and for $\psi = 3.162$ (linear scale contour)

where a_1, a_2 are the equivalent roughnesses of the finger and of the sample surface; λ_1, λ_2 are the spatial periods of the two surfaces; u is the relative sliding speed of the surface with respect to the finger; ϕ is a phase shift between the two sine profiles. The equivalent contact stiffness k in the Winkler approach is defined assuming hertzian contact between the ridges of the finger and those of the sample surface; this choice is discussed in Ref. [3].

Results and discussion

Thanks to the proposed model, the quality of perception of a sinusoidal surface can be evaluated. An index of perception ρ is defined as the maximum value of the normalized cross-correlations between the dimensionless vertical velocity of the fingertip $\dot{Z}$ and the surface shape. In fig. 2 a comparison between Case 1 ($\eta < 1$, η ratio of the spatial period of the surface over the spatial period of the fingerprint) and Case 2 ($\eta > 1$) is shown. This result points out that the periodic surface is perceivable by vibrations only if $\eta < 1$. An additional parametrical investigation (see fig. 3) shows that tactile perception of a periodic rough surface is optimal within a range of values of the dimensionless load W. This optimal range goes between 0.1 and 10, in accordance with experiments [4].

Conclusions

The proposed numerical model clarifies why periodical rough surfaces are not perceivable by vibrations if their spatial period is larger than the spatial period of the fingerprint. For reasonable values of the normal load, the vibration signal induced at the contact is largely dominated by superharmonic components at frequencies corresponding to the fingerprint spatial period, which hide the fundamental frequency of the touched surface.

References

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