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TACTUAL INTERFACES: THE HUMAN PERCEIVER

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Increasingly complex human-machine interactions, such as in teleoperation or in virtual environments, have necessitated the optimal use of the human tactual channel for information transfer. This need leads to a demand for a basic understanding of how the human tactual system works, so that the tactual interface between the human and the machine can receive the command signals from the human, as well as display the information to the human, in a manner that appears natural to the human. The tactual information consists of two components: (1) contact information which specifies the nature of direct contact with the object; (2) kinesthetic information which refers to the position and motion of the limbs. In this talk, we shall mostly be concerned with contact information.

A wide variety of tactile perceptions that we distinguish can be thought of as combinations of two classes of "primitives": mode of contact (static indentation, relative tangential motion or slip, and vibration) and object properties (surface microtexture, shape, and compliance). It is plausible that by understanding the peripheral and central processing involved in each pairwise combination among the primitive classes, the processing of more complex natural stimuli can be unravelled. Our knowledge of cutaneous information processing is mostly based on human psychophysics and electrophysiological recordings from monkey afferent fibers. These fibers are of four types: Two types of slowly adapting fibers (SA I and II) that are associated with Merkel cells and Ruffini endings, and are responsive both when an object in contact is moving against the skin as well as under steady indentations; Two types of rapidly adapting fibers which respond only when the skin is moving, one type (RAs) terminating in Meissner corpuscles, and the other (PCs) in Pacinian corpuscles. When a probe indenting the skin is vibrated, lowest response threshold amplitudes for SAs are at frequencies of 0-10 Hz, for RAs at 20-50 Hz, and for PCs at 100-300 Hz. Summarized below are some of the known results on the detection of slip and microtexture, shape, and compliance.

Humans cannot detect the slip of a smooth glass plate on the skin; existence of detectable features on the surface is necessary. However, surprisingly small features (for example, 2 microns high dot causes RAs to respond and 0.06 microns high grating causes PCs to respond) on smooth surfaces are detected by humans and lead to the detection of slip of these surfaces, with the geometry of the microfeatures governing the associated neural codes. The division of labor among the different types of fiber populations in signaling the different events on the skin is clear-cut: SAs signal the direction of skin stretch and hence the direction of impending slip; RAs and PCs signal the occurrence of slip with spatiotemporal or intensive codes, depending on whether the microfeature is a local one on a smooth background, or is distributed on the surface, respectively. When the surface features are of sizes greater than the response thresholds of all the receptors, redundant spatiotemporal and intensive information from all three afferent fiber types is available for the detection of slip.

Among the different possible geometric representations of the shape of objects, the intrinsic description, i.e., the surface curvature as a function of the distance along the surface, seems to be relevant for tactile sensing. Recordings of afferent responses to diverse shapes show that the depth of indentation and the change in curvature of the skin surface are represented in SA responses; in addition, the velocity and the rate of change in skin surface curvature are represented in both SA and RA responses. The primary reason for such neural encoding is the form of the spatial variation of the pressure imposed by the object on the skin surface: Pressure peaks occur where the depths of indentation and/or changes in the skin surface curvature are high. The skin effectively acts as a low-pass filter in transmitting the mechanical signals, and the mechanoreceptors respond to the blurred versions of the surface pressure distribution, thus encoding the shape of the object in terms of its surface curvatures.

Compliant objects can be of two types: (1) those with a rigid surface (such as a piano key); (2) those with a deformable surface (such as cheese). By conducting psychophysical experiments under both active and passive touch, with or without local anesthesia that blocked the contact information, the following conclusions were reached. Humans are very good at discriminating softness of objects with deformable surfaces, and the discrimination is based on contact information. For compliant objects with rigid surfaces, discrimination of compliance is reliable only under active touch, when both contact and kinesthetic information is available, and the discriminability is poorer than that for objects with deformable surfaces. Preliminary neurophysiological data show that mostly SA and to a lesser extent RA responses provide the basis for our ability to discriminate compliance.