

Chapter 2

Tactile Sensing: Definitions and Classification

Abstract The ‘sense of touch has been used as a layman term in Chap. 1. However, ‘sense of touch’ and ‘tactile sensing’ are not same. This chapter provides the definitions of various terms associated with the touch sense modality. Generally, the ‘sense of touch’ in robotics gets inspiration from humans. Thus, various terms associated with human sense of touch are presented first. Following this, the analogous terms for robotic applications are defined.

Keywords Sense of touch · Tactile sensing · Classification · Definitions · Extrinsic tactile sensing · Intrinsic tactile sensing · Cutaneous · Kinesthetic · Haptics · Perception

2.1 Definitions

The ‘sense of touch’ in humans comprises of two main submodalities—cutaneous and kinesthetic—characterized on the basis of their sensory inputs. Cutaneous sense receives sensory inputs from the receptors embedded in the skin and kinesthetic sense receives sensory inputs from the receptors within muscles, tendons and joints [1, 2]. It should be noted that the sensory inputs are not only mechanical stimulations but also heat, cooling and various stimuli that produce pain.

In context with the submodalities mentioned above, most researchers have distinguished among three sensory systems—cutaneous; kinesthetic and haptic. According to Loomis and Lederman [1, 3], cutaneous system involves physical contact with the stimuli and provides the awareness of the stimulation of the outer surface of body by means of receptors in the skin and associated somatosensory area of Central Nervous System CNS. The *kinesthetic system* provides information about the static and dynamic body postures (relative positioning of the head, torso, limbs and end effectors) on the basis of: (a) Afferent information originating from the muscles, joints and skin, and (b) Efference copy, which is the correlate of muscle efference available to the higher brain. It should be noted that the involvement of the afferent information from skin, in kinesthetic sensing, indicates its dependence on cutaneous sensing. The haptic system uses significant information about objects and events both from cutaneous and kinesthetic systems [1, 3].

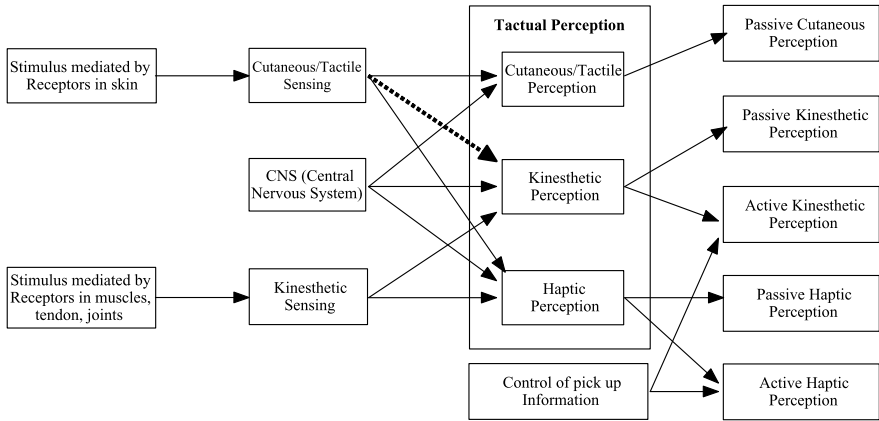


Fig. 2.1 The components of tactual perception. *Dotted line* represents the partial dependence of kinesthetic perception on stimulus mediated by receptors in the skin, or in other words, on cutaneous sense. (With permission from [10], ©IEEE [2010])

The perception of a stimulus can be categorized as cutaneous perception, kinesthetic perception and haptic perception—on the basis of three sensory systems discussed above. The perception of stimulus coming from cutaneous part is called cutaneous or tactile perception. In terms of Loomis and Lederman [1], the ‘tactile’ perception refers to the perception mediated solely by variations in cutaneous stimulation. Kinesthetic perception is mediated exclusively or nearly so (as kinesthetic sense partly depends on the cutaneous sense as well) by the variations in kinesthetic stimulation e.g. the perception of stimulus when cutaneous sensibility is disabled by anesthesia. Kinesthetic perception may include contact or lack thereof, between skin surface and external stimuli without providing any spatial or textural information e.g. discriminating length of objects—whether touched or not the perception of length comes from the kinesthetic part. All perceptions mediated by cutaneous sensibility and/or kinesthesia are referred as tactual perception. The haptic perception is the tactual perception in which both cutaneous and kinesthetic systems convey significant information.

Investigation of the properties of peripheral nervous system is done in two ways: first, in which observer is touched by moving objects and second, which involves the purposive exploration of objects by observer. Accordingly, the ‘sense of touch’ is classified as passive and active touch. Loomis and Lederman [1] made distinction between passive and active touch by adding the motor control inputs to the afferent information, as shown in Fig. 2.1. In everyday context, the touch is active as the sensory apparatus is present on the body structures that produce movements.

The above classification is suitable to define tactile sensing and associated terms for robotics applications. Most of the times, the robotic tactile sensing has been associated with detection and measurement of forces in a predetermined area. Jayawant [4] defined it as the continuous detection of forces in an array and further made a distinction between tactile sensing and force sensing, on the basis that the tactile

sensing involves force sensitive surfaces that are capable of generating continuous graded signals as well as parallel processing. Crowder [5] defined tactile sensing as detection and measurement of perpendicular forces in a predetermined area and subsequent interpretation of the spatial information. Following human sense of touch, this definition of tactile sensing is narrow for not including contact parameters other than perpendicular forces, and it is broad for including the ‘interpretation’ of spatial information—which is basically ‘perception’, that includes the role of both cutaneous sensing and the corresponding area of analysis in somatosensory cortex in CNS. The tactile or cutaneous sensing is associated with the detection and measurement of contact parameters which can be a mechanical stimulation (force, stress, roughness etc.), temperature, moistness etc. In this context, definition of tactile sensor by Lee [6] is more complete as the tactile sensor is defined as a device or system that can measure a given property of an object through contact in the world. As discussed later in the next chapter, the studies on cutaneous sensing has shown the presence of some coding or pre-processing of the stimulus information at the receptor level i.e. before transmitting the stimulus information to higher levels [7–9].

In view of these facts, tactile sensing is defined as the process of detecting and measuring a given property of a contact event in a predetermined area and subsequent pre-processing of the signals—before sending them to higher levels for perceptual interpretation [10]. On similar lines, touch sensing can be termed as tactile sensing at single contact point. These definitions of tactile and touch sensing, are used in this book. The analogous terms, for cutaneous and kinesthetic sensing, in robotics are termed as extrinsic (or external) and intrinsic (or internal) sensing respectively. In robotic applications, extrinsic or tactile sensing is achieved through tactile sensing arrays or a coordinated group of touch sensors.

At the system level, tactile sensing system can be said to be made of various components that lead to the perception of a contact event. For example, the extrinsic or tactile sensing and the computational processing unit in robots can be termed as extrinsic or tactile sensing system—analogue to the cutaneous sensing system in which each receptive field is associated with a specific area of analysis in the somatosensory cortex of CNS (Fig. 2.1). On similar arguments intrinsic sensing system and haptic system can also be defined for robotic applications.

2.2 Classification

A broad classification of robotic tactile sensing is given in Fig. 2.2. Based on the function or the task to be accomplished, the robotic tactile sensing may be grouped into two categories—first, ‘Perception for Action’ as in grasp control and dexterous manipulation and second, ‘Action for Perception’ as in object recognition, modeling and exploration. In addition to these two functional categories, a third category—not shown in Fig. 2.2—could be haptics, which involves action and reaction or in other words, two way transfer of touch information.

Based on the site where a sensor is located, the robotic touch sensing can be categorized as extrinsic and intrinsic sensing. While intrinsic sensors are placed within

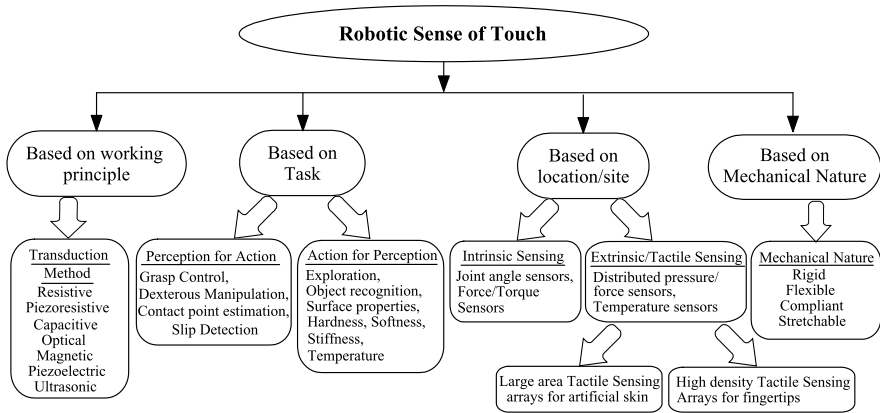


Fig. 2.2 The classification of touch sensing in robotics. (With permission from [10], ©IEEE [2010])

the mechanical structure of the system and derive the contact data like magnitude of force using force sensors; the extrinsic or tactile sensors/sensing arrays are mounted at or near the contact interface and deal with the data from localized regions. Like cutaneous sensing in humans, discussed in next chapter, the spatial resolution of touch sensors need not be uniform throughout the body/structure. As an example, in humans the spatial discrimination is finest in the fingertips, where the touch receptors are plentiful and the receptive fields are small. In other regions such as trunk, the spatial information is less precise because the receptors are fewer and thus have large receptive fields. Following this argument, the extrinsic or tactile sensing can be further categorized in two parts—first, for highly sensitive parts (e.g. fingertips) and second, for less sensitive parts (e.g. palm or large area skin). Whereas former requires a high density tactile sensing arrays or a large number of touch sensors in a small space (~ 1 mm spatial resolution) and fast response (of the order of few milliseconds); such constraints, especially one related to spatial resolution, can be relaxed for the latter.

Both, extrinsic/tactile and intrinsic sensing can also be classified—not shown in Fig. 2.2—on the basis of the working principle of sensors and on the basis of physical nature of the sensors. On the basis of working principle, tactile sensors can be resistive, capacitive, inductive, optical, magnetic, piezoelectric, ultrasonic, magneto-electric etc. On the basis of the mechanical nature, the sensors can be flexible, compliant, stiff and rigid etc. A detailed discussion on sensors, based on these classifications, is present in Chap. 5.

The discussion in this book is primarily focused on the extrinsic/tactile sensing. Hereafter, for simplicity, the term ‘tactile sensing’ is used for ‘extrinsic/tactile sensing’ in robotic applications.

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