Biology to Technology in Active Touch Sensing – Introduction to the Special Section

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1 Introduction

Recent years have seen increased study of the role of active touch sensing in animal behavior. Touch is an important means through which animals acquire information about their surroundings. The behavioral tasks enabled by active touch, and the goals that these tasks subserve, are extraordinarily diverse. They may range from locomotion (walking, climbing, and crawling), to foraging, feeding, grooming, and tool use. In most cases, these tasks would be impossible to complete without touch sensation. This notion should be familiar to anyone who has dismissed the possibility of eating after a visit to the dentist that included local anesthesia. The close interplay between movement and somatosensation is a distinctive hallmark of the haptic modality.

Our understanding of haptic perception has built on research that has unfolded over the course of a century. This pace stands in stark contrast to the rapid advances in robotic systems, engineering design, and control that have occurred over a much shorter time span, measured in years or, at most, decades. Even as the operational capabilities of such systems has expanded, it has become increasingly clear that touch sensing is indispensable for robotic systems that are required to function effectively in real-world environments. Many tactile sensing technologies have been developed during the last few decades [14], but the important role played by motor behavior in touch sensing is only beginning to receive wide attention in the robotics community. This has served as further motivation for the present special section on active touch sensing in humans, robots, and other animals.

Active touch sensing is recovering information about the world by "touching" rather than "being touched" [6]. There are differences of opinion, however, about the extent to which touching motions must be "purposeful" in order to qualify as active touch. While "passive touch" refers unambiguously to the activation of mechanoreceptors by an external force, the term "active touch" embeds both physiological and psychological components [4], [5], [6], [8], [9], [10]. The physiological component is the activation of mechanoreceptors via self–generated movement, while the psychological component is the intent of the movement: either to displace a limb to a different position in space (e.g., reaching or locomotion), or to acquire sensory information (e.g., when determining fabric texture or when manipulating a tool) [10]. For example, walking would not typically be used as an example of "active touch," but tapping one's foot against mud to sense compliance would be – even though these two behaviors might actively stimulate the foot in similar manners.

In engineering language, active touch refers to the idea of interpreting touch–elicited signals that are captured by sensors whose motion is deliberately controlled to facilitate information gain or to otherwise achieve behavioral goals that depend on it [3].

Thus, the term "active" is applied to suggest an essential role of motor behavior in eliciting or shaping sensory signals, at least when the movement is intended to capture information via touch. This can be contrasted with familiar situations such as stationary listening to an auditory scene, which might involve cognitive activity on the part of the listener, but which are otherwise largely independent of the movements of the listener. The movements involved in active sensing may be deliberate, or they may be reflexive, driven by hardwired behavioral patterns or activity controlled at earlier stages in neural processing. In an engineered system, the former might refer to a reactive algorithm for exploration that adapts motor behavior to what is felt in a continuous fashion, while the latter would suggest a pre–programmed strategy in which a touched surface is systematically probed in a way that elicits sensor signals that are to be interpreted at a later stage.

As such, in animals or robots, the behavior involved may depend to a greater or lesser degree on the sensory signals that are felt. This has led to some ambiguity, and some authors [3], [5] have preferred the term "active perception" as opposed to "active sensation." The former emphasizes that the process of controlling the sensor is indeed understood to capture sensory information that can refine integrated percepts or achieve related goals of the organism.

In animals, the process of active touch sensing can engage multiple body parts and employ highly evolved specializations of the sensory and motor systems. In humans, the

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distinctive capabilities of the hands and fingers are especially important for touch sensing, and we use them to explore the world in ways that are expressly adapted to extracting salient object features: following a contour to determine shape, sliding a finger against an object to gauge surface texture, and so forth [8]. Likewise, the sensory whiskers (vibrissae) that are present in nearly all mammals are somatosensory structures that actively probe their environment, either through head motions or muscles specifically used to move the vibrissae, moving in contact with objects or fluids in order to extract information through touch [1], [4], [7], [10]. These ideas have been influential in our understanding of haptic perception, and have also influenced thinking about active touch sensing in robots [13], [16].

Robotic systems that employ active touch sensing have been designed to utilize an array of different technologies [14], and have, in some cases, been modeled on specializations seen in biology, especially on the capabilities of human fingers (e.g., [2]), but also, more recently, on tactile sensing in other mammals (e.g., [16]). A large diversity of embodiments of robotic systems has been proposed in recent years. Larger still, however, is the range of potential approaches to tactile sensing that could be drawn from the many hundreds of thousands of biological species that utilize it. Consequently, one might conclude that the number of potential paradigms for robotic touch sensing that remain to be explored far exceeds those that have been studied until now.

2 Contents of the Special Section

The contents of the special section include six papers on topics addressing diverse challenges of active touch sensing in robots, humans, or other animals. Of these, two papers address tactile sensing in non-human animals, two papers concern tactile behavior for artificial human hands those of robots or of upper limb prostheses, one paper provides a comparative examination of three paradigms for active touch with biomimetic whiskers and fingertips, and one paper focuses on active touch sensing of surface texture in humans. Together, these papers highlight the breadth of research in the field, and the extent of cross-disciplinary inquiry that is frequently involved.

The first papers concern themselves with the great extent to which mechanical interactions affect touch interactions in animals. The mammalian vibrissal system has been an important and highly influential model system for research on the neuromechanics of active touch. In "Simulations of a Vibrissa Slipping along a Straight Edge and an Analysis of Frictional Effects during Whisking," Lucie A. Huet and Mitra J. Z. Hartmann investigate the effect of friction on whisker motion and what sensory information is available to the animal, when a rat palpates, or whisks, an object in its surroundings with its vibrissae. In "Biomimetic Active Touch with Fingertips and Whiskers" Nathan F. Lepora demonstrates that the same approach for biomimetic active touch applies to three distinct sensing technologies: tactile vibrissae and two types of tactile fingertip.

Although the vibrissal system has been intensively studied for over a century [11], [12], the tactile capabilities of the pectoral fish fin has been the subject of more recent attention. Using a robotic model of the pectoral fin, Jeffrey C. Kahn Jr. and James L. Tangorra in "The Effects of Fluidic Loading on Underwater Contact Sensing with Robotic Fins and Beams" demonstrate the important role played by fluidic loading in affecting the time course of strain in a rayed-fin appendage.

It has increasingly become apparent that in order to realize artificial hands capable of interacting with previously unknown objects, it is valuable for them to possess not only adequate motor abilities, but also sensory input. In "Neuromimetic Event-Based Detection for Closed-Loop Tactile Feedback Control of Upper Limb Prostheses," Luke Osborn, Rahul R. Kaliki, Alcimar B. Soares, and Nitish V. Thakor adopt a biomimetic approach to providing tactile feedback to a prosthetic hand. They employ a spiking representation of tactile information as input to a local control algorithm capable of performing compliant grasp or slip prevention during object grasping. In "Single-Grasp Object Classification and Feature Extraction with Simple Robot Hands and Tactile Sensors", Adam J. Spiers, Minas V. Liarokapis, Berk Calli, and Aaron M. Dollar address the problem of tactile sensing for a robotic hand using data acquired from tactile sensors during simple, un-planned grasps. Their system is able to process this data using machine learning algorithms or object property estimation algorithms in order to accurately classify the grasped object.

In human hands, as in robotic hands, what is felt when an object is touched can vary tremendously from trial to trial, and even given knowledge of the object parameters and pose, it is often difficult to relate the mechanical signals elicited by active touch sensing to the properties of the touched surface. In the last article "On Frictional Forces between the Finger and a Textured Surface during Active Touch," Marco Janko, Richard Primerano, and Yon Visell measured and characterized the frictional forces felt by a finger as it slides across a textured surface. They observed large trial to trial variations that eluded any simple explanation in terms of interaction parameters, and that made the task of designing a model that could predict these force signals prohibitively difficult.

This collection of papers on humans, animals, and robots reflects several key directions in current research on active touch sensing. Together, they highlight the diverse possibilities for the embodiments of active touch sensing systems, the environments in which they operate, the goals they subserve, and the multidisciplinary challenges posed by this field of research. We expect knowledge in this area to continue to grow, in part due to the fertile interactions between activities in biology, neuroscience, robotics, and haptics.

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