Better Manipulation with Human Inspired Tactile Sensing

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Introduction: Understanding what properties of the human hand can to be incorporated in robotic hands has been an active area of investigation for a long time. Good strides have been made in designing robotic hands and a number of working dexterous robotic hands have also been built [1, 2]. However, the use of touch sensory (both, cutaneous/tactile/extrinsic as well as kinesthetic/intrinsic) information for dexterous manipulation still lags the mechanical capability of such hands. This work presents how extrinsic touch sensing, the cutaneous/tactile analogous of human sense of touch in robotics, can help improving the manipulation capability of robotics hands. Some features of human cutaneous sense, namely, the role of skin biomechanics and skin microstructures, the spatio-temporal response, information coding and transfer are presented as they may help extending the usage of tactile sensing in robotic manipulation. If introduced, such features can help extending the intrinsic touch sensing and tendon driven based gross manipulation capability of present day robotic hands to precise manipulation. The discussion is followed by presenting the POSFET (Piezoelectric Oxide Semiconductor Field Effect Transistor) based tactile sensing arrays, inspired from cutaneous/tactile sense of touch in humans, for the fingertips of humanoid robot 'iCub' [3].

Tactile sensing for Manipulation by humans and robots: It is difficult to hold or safely manipulate real world objects without physically touching them. The sense of touch is of essence to any manipulative task. Robot's guidance and force based control has mainly depended on the kinaesthetic information from intrinsic tri-axial or 6D force sensors located close to wrist and on the actuation of tendon-driven fingers by motors located in the forearm. However, transmission dynamics such as friction, backlash, compliance, and inertia make it difficult to accurately sense and control endpoint positions and forces based on intrinsic sensors and actuator signals alone – which point towards the insufficiency of kinaesthetic information for manipulation in robotics [4]. Thus, there is need for augmenting the kinesthetic information with the tactile information. In humans, the impaired tactile sensibility makes manipulation difficult as brain lacks the information, about mechanical contact, needed to plan and control manipulation – which is centered on the mechanical events that mark transitions between consecutive action phases [5]. Signals from tactile afferents play decisive role during such transitions. As an example, various phases of a grasping action, namely reaching, loading, lifting, holding, replacing and unloading, are characterized as discrete sensory events by specific tactile afferent responses. The FA (fast adapting) receptors respond to transient stimulation - FAI responds at end of reaching and unloading phases and FAII responds at beginning of loading and unloading phases. Similarly, SA-I (slow adapting) and SA-II afferents respond when static forces are applied to the object. The activity of receptors during various phases of grasp gives an idea of contact timing, contact site, direction of contact forces and shape of contact zone. Brain uses such tactile afferent information when humans manipulate objects and similar information is needed by robots for manipulating objects. Measuring material properties such as hardness, temperature etc., in addition to the measurement of contact forces, with tactile sensors can also be useful for manipulating real world objects.

Human tactile sensing for better design of Tactile Sensors: Designing of a meaningful robotic tactile sensing system should be guided by a broad but integrated knowledge of how tactile information is encoded and transmitted at various stages of interaction via touch sensing. In this context, various studies on human tactile sensing provide a good starting point. Such studies are also important due to the lack of any rigorous robotic tactile sensing theory that can help in specifying important system parameters such as sensor density, resolution, location, and bandwidth etc. - which are also likely to be task or application dependent.

Human skin structure is quite complex with tactile information elaborated by different kind of mechanoreceptors - embedded in the skin at specific locations and depths and transducing signals with specific spatio-temporal characteristics [6]. Density of various receptors too varies with body site. As an example, FA-I receptors have higher density [5] than SA-I receptors on fingertips, thus, reflecting the importance of extracting spatial features of dynamic mechanical events and supporting the need for dynamic tactile sensors in robotics.

The mechanoreceptors are not just transducers. Both independently and as a group they also involve some local processing. Different firing rates of mechanoreceptors helps their independent coding of contact events. When considered as a group, the relative timing of their first spikes provides precise information about the shape of the contacted surface as well as the direction of the force exerted on the hand, and it does fast enough to account for the speed with which tactile signals are used in object manipulation tasks [5]. Such processing of data is useful as it helps optimum usage of the limited throughput of the nervous system. For robotics, these results not only underlie the importance of having tactile sensing arrays on robotic hand, but, also local processing of the data collected by them. Minimizing the data by way of local processing not only helps optimum usage of the limited computational resources of a robot, but also facilitates the speedy transfer of contact information for any control task.

The elasticity of skin varies with depth, which can influence the intensity of the tactile signal that the receptors receive. Further skin contains some ridge like patterns, comprising of papillary ridges or fingerprints, intermediate ridges and limiting ridges [7]. Both papillary ridges and intermediate ridges are believed to affect the response of various receptors in the skin to a different degree [7-9]. At their tips, intermediate ridges house the Merkel cell complex and hence they are believed to influence the response of SA-I receptors [8]. Similarly in addition of enabling better grip [10], the fingerprints or papillary ridges are also believed to enhance the tactile sensitivity of Pacinian Corpuscles and hence help feeling fine textures[9]. Mimicking complex human skin structure - with receptors embedded at specific depths and locations, performing different functions and responding optimally in

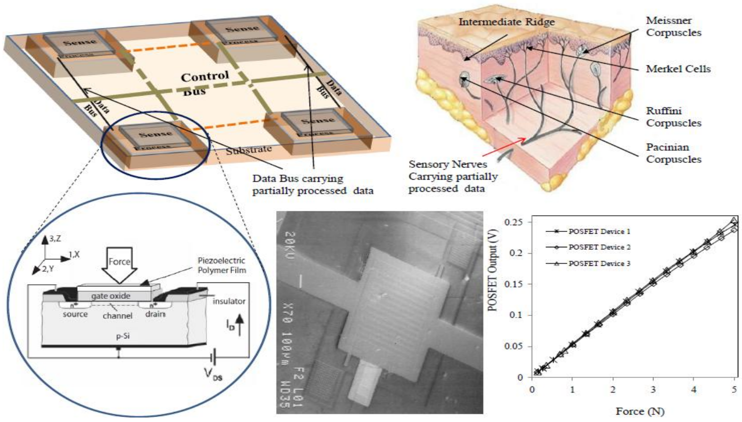

Fig. 1: Concept of POSFET Tactile Sensing array and the SEM picture of implemented POSFET tactile sensing device. Like mechanoreceptors in human skin, each POSFET device is capable of sensing and processing the touch information at same site. The output of POSFET touch sensing device is linear (with a slope of 50 mV/N) for tested range of normal forces (0.15-5 N)

different frequency ranges, is a challenging technological issue. Nonetheless, adding functional equivalent of a mechanoreceptor (e.g. Pacinian Corpuscles) to an ordinary tactile sensor, by using soft protective rubber cover patterned with fingerprint like microstructures can help in broadening the usage of tactile sensing and in bringing the level of tactile sensitivity and acuity, that human possess, to robotic devices.

Human Inspired POSFET Tactile Sensing Arrays: It is desirable to have tactile arrays or distributed tactile sensors with density and spatial distribution of taxels (tactile elements) varying with body site. For the sites like fingertips a large number of fast responding (of the order of few milliseconds) taxels are needed in a small space (~ 1 mm spatial resolution). Further, local processing and use of less number of wires are also desired. Keeping in view such facts, tactile sensing array using POSFET touch sensing devices have been developed. Designs of, both, POSFET devices and the array are inspired from cutanous sense in humans. Tactile sensing device is fabricated by spin coating a piezoelectric polymer (PVDF-TrFE) film on the gate area of MOS (Metal Oxide Semiconductor) devices. A force applied on piezoelectric polymer generates charge, which in turn modulates the charge in the induced channel - thereby converting force in to voltage. Contrary to conventional approaches - where transducers and conditioning electronics are separate entities connected through wires – each POSFET touch sensing element presents an integral unit comprising of transducer and transistor. As shown in Fig. 1, each POSFET element, as an integral "sensotronic" unit, is capable of 'sensing and partially processing' the touch signal at 'same site' – as is done by the receptors in human skin. Further, absence of any wire between transducer and the transistor can help solving the wiring complexity, which is one of the major issues hindering the wide usage of distributed tactile sensing. A system on chip or system in package with on-chip conditioning electronic circuitry and local processing will further improve the overall performance of POSFET tactile sensing arrays and utilization of the tactile data in a control task. To match the spatial resolution and acuity of human fingertips, the size of each touch element is 1 mm x 1 mm and the center to center distance between adjacent elements is 1 mm. POSFET elements have linear response up to 5 N and constant gain over tested frequency range of 2.13 KHz. In present format POSFET tactile sensing arrays use a plain thin rubber cover i.e. one without any microstructure like fingerprints or intermediate ridges. However, POSFET tactile sensing arrays in future will have the cover patterned with microstructures, as in human skin.

Conclusion: The ways in which biological sensory systems are structured and process information to control behavior may not always lead to the best engineering solutions for robots, nevertheless they provide useful insights into how behaving organisms respond to dynamically changing environments, and also provide a comprehensive multi-level conceptual framework within which to organize the overall task of designing the sensors for robotic systems. The approach may bring up new ideas that can help improving the level of tactile sensitivity and acuity of robots to the human range. With this premise, human inspired POSFET tactile sensing arrays have been developed and presented here. The POSFET tactile sensing arrays are good for dynamic contact events – like FA receptors in the skin. However, the structure can be modified to include other mode of transduction that is sensitive to static or quasistatic contact events.

References:

[1] G. Bekey, *Autonomous Robots: from Biological Inspiration to Implementation and Control*. Cambridge: MIT Press, 2005.
[2] Touch Bionics, "The i-LIMB Hand," http://www.touchbionics.com/, 2007.
[3] www.robotcub.org, "iCub," 2009.
[4] R. S. Dahiya, G. Metta, M. Valle, and G. Sandini, "Tactile Sensing: From Humans to Humanoids," *IEEE Transactions on Robotics*, 2009 *(in press)*.
[5] R. S. Johannson and J. R. Flanagan, "Coding and use of tactile signals from the fingertips in object manipulation tasks," *Nature Reviews Neuroscience*, vol. Advance Online Publication, pp. 1-15, 2009.
[6] K. O. Johnson, T. Yoshioka, and F. Vega-Bermudez, "Tactile functions of mechanoreceptive afferents innervating the hand," *J Clin Neurophysiol*, vol. 17, pp. 539-58, Nov 2000.
[7] G. J. Gerling and G. W. Thomas, "Fingerprint Lines may not directly affect SA-I mechanoreceptor response," *Somatosensory and Motor Research*, vol. 25, pp. 61-76, 2008.
[8] N. Cauna, "Nature and functions of the papillary ridges of the digital skin," *Anatomical Record*, vol. 119, pp. 449-468, 1954.
[9] J. Scheibert, S. Leurent, A. Prevost, and G. Debregeas, "The Role of Fingerprints in the Coding of Tactile Information Probed with a Biomimetic Sensor," *Science*, vol. 323, pp. 1503-1506, 2009.
[10] T. Maeno, K. Kobayashi, and N. Yamazaki, "Relationship between the Structure of Human Finger Tissue and the Location of Tactile Receptors," *Bulletin of JSME International Journal*, vol. 41, pp. 94-100, 1998.