Mechanical Engineering Doctoral Defense

Towards Haptic Intelligence for Artificial Hands: Development and Use of Deformable, Fluidic Tactile Sensors to Relate Action and Perception

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abstract

Human fingertips contain thousands of specialized mechanoreceptors that enable effortless physical interactions with the environment. Haptic perception capabilities enable grasp and manipulation in the absence of visual feedback, as when reaching into one's pocket or wrapping a belt around oneself. Unfortunately, state-of-the-art artificial tactile sensors and processing algorithms are no match for their biological counterparts. Tactile sensors must not only meet stringent practical specifications for everyday use, but their signals must be processed and interpreted within hundreds of milliseconds. Control of artificial manipulators, ranging from prosthetic hands to bomb defusal robots, requires a constant reliance on visual feedback that is not entirely practical. To address this, we conducted three studies aimed at advancing artificial haptic intelligence. First, we developed a novel, robust, microfluidic tactile sensor skin capable of measuring normal forces on flat or curved surfaces, such as a fingertip. The sensor consists of microchannels in an elastomer filled with a liquid metal alloy. The fluid serves as both electrical interconnects and tunable capacitive sensing units, and enables functionality despite substantial deformation. The second study investigated the use of a commercially-available, multimodal tactile sensor (BioTac sensor, SynTouch) to characterize edge orientation with respect to a body fixed reference frame, such as a fingertip. Trained on data from a robot testbed, a support vector regression (SVR) model was developed to relate haptic exploration actions to perception of edge orientation. The model performed comparably to humans for estimating edge orientation. Finally, the robot testbed was used to perceive small, finger-sized geometric features. The efficiency and accuracy of different haptic exploratory procedures and supervised learning models were assessed for estimating feature properties such as type (bump, pit), order of curvature (flat, conical, spherical), and size. This study highlights the importance of tactile sensing in situations where other modalities fail, such as when the finger itself blocks line of sight. Insights from this work could be used to advance tactile sensor technology and haptic intelligence for artificial manipulators that improve quality of life, such as prosthetic hands and wheelchair-mounted robotic hands.

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