Precise tool manipulation and positioning of a soft sensorised anthropomorphic hand through feedback control and machine learning

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Technical Abstract

Current robotic implementations are struggling to move away from the highly controllable industrial settings towards the more chaotic and unpredictable human environments. As society evolves, there seems to be an increased need for such robots which can achieve a range of different tasks. This is true in many fields including healthcare, agriculture, rescue and personal service robots. When comparing human capabilities to those of existing robots, there are many disparities. The capacity to adapt to new situations, agility, dexterity, and tactile sensing, are all superior for human beings. While robots excel in vision and auditory sensing, their tactile sensing is often reduced, limiting the scope of interactions with their environment. On the other hand, the human hand contains an extreme receptor density, particularly in fingertips, with over 17,000 tactile mechanoreceptors enabling fast feedback of contact forces, temperature and textures. By making robots more human-like, their capabilities to navigate and interact with human environments improves. This makes robotic manipulation an ongoing research area with increasingly diverse applications.

The goal of this project is to improve robotic manipulation capabilities by presenting a novel tactile sensing technology relying on barometric sensing. The proposed solution is a soft silicone skin containing air chambers which change in volume when the skin deforms under contact. The chambers are connected to barometric sensors which continuously measure their internal pressure and provide feedback to the controller. This skin is molded over a 3D printed anthropomorphic skeleton-like hand resulting in a low-cost and highly customisable solution.

Previous research has shown the potential of soft materials, often inspired from biological systems, for improved performance in noisy environments. Embedded compliancy enables a shift of complexity from the controller to the non-linear dynamics of the soft system. However, the issue with soft materials is the difficulty to integrate them with traditional hard sensors. Such sensors constrain surface materials resulting in poor soft properties (e.g. low friction and low deformation) and their use is often limited by interfaces issues with soft components. Although many tactile sensing implementation exist, no solution enables the high design freedom allowed by the proposed approach while maintaining fine sensing and good material properties.

Tasks requiring tactile feedback in robotic manipulation are hugely diverse so choices were made to limit the scope of this project. for this reason, this thesis focus on the problems of data interpretation for tool use. The use of tools demonstrates in-hand manipulation, exploration and dexterity for anthropomorphic hands. Moreover, for a robot to fully integrate in human environments it must be able to use tools designed for humans. Taking a specific example: using a screwdriver to screw a screw, it can be decomposed into a set of different problems. Understanding 3-axis contact modelling (i.e. how the sensors in the skin respond to contacts) is the first requirement. A solution to this problem is presented through the use of machine learning for data interpretation; the orientation of a contact can be predicted solely from tactile data. Results are presented for two topologies of neural networks. The second step in using a tool is remote sensing for exploration and feature detection. In the case of using a screwdriver, this would be finding the screw head and placing the screwdriver appropriately in the screw drive. To mimic this scenario, the classic robotic peg-in-hole assembly was implemented using a chopstick pinched between two fingers. This system is successfully able to search and detect a small (5mm) hole in a flat table before inserting the chopstick in it.

Such problems can be resolved thanks to careful sensor placement in the soft skin, allowed by a very configurable design. Sensors can be placed in closed proximity (2-4mm) to mimic the dense tactile inputs in human skin. The sensors characteristics also allow for very precise sensing. By mounting the hand on a UR5 robotic arm for repeatable testing, the sensors were characterised as being able to detect forces ranging from 23mN to 5700mN and having a bandwidth of 20Hz. These parameters exceed the typical requirements for exploration, grasping and dexterous manipulation.

In conclusion, this thesis reports the potential of a novel soft sensing approach through characterisation data and a remote sensing application using a tool. This opens directions for further research in the hope of enabling such technology to become readily accessible for any robotic system concerned with manipulation and tactile sensing.