Abstract of

Advanced teleoperation methods for multi-finger grippers with external sensors

by

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Robots with manipulators are increasingly used in search & rescue missions. Teleoperation is the primary way to use such robots, as the environment is unknown and dangerous, so missions highly benefit from cognitive abilities of robot operators, especially when grasping and manipulation is required. Well designed interfaces for teleoperation are essential as human errors are the primary cause of failure in search & rescue missions. The value of interfaces is even more significant when using multi-finger grippers, which offer greater dexterity than jaw-like grippers, but at the expense of a more challenging control for the operator.

In this thesis, various methods of improving the teleoperation pipeline for multi-finger grippers are investigated. In particular, we focus on the human factors, and how technologies derived from soft robotics and machine learning can support the operator.

Research topics were investigated by prototyping several new elements of the telemanipulation interfaces. The goal was to provide better intuitiveness, adjusted to particular needs of search & rescue robot operator and designed considering the guidelines originating from human-robot interaction field.

An in-house built Sensor Glove was used to create a mapping algorithm from human hand pose to a pose of a nonanthropomorphic robotic gripper. The glove uses flex sensors which are resistive sensors that have a high sensitivity to bending angle. Sensors are connected to a purpose-built circuit based on an ARM microcontroller, with WiFi or UART communication capability.

A large number of data was collected during experiments with several users wearing the Sensor Glove and grasping various physical or imaginary object using different grasp types. The data was used to create a classifier for grasp types. In the second experiment, users changed the pose of the gripper to match the pose of their hands at the specified grip. Using this data a regressor matching a glove sensor readouts to a pose of a gripper in a selected grasp was created. Finally, a mixing algorithm was proposed that used an estimated probability of pose being a specific grip type to mix mappings of different grasp types.

The use of the algorithm resulted in a smoothening of the behaviour of the gripper in cases where human hand pose could not be clearly classified as one or another grasp, as

well as allowed to use the degrees of freedom absent in the human hand (the rotation in the base of the fingers of the Schunk SDH-2 gripper).

Integrated vision systems were used to extend telemanipulation capabilities and provide a hand position tracking and gesture control. Two commercially available integrated vision systems – Leap Motion and Three Gears, were compared regarding their precision, ease of use and robustness. Leap Motion gave better overall results, but neither device provided robust enough results for finger pose tracking, mainly due to self-occlusion. However, despite the limitations, some methods have been proposed to support teleoperation: the well-behaving whole-hand position tracking capability provided by the integrated vision system can complement the hand pose tracking by the Sensor Glove, gesture recognition can be used to switch modes of operation. Moreover, in the case of a jaw-like gripper, a mockup gripper tracked by the vision system can be used.

A simple mechanomyographic probe was designed and constructed to augment teleoperation further. A data acquisition procedure was created, using a Python language program and the ROS system and several algorithms for operators' hand stiffness classify classification, were evaluated using the acquired data. Various data processing methods and machine learning algorithms were compared to provide a best classification accuracy and robustness. Using Wavelet Packet decomposition and convolutional neural network a precision of 94% was accomplished. Other simpler data processing schemes achieved precisions between 74% – 91%.

A soft robotic glove, based on jamming phenomena was created for providing the operator with kinesthetic feedback. Jamming phenomena occur when granular material or layers of material enclosed in an elastic membrane provide no resistance to external forces at normal pressure but stiffen and resist forces when a pressure in the elastic container is lowered. Properties of different filling materials were compared with layers of materials (layer jamming) having the highest change in stiffness with a pressure drop.

Two elements exploiting the jamming phenomena were proposed and their dynamic and static properties measured. Jamming tubes is a design where an elastic tube filled with a jammable material is placed on the inside of the hand and connected to a finger through an elastic harness. The tube moves freely with the finger but when an imitation of an object is needed then the pressure in the tube drops and the tube resists forces, which is perceived by the operator as a grasped object. A haptic device using these elements has been constructed, supplemented by a cutaneous interface and connected to a sensory glove.

A telemanipulation pipeline was designed using the Kuka KUBE robotic station and the developed elements. Schunk SDH-2 three finger robotic gripper tactile sensors was investigated for closing the telemanipulation feedback loop. Schunk SDH-2 gripper is equipped with a tactile sensor array on each finger. Sensor arrays were tested for repeatability, hysteresis and cell relative mismatch. We noted that arrays have high mismatch and hysteresis, which confirms the results obtained by other researchers. An equation mapping the readings of the tactile array to the external joint torques was derived, which allowed to create a joint space stiffness regulator for the gripper and to provide the operator with the haptic feedback. All elements were connected using Robot Operating System (ROS) to form a telemanipulation system containing: vision (tracking and gestural), mechanomyographic and flexion information as input coming from the operator and jamming based kinesthetic information and video feed as a feedback to the operator.

The proposed pipeline shows that the designed elements and algorithms can be used to control a multi-finger gripper effectively. New elements give the operator a natural way to control the gripper and provide him with haptic feedback. The glove-based interface is also considerably lighter and possibly less expensive than currently available devices, while the use of machine learning to create a mapping between the Sensor Glove readouts and a pose of multi-finger gripper could give the end-user much flexibility as properties of mapping can be easily modified.