Commanding the object orientation using dexterous manipulation

Abstract. This paper presents an approach to change the orientation of a grasped object using dexterous manipulation teleoperated in a very simple way with the commands introduced by an operator using a keyboard. The novelty of the approach lays on a shared control scheme, where the robotic hand uses the tactile and kinematic information to manipulate an unknown object, while the operator decides the direction of rotation of the object without caring about the relation between his commands and the actual hand movements. Experiments were conducted to evaluate the proposed approach with different objects, varying the initial grasp configuration and sequence of actions commanded by the operator.

1 Introduction

Teleoperation of robots is a challenging subject in applications in which an operator takes decisions and the robots perform actions following the commands of the operator. Some application fields where the teleoperation is relevant are: handling hazardous material, telesurgery, underwater vehicles, space robots, mobile robots, among others [1]. Object dexterous manipulation is a problem which is involved in this fields. A detailed discussion of the general problems related to teleoperation as well as a description of typical applications was presented in [2].

Autonomy of the robotic system in teleoperation has been addressed following different approaches. In some of them, the operator has the control of the movements and actions of the robot (a fully teleoperated system), but the control can also be shared between the operator and the robot [3]. Multiple examples of fully teleoperated systems have been introduced, most of them teleoperate robot arms and hands, which are commanded using input interfaces as trackers [4], wiimotes [5] for the arm, and gloves [4, 6], multi touch interfaces [7], or video based systems [5] for the hand; these approaches are oriented to solve the mapping between the human pose and movements, and those of the robot.

In the case of dexterous telemanipulation, the terminal element (gripper or robotic hand) can also be fully controlled by the operator or the control can be shared with the robot. In the first case, a mapping between the terminal element and the hand of the operator is required. Three mapping methods can be distinguished in the literature [8]: joint-to-joint mapping, which is applied to anthropomorphic hands [9]; pose mapping, which tries to find robot hand poses, which can be correlated with human hand poses[10]; and point-to-point mapping, which is the most used common approach, in the point-to-point mapping the fingertip positions of the human hand are mapped to the fingertip positions of robot hand [11]. However, in dexterous telemanipulation a natural approach is to share control of the object manipulation while giving the human operator direct access to remote tactile and force information at the slave fingertips [12]. In this work we use the shared control scheme, the operator commands the robotic hand to manipulate an object (perform the grasping and rotation), while the robotic system uses the tactile and kinematics information to control the forces and movements in order to avoid object falls. It must be remarked that the geometric model of the object is unknown.

The manipulation of unknown objects has been addressed using different strategies. A virtual object frame is used to change the pose of the object varying the triangular fingertip configuration of a three-fingered hand. A control law to manipulate the object also was introduced in [13], however the lack of sensorial feedback limits the accuracy of the method. A composite position-force control scheme was presented in [14]. The object relative position with respect to the hand is changed following an input trajectory; the control scheme is evaluated in simulations introducing noise on the sensor measurements to simulate a real environment, however other grasp aspects, as the initial grasp configuration or the stability of the grasp, are not addressed. In a previous work [15], the shape of an unknown object was recognized using tactile information obtained during the object manipulation.

The paper is arranged as following. After this introduction, Section 2 introduces the approach overview. Section 3 presents the dexterous manipulation details and the motion strategy to avoid object falls. Experimental results are described in Section 4. Finally, Section 5 presents the summary and future work.

2 Approach overview

Teleoperated dexterous manipulation is the main problem addressed in this work, the teleoperation is performed by an operator using an input interface like a keyboard, while the dexterous manipulation is executed by the hand following the inputs from the operator. The hand is fixed on a base over a table, but it can be in a robotic arm as well, this is not relevant for the proposed approach.The teleoperation of the robotic arm is out of the scope in this work. The manipulation task is focused on changing the object orientation (rotating the object) when this is grasped by the hand, thus the operator can command the hand to close, open, turn clockwise or counter clockwise when the object is grasped. The commands are sent using four keys of a keyboard. In this work we consider that the absolute position of the object in the space can be controlled by the arm, and therefore only the orientation will be controlled by the fingers of the hand.

The Schunk Dexterous Hand (SDH2) is the robotic hand used for the experimentation. This is a three finger hand (gripper) with seven active degrees of freedom (*dof*). The SDH2 has tactile sensors attached to the surface of the proximal links and the distal links, thus the tactile sensor system has six sensor pads. Two fingers of the hand are coupled and can be rotated on the base to work opposite to each other in the same plane (see Figure 1). Using the coupled

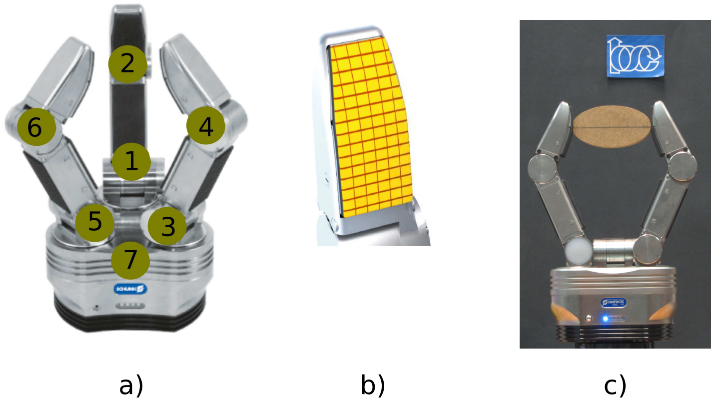


Fig. 1. a) Schunk Dexterous Hand (SDH2) with the joints labels. b) detail of the sensor pad showing the texels on the fingertip. c) Grasp configuration with two fingers working in a opposite way.

fingers it is possible to perform a prismatic precision grasp [16], which is comparable with a human grasp using the thumb and index fingers. Thus, the two coupled fingers of the SDH2 are rotated on their bases to work opposite to each other on the same plane, as it is shown in Fig. 1c.

The manipulation algorithm is described by the state machine shown in Fig. 2, we distinguish the following states with their associated actions:

$S_{\mathbf{init}}$. The hand is in the initial configuration, ready to perform a grasp.
$S_{\mathbf{close}}$. The fingers are closed until reaching a desired grasp force.
$S_{\mathbf{open}}$. The fingers are opened to release the grasped object.
$S_{\mathbf{grasp}}$. The object is grasped and the hand is waiting for a command.
$S_{\mathbf{turnC}}$. The next configuration for a clockwise rotation of the graped object is computed.
$S_{\mathbf{turnCC}}$. The next configuration for a counterclockwise rotation of the graped object is computed.
$S_{\mathbf{move}}$. The hand executes the next configuration rotating the object.

The state transitions are determined by:

Keyboard signals. These are four signals generated by the operator using a standard keyboard, each signal is simply generated by pressing a predetermined key. The signals command the four available actions during the teleoperation: close (K_c), open (K_o), rotate clockwise (K_{tc}) and rotate counterclockwise (K_{tcc}).

Force signal. The force signal is activated when $F_k > F_d$, where F_k is the grasp force in the k-th iteration and F_d is a desired maximum grasping force. This condition is reached when the hand has been closed and the object is in contact with the sensor pads.

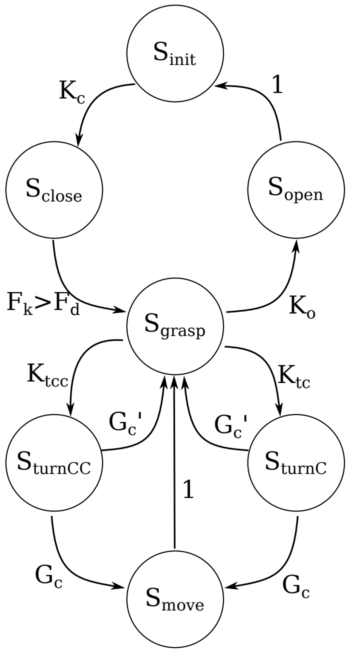


Fig. 2. State machine for the teleoperation approach.

Friction signals. The friction signal G_c is active when the friction constraints allows the grasp to firmly hold the object(these constraints are detailed in Section 3), and a signal $G\prime_c$ is active otherwise.

The state machine for the teleoperation starts in the state S_{init}, where the hand is waiting for the command K_c, to be introduced by the operator in order to close the fingers. When the command K_c is introduced, the system evolves to the state S_{close}. The system remains in the state S_{close} until the measured force on the sensor pads is greater than a desired grasp force, and the object is actually grasped. Once the grasp is done and the proper force is detected, the system evolves to state S_{grasp}. In the state S_{grasp} the system is waiting for the commands K_{tc}, K_{tcc} or K_o, in order to rotate clockwise, counterclockwise or to open the fingers to release the object, respectively. The finger movements to rotate the object are computed in the states S_{turnC} and S_{turnCC} depending on the direction of rotation indicated by the operator. In these states an autonomous dexterous manipulation algorithm is applied,

which is introduced in Section 3. If the friction constraints are satisfied, then the system evolves to the state S_{move} where the movement of the fingers is performed and then the system comes back to S_{grasp}. Else, there is not a possible movement and the system comes back to S_{grasp} without producing any movement.

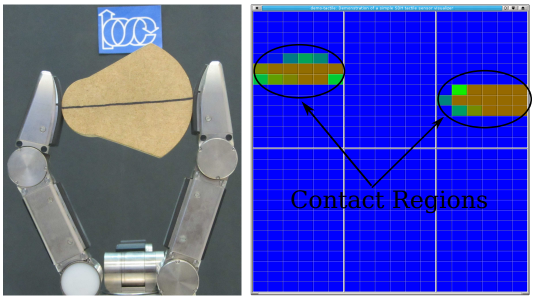


Fig. 3. Detected contact region on sensor pads when an object is grasped.

3 Dexterous manipulation

Consider a global reference system located at the base of the finger f_1, the initial grasp produces two contact points, namely P_1 on finger f_1 and P_2 on finger f_2. Usually the contact with the object produces a contact region, we consider the barycenter of this region as the contact point and the average force over all the region as the contact force, as is proposed in [17] (See Fig. 3). The absolute positions of P_1 and P_2 are computed using the sensor contact information and the hand kinematics.

Dexterous manipulation is based on a reactive control scheme, in which the current information of the contacts and the kinematic information of the hand are used as inputs. The reactive control action is applied to update the distance d_k between the contact points P_1 and P_2. The controlled distance d_{k+1} is a function of the measured force F_k, d_{k+1} is computed as,

$$d_{k+1} = d_k + \Delta d \tag{1}$$

with Δd being a function of the force measured by the tactile sensors according to the follow relationship,

$$\Delta d = \begin{cases} 0 & \text{if } F_{\min} < F_k < F_{\max} \\ +\lambda & \text{if } F_k \leq F_{\min} \\ -\lambda & \text{if } F_k \geq F_{\max} \end{cases}$$

where the constant values $F_{\min}, F_{\max}$ and λ are empirically determined based on the sensors response, and k denotes a manipulation iteration.

The distance d_k between contact points is given by,

$$d_k = \sqrt{(P_{x1_k} - P_{x2_k})^2 + (P_{z1_k} - P_{z2_k})^2} \tag{2}$$

The grasping force F_k is computed as the average of the both contact forces F_{1_k} and F_{2_k} measured, respectively, by the sensors of each fingertip,

$$F_k = \frac{F_{1_k} + F_{2_k}}{2} \tag{3}$$

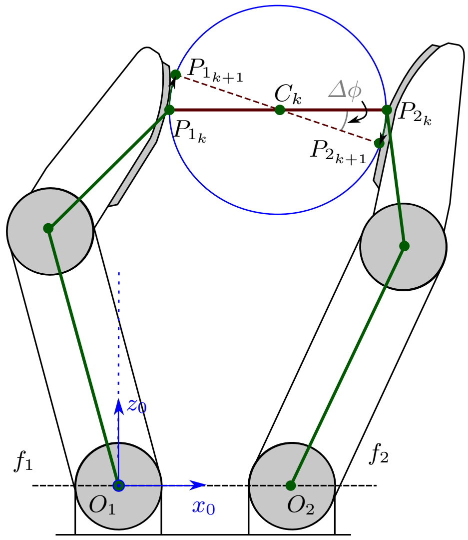


Fig. 4. Two-finger model used for the control of the object orientation.

In order to compute the expected position of the contact points, we consider the hypothesis that the fingers are moved over a circular path whose diameter is given by the controlled distance between contact points, d_{k+1}, as it is shown in Figure 4. Both fingers are moved to $P_{1_{k+1}}$ and $P_{2_{k+1}}$ at same time. Let's call ϕ the object orientation. The orientation resulting from the initial grasp is considered as the reference orientation (i.e. $\phi = 0$). The expected contact points $P_{1_{k+1}}$ and $P_{2_{k+1}}$, are computed as,

$$P_{x1_{k+1}} = C_{x_k} - (d_{k+1}/2)\cos(\phi + \Delta\phi) \tag{4}$$

$$P_{z1_{k+1}} = C_{z_k} - (d_{k+1}/2)\sin(\phi + \Delta\phi) \tag{5}$$

$$P_{x2_{k+1}} = C_{x_k} + (d_{k+1}/2)\cos(\phi + \Delta\phi) \tag{6}$$

$$P_{z2_{k+1}} = C_{z_k} + (d_{k+1}/2)\sin(\phi + \Delta\phi) \tag{7}$$

where $\Delta\phi$ is chosen positive to turn the object clockwise or negative to turn the object counterclockwise. $\Delta\phi$ is chosen small enough to assure small movements of the object on each manipulation step. The point C_k is the center of the circular path which is followed by the fingers, and it is given by,

$$C_{x_k} = \frac{P_{x2_k} - P_{x1_k}}{2} + P_{x1_k} \tag{8}$$

$$C_{z_k} = \frac{P_{z2_k} - P_{z1_k}}{2} + P_{z1_k} \tag{9}$$

In order to avoid sliding, each force applied on the object must be located within the friction cone centered at the direction normal to the sensor surface

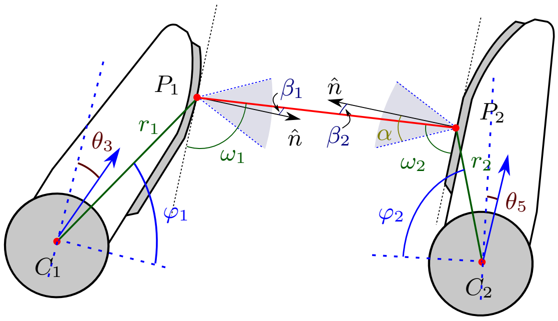


Fig. 5. Detail of the fingertips and angles considered to compute the friction constraints.

at the contact point. A planar grasp with two frictional contact points is force-closure when the segment connecting the contact points lies inside the friction cone at both contact points, as it is showed in Figure 5. The friction cone is given by $\alpha = \arctan \mu$, with μ being the friction coefficient, following the Coulomb friction model. Any applied force that belongs to the friction cone will not produce slippage, therefore the angle β_i $i = 1, 2$, between the normal direction at each contact point and the segment between the two contact points must satisfy $\beta_i < \alpha$. Then, the above condition can be expressed as,

$$\pi/2 - \alpha < \omega_i < \pi/2 + \alpha \tag{10}$$

where $\psi_i, i = 1, 2$ is computed for both contact points as,

$$\omega_1 = \arccos\left(\frac{-|C_1P_2|^2 + r_1^2 + |P_1P_2|^2}{2r_1|P_1P_2|}\right) - \theta_3 - \pi/2 + \varphi_1 \tag{11}$$

$$\omega_2 = \arccos\left(\frac{-|C_2P_1|^2 + r_2^2 + |P_1P_2|^2}{2r_2|P_1P_2|}\right) - \theta_5 - \pi/2 + \varphi_2 \tag{12}$$

The points C_1 and C_2, the distances r_1 and r_2, and the angles φ_1 and φ_2 are computed using the kinematics of the hand and the information of the contact point. A complete description of the hand kinematics for the SDH2 can be found in [18].

4 Experimental results

The described approach has been fully implemented using C++ for unknown object telemanipulation with the SDH2 hand. Figure 6 shows the set of objects used in the experimentation. Each object is held between the two coupled fingers of the SDH2, then the operator introduces the command, clicking the proper key in the keyboard, to close the fingers until the measured force reaches a desired value $F^d = 2$ N. Note that the initial contact points are unknown, i.e. the initial grasp configuration changes at each execution of the experiment. After this, the operator can manipulate the object, rotating it clockwise or counterclockwise by means of a simple teleoperation.

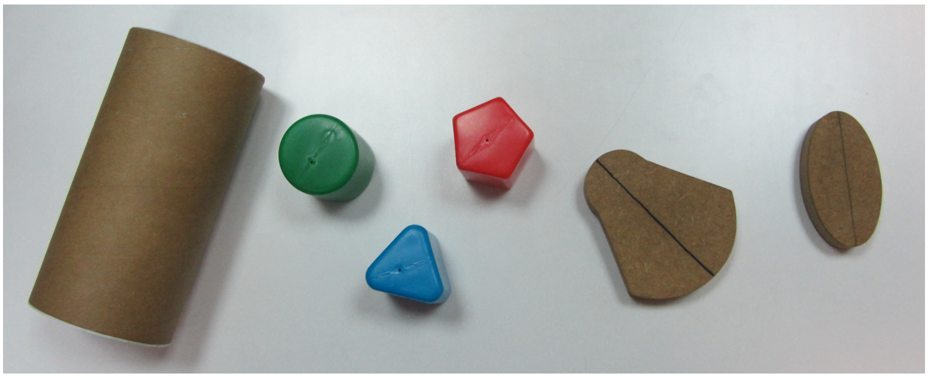


Fig. 6. Set of manipulated objects.

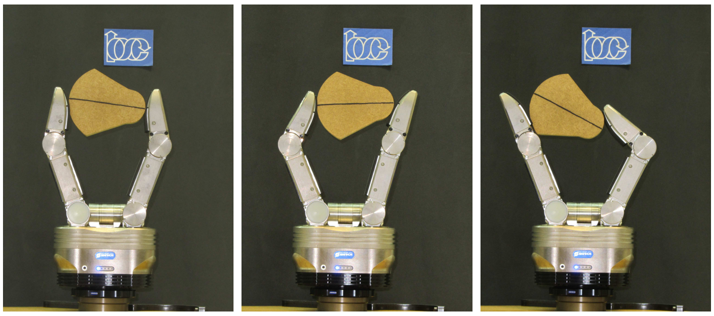
The material of the sensor pads is rubber and the material of the objects is wood, cardboard or plastic, thus we consider a worst case friction coefficient $\mu = 0.4$, which is lower than the friction coefficient between rubber and wood $\mu = 0.7$, and rubber and cardboard $\mu = 0.5$ [19], the friction coefficient between rubber and plastic is greater than the aforementioned. The constant λ to adjust the distance d_k is set to 1 mm.

Fig. 7 and Fig. 8 show snapshots of the telemanipulation process, the left snaps show the initial configuration of each object, the center snaps show the configuration when the limit of rotation is reached in counterclockwise direction and the right snaps show the configuration when the same limit is reached in clockwise direction.

5 Summary and Future work

This work has proposed a telemanipulation method to rotate unknown objects based on tactile information and force feedback autonomously managed by the system. The telemanipulation allows to change the orientation of the object according to the commands introduced by an operator using a keyboard. The experimental results showed that the approach is effective to manipulate different objects.

An extension of the implemented work is to consider the use of three fingers in the manipulation process, which would allow to consider other motion strategies.



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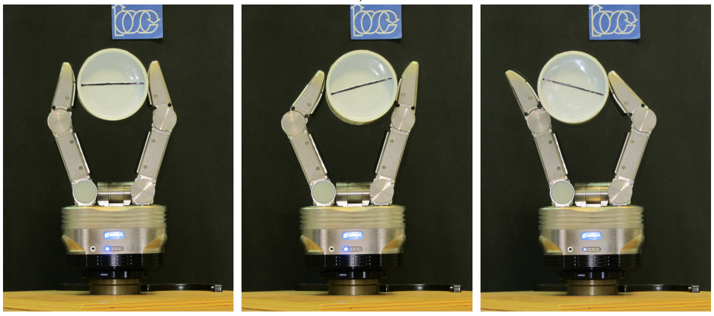

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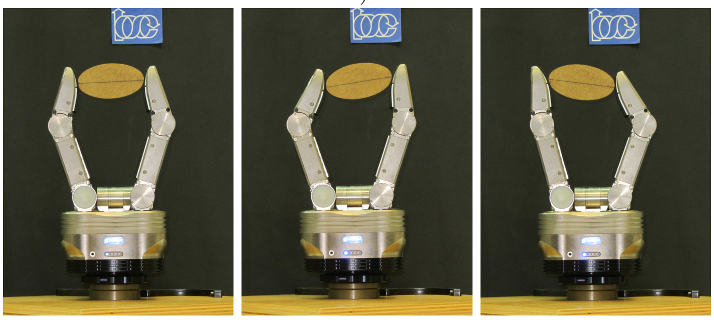

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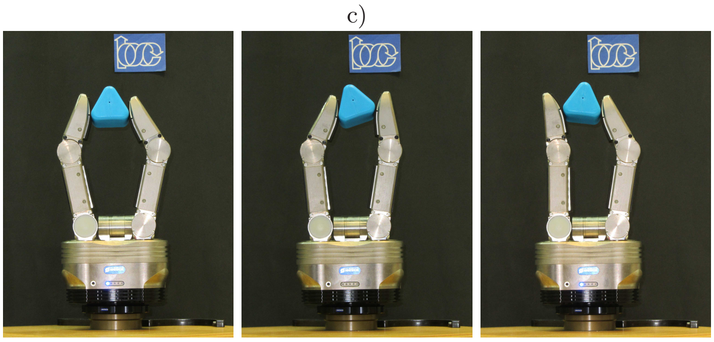

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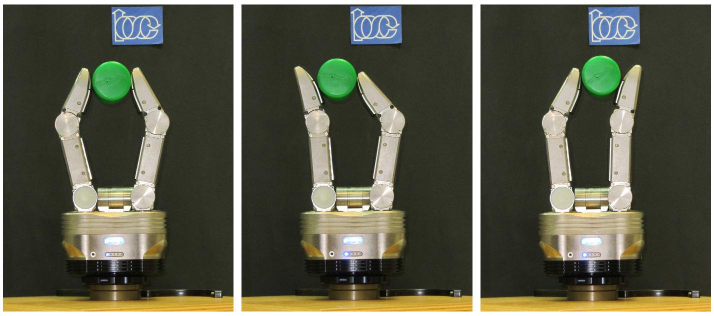
Fig. 7. Snapshots of the telemanipulated objects.



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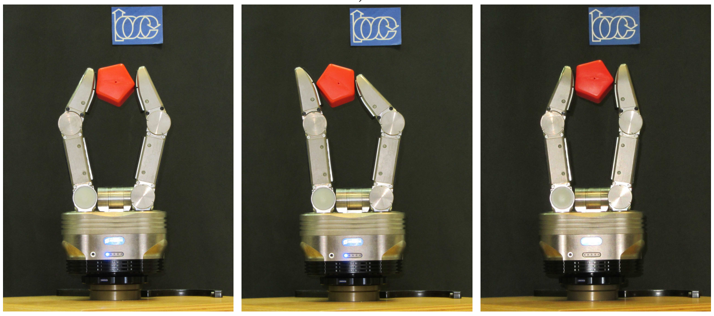

f)

Fig. 8. Snapshots of the telemanipulated objects.

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