Fine Sensitive Manipulation

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Abstract

Fine manipulation tasks are traditionally executed with high precision robotic hands that rely on the existence of a well defined model. Here, we present a different approach based mainly in tactile and force feedback known as "sensitive manipulation".

We have implemented this approach to provide a general purpose robot with the dexterity needed to manipulate the stones used in the game GO. The robot was designed with the features needed for sensitive manipulation namely compliant actuators, force, and tactile sensing. These tactile sensors are deformable, highly sensitive, detect normal and lateral forces.

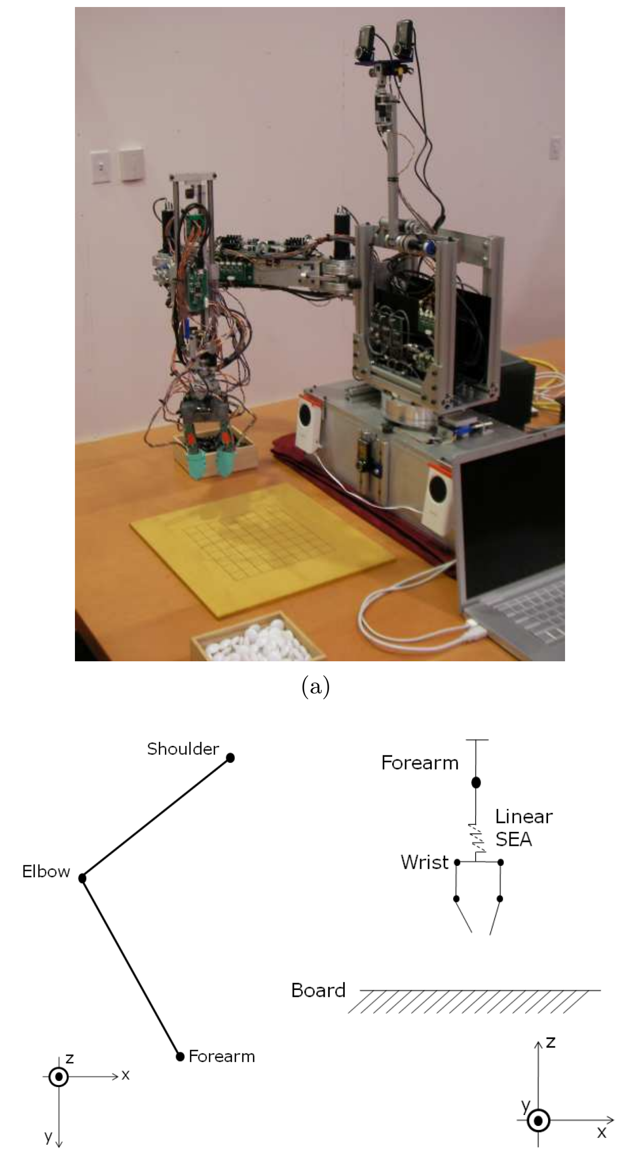
We present the benefits of "sensitive manipulation" by implementing three manipulation tasks that were identified as necessary to play GO: (a) pick up a stone from a bowl, (b) place a stone on the board, and (c) pick up a stone from the GO board.

1 Introduction

In this paper, we use "sensitive manipulation" to perform fine manipulation tasks. Sensitive manipulation has been introduced in [Torres-Jara, 2007] as an alternative approach to model-based manipulation. It has been used to perform grasping of unknown objects based mainly in tactile and force feedback. In this work, we use this approach to handle small, low mass objects.

The objects considered in this case are the stones used to play the game GO. We use these objects because this work is part of a larger project whose goal is to build a robot capable of playing GO (see Fig. 1). The emphasis of this paper is on the manipulation tasks that the robot needs to perform within this context.

However, it should be noted that the robot that we designed is not specialized for the game of GO. For instance, it does not use suction cups or a similar method



(a) (b) (c)

Figure 1: **GO playing robot.** **(a)**Photograph of the robot and its schematics: **(b)** Top view **(c)** frontal view.

to handle the stones. Instead, the robot performs dextrous manipulation using a general purpose hand.

The task of handling GO stones presents interesting scenarios for manipulation. For example, lifting a stone that is surrounded by other stones on the board can be achieved by pressing, with one finger, on one side of the stone to tilt it and to allow other finger to reach under the stone. This task, simple for humans, requires careful attention to the interaction between the robot and the environment.

For instance, we use compliance in the joints of the fingers and arm to come in contact gently with the environment. In this case, the compliance is achieved by using series elastic actuators (SEA) [Williamson, 1995]. This type of actuator reduces the mechanical impedance of the joints. Nevertheless, a consequence of using compliant joints is that the precision in the position control is generally reduced. This is one of the main reasons why compliant hands are not usually used for precise or fine manipulation tasks.

In sensitive manipulation, this is compensated by using additional sensing. For example, for the robot's finger to touch a stone, it could be moved until either a position is precisely reached or a contact is detected. The fact that this contact can be detected compensates for the lack of precise positioning. However, detecting the contact between a finger and the stone implies that there is a sensor capable of doing this task. Tactile sensors, in principle, should be able to do this task but most of the available ones lack of the features needed for robotic manipulation [Maheshwari and Saraf, 2006]; [Someya *et al.*, 2005]; [Someya *et al.*, 2004];[Engel *et al.*, 2003]. These force sensors focus on: force/pressure fidelity and spatial resolution. But, they work only when an object comes in contact with them at the right angle. Thus, they mainly detect normal forces and are usually tested on a laboratory bench. Therefore, they are not useful for real manipulation problems.

In our case, we use a tactile sensor that is biologically inspired [Torres-Jara *et al.*, 2006] to cover the fingers of the robot. The inspiration comes from the alternating papillary ridges and grooves found on human glabrous skin that form our fingers and palms [Mountcastle, 2005]. This sensor has features that are useful for robotic manipulation, such as the level of sensitivity, the detection of normal and sheer forces, the high friction coefficient, and its capability to deform.

2 Experimental setup

We have built a robot that have a torso, a head with an active vision system, an arm, and a two fingered hand as shown in Fig. 1.

The head can pan and tilt and it is mounted on a long neck that can also tilt. The arm is of the SCARA (Selective Compliance Assembly Robot Arm) type [Furuya and Makino, 1980]. It has a shoulder and an elbow to do the positioning in the XY plane. The arm also has a linear degree of freedom (DOF) that moves the wrist in the Z axis. The wrist has one DOF in order to rotate in the XY plane. The robot has one additional DOF on the waist to increase its arm's reach. The hand of the robot consists of two fingers with two phalanges each. All the DOFs in the hand and in the arm use Series Elastic Actuators (SEA). Therefore, these DOFs have a reduced mechanical impedance and can work under either force or position control. The reduced mechanical impedance in the DOFs gives them compliance.

The distal phalanges of each finger are covered with eight tactile sensors. The sensors consist of a semi-sphere dome whose response to contact is measured optically. These tactile sensors are deformable, highly sensitive and detect normal and lateral forces. These tactile sensors are a new version of the sensors used in the robot "Obrero" [Torres-Jara, 2007]; [Torres-Jara *et al.*, 2006] and they have been reduced from a diameter of 15mm to 8mm.

The robot has four USB cameras (see Fig. 1). Two in the head one in the robot's belly and one in the wrist. The camera in the belly helps to inspect the robot's hand when positioned in front of the camera. The one in the wrist is used to visual servo the position of the hand respect to a visual goal (e.g., a GO stone).

The robot has four microcontrollers Phillips LPC2148 [Phi, 2005] on board. One controls the pan and tilt of the head, the tilt of the neck and the position of the waist. Other two microcontrollers are used for the hand and the arm DOF's respectively. The last one reads the tactile sensors. Each one of these microcontrollers connects to a MAC laptop via a USB hub. The USB communication is based on the open-source USB stack LPCUSB [lpc, 2006]. There are two USB hubs in total, one for the cameras, one for the microcontrollers. This hubs are connected to the two USB ports of a MAC laptop computer.

The robot and its task-environment can be seen in Fig. 1.

3 Experiments and results

There are three manipulation tasks that were identified as necessary to play GO: pick up a stone from board, place a stone on the board, pick up a stone from the bowl. They are described in detail in the following sections.

These tasks assume that the board is somehow parallel to the table where the robot is sitting and that the board is reachable by the hand.

3.1 Pick up a stone from the board

In this task we assume that the stone is biconvex and lies in a flat surface.We also assume that the robot has moved its hand over the stone using the camera on its wrist as feedback. The approach followed is to push the stone on the edge with one finger in order to lift the opposite side of the stone. The other finger approaches the stone from the other side to grab the stone and lift it. This sequence can be observed in the Fig. 2b.

To describe the sequence in detail, we have divided it in time intervals as shown in Fig. 2a. In the interval I1, the hand is moving down with the left finger extended and the right finger bend it. The left finger is extended to come in contact with the stone. This contact is detected by the tactile sensors on the tip of the finger. In this configuration, the right fingertip is lower than the left one (see Fig. 2b for details). Consequently, the right fingertip could come in contact with the surface before the left one comes in contact with the stone. In order to handle this interaction, the two joints of the right finger rely on the passive compliance given by the SEA's in the joints. This passive compliance makes possible that the finger adjust its position as a reaction to the contact. This can be observed in the interval I2 in the Fig. 2a where the hand's joint angles are depicted. In this interval, the tactile sensors on the left finger detect the contact with the stone. The detection is done by using a threshold on the change of the tactile sensor readings. It should be noted that even though the detection is done at the beginning of the interval, the arm takes sometime to come a complete stop. During this time, the passive compliance of the fingers and tactile sensors allows for a smooth interaction between the fingers, the stone and the table.

Once the left finger come in contact with an edge of the stone, the diametral opposed side of the stone is lifted which could make the stone to slip. The slippage effect is in part cancelled because of the frictional force exerted by the tactile sensors. This force is distributed over the surface of the stone because the tactile sensors conform to the stone's shape due to the sensors design.

The force direction detected on the tactile sensor is mainly normal to the sensor as shown in Fig. 2c. Therefore, we use the magnitude of this component to detect the contact. The lateral components are not shown for clarity.

In interval I3, Fig. 2a, we want to have the right fingertip under the lifted edge of the stone. This is achieved by increasing the gains of the right-finger-joint controllers to position the finger tip as low as possible. We observed this in the Fig. 2a, the right proximal angle is closer to its desired value. This causes the motion of the right distal phalange. Because the finger is in contact with the table, increasing the gains also produces a force in the wrist which will cause a greater deflection of the spring on the forearm's SEA. The motion of the right finger is also detected on the tactile sensors as shown in Fig. 2c. Later, the right distal phalange is moved towards the stone as shown in the interval I4 of the Fig. 2. The desired angle of the distal phalange is not reached because the finger is stopped by the table and the stone. The stone is also moved as a consequence of this motion. This motion is reflected on the readings of the tactile sensors. The force on the left tactile sensors increased because the stone is being pressed by the right finger.

At this point, the hand is moved up but the desired angles of the phalanges are not changed. As the hand moves up the right fingertip is not stopped by the table and moves towards the left fingertip. The stone is rotated and move up respect to the left distal phalange. The stone is held between the right fingertip and the left distal phalange. This motion is reflected in the tactile sensor readings (see Fig. 2c). The left tactile sensors decrease its reading because the lost contact with the stone, but the right tactile sensors reading increase because they are pressing harder against the stone.

3.2 Place a stone on the board

This task is performed after a stone has been picked up from the bowl using the strategy explained in section 3.3. Consequently, the stone is between the two fingertips and the normal forces applied to the stone by the fingers are detected by the tactile sensors as shown in Fig. 3b.

The first step in this strategy is moving the hand downward to come in contact with the board. It is assumed that the hand has been positioned above the desired position on the board using the camera on the wrist for feedback. As shown in the Fig. 3b, the stone will touch the board deforming the sensors in the lateral direction instead of in the normal one. This shear force is detected by the sensors and used to stop the motion of the hand. In our implementation, we expect at least one of the four sensors to reach a given threshold. This is observable in the interval I1 of Fig. 3c.

This is possible because the sensors can detect normal and sheer forces.

Later, the left proximal phalange is moved towards the right and the right distal phalange is moved downwards in order to lean the stone towards its right side. The changes on the contact between the fingers and the stone are reflected in Fig. 3c. In a next step the right distal phalange is further opened and the hand is moved up to release the stone.

3.3 Pick up a stone from the bowl

In this case the strategy is to introduce the fingers between the stones in the bowl. It is assumed that the hand is over and around the center of the bowl. We proceed by having the phalanges positioned in a straight line. This position will take advantage of the structure of the fingers to apply force. In this configuration we use the tactile sensors on the tips to detect contact with the stones. We consider that we have a good contact when at least one tactile sensor on each fingertip has reached an specified threshold.

At this point, the proximal phalanges are closed to gather stones between the fingertips. Then, the fingers are moved to have the finger tips parallel to each other. This motion does the picking because it moves the tips close to each other and upwards.

4 Discussion

In this paper, we have presented algorithms to realize precise manipulation of small objects using a compliant robotic arm and hand. We use a general purpose robot that is not specialized for the GO game.

The robot has useful features, such as a polygonal approximation to the round shape of the human fingertips. It also has multiple sensing capabilities that work at different ranges, for instance, joint force (course sensing), and tactile force (fine sensing).

The manipulation algorithms are implemented based on the sensitivity of the sensors and the compliance of the fingers, wrist, and sensors. The sensing capabilities compensate for the lack of precision when controlling compliant joints. This makes possible to do precise grasping using compliant fingers.

The features of the sensors allow us to handle GO stones, even though their size is too small compared to the size of the sensors. As an analogy, this would be like handling a rice grain with our fingers. Therefore, little information of the shape of the object can be extracted with the current implementation.

It should be noted, that we use computer vision only to determine the initial position of the hand by visually servo-ing on the target (e.g., bowl, stones, board's grid).

Acknowledgments

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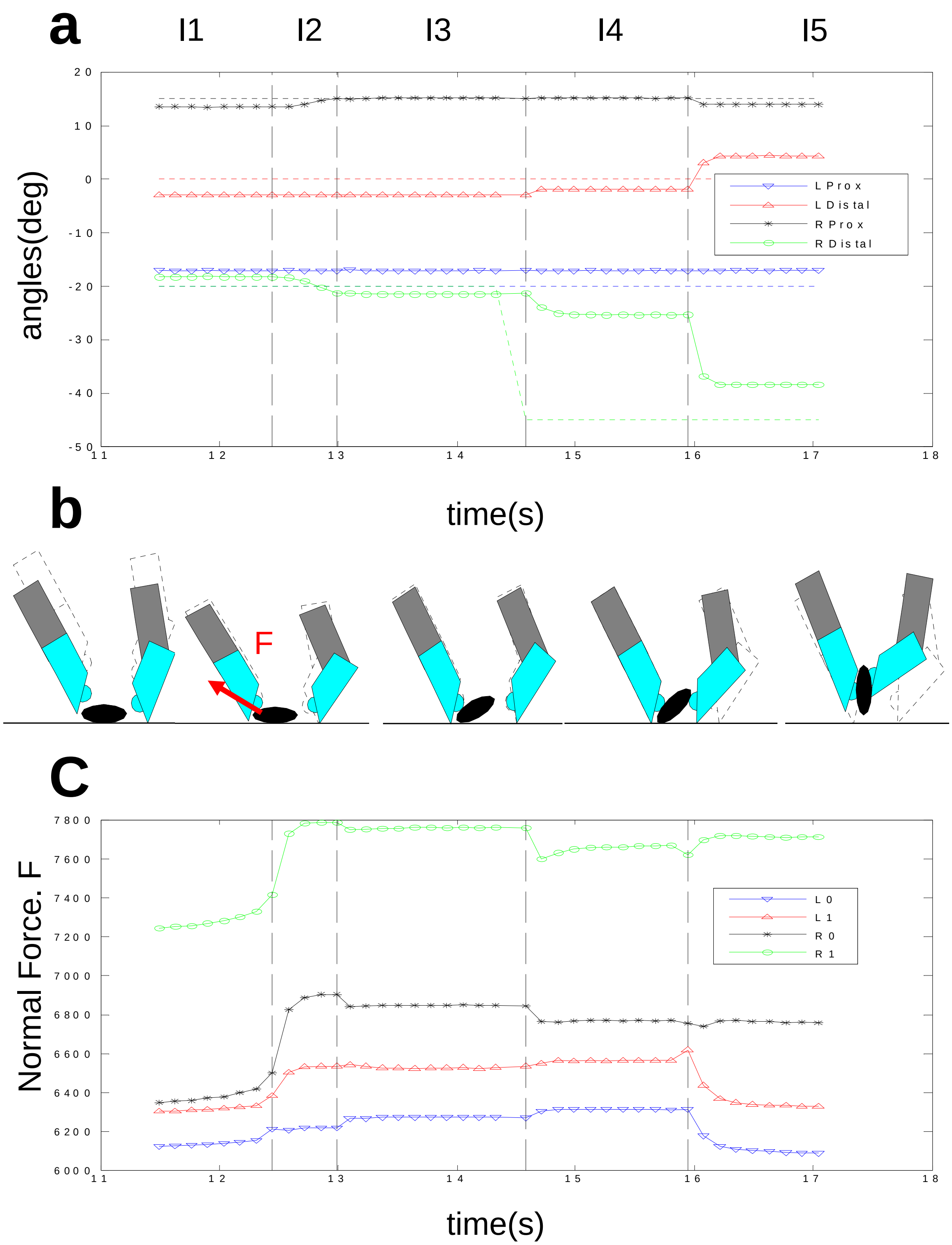

Figure 2: **Picking up a GO stone from the board**. **(a)** Hand's joint angles: left proximal (LProx), left distal (LDistal), right proximal (RProx), right distal (RDistal). **(b)** Sequence of the interaction. **(c)** Normal forces detected by the sensors: left fingertip sensors (L0 and L1), right fingertip sensors (R0 and R1).

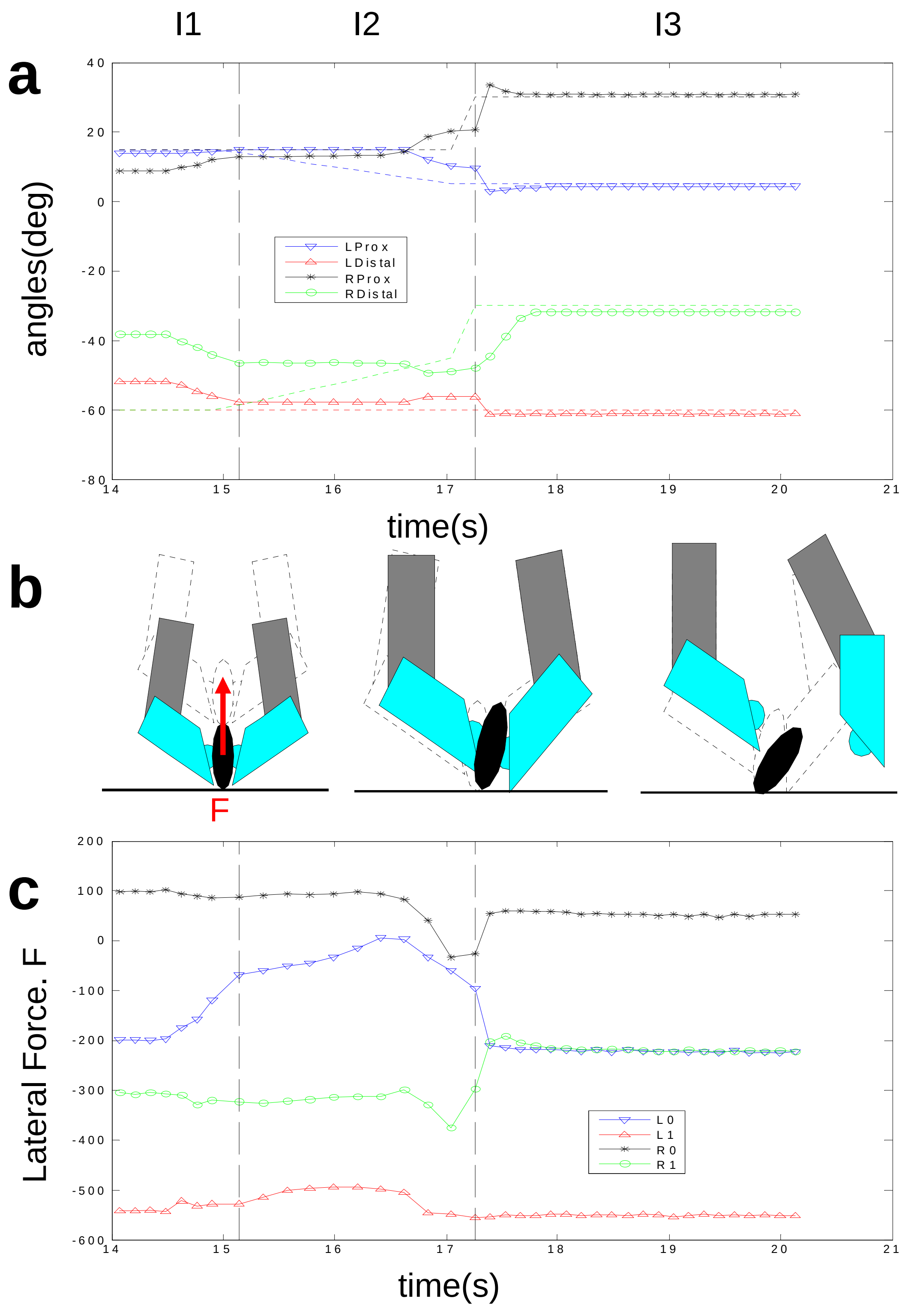

Figure 3: **Placing a GO stone on the board.(a)** Hand's joint angles: left proximal (LProx), left distal (LDistal), right proximal (RProx), right distal (RDistal). **(b)** sequence of the interaction. **(c)** Lateral forces detected by the sensors: left fingertip sensors (L0 and L1), right fingertip sensors (R0 and R1).

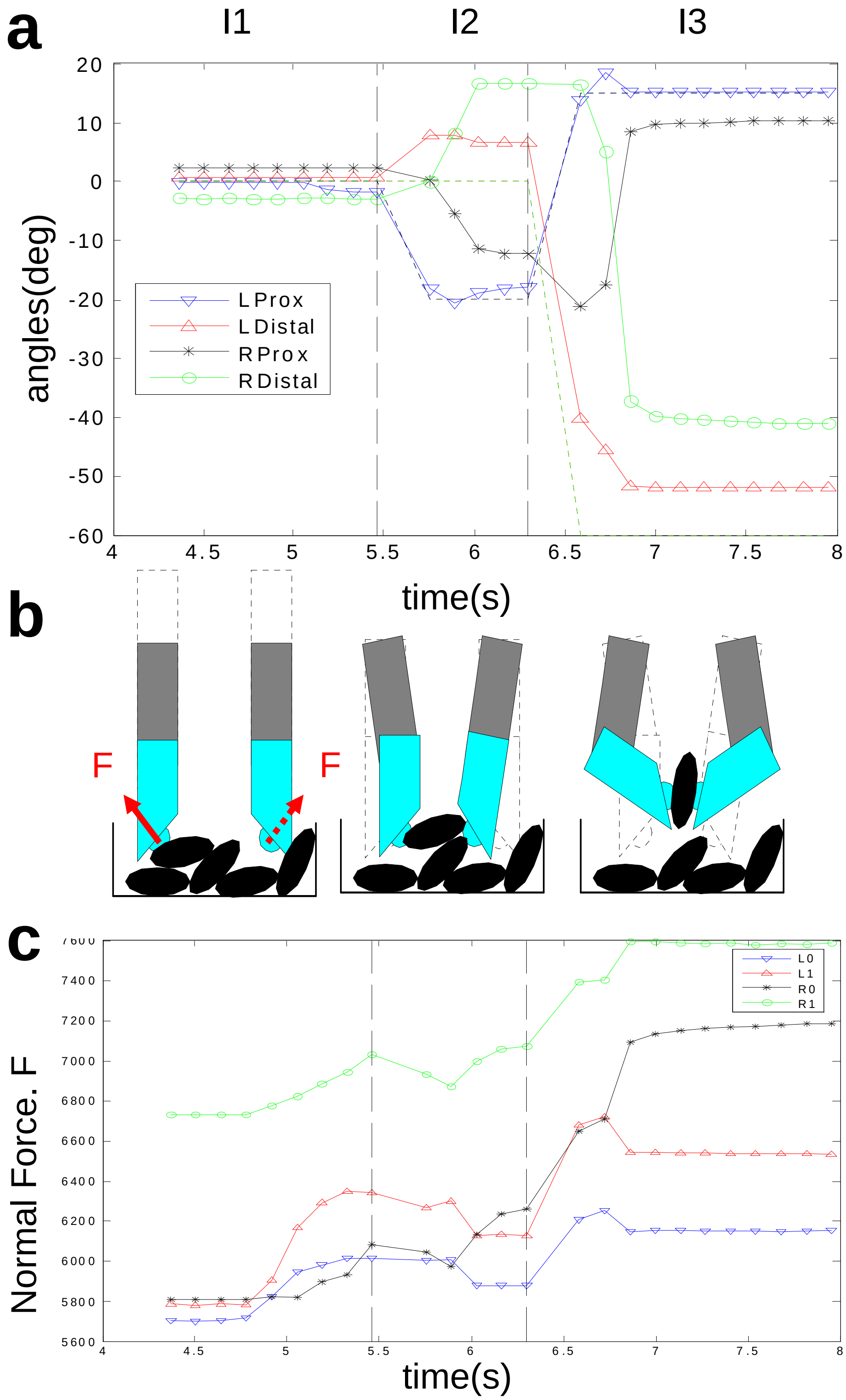

Figure 4: **Picking up a GO stone from the bowl.(a)** Hand's joint angles: left proximal (LProx), left distal (LDistal), right proximal (RProx), right distal (RDistal). **(b)** Sequence of the interaction. **(c)** Normal forces detected by the sensors: left fingertip sensors (L0 and L1), right fingertip sensors (R0 and R1).