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In-hand recognition and manipulation of elastic objects using a servo-tactile control strategy

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ABSTRACT

Grasping and manipulating objects with robotic hands depend largely on the features of the object to be used. Especially, features such as softness and deformability are crucial to take into account during the manipulation tasks. Indeed, positions of the fingers and forces to be applied by the robot hand when manipulating an object must be adapted to the caused deformation. For unknown objects, a previous recognition stage is usually needed to get the features of the object, and the manipulation strategies must be adapted depending on that recognition stage. To obtain a precise control in the manipulation task, a complex object model is usually needed and performed, for example using the Finite Element Method. However, these models require a complete discretization of the object and they are time-consuming for the performance of the manipulation tasks. For that reason, in this paper a new control strategy, based on a minimal spring model of the objects, is presented and used for the control of the robot hand. This paper also presents an adaptable tactile-servo control scheme that can be used in in-hand manipulation tasks of deformable objects. Tactile control is based on achieving and maintaining a force value at the contact points which changes according to the object softness, a feature estimated in an initial recognition stage.

1. Introduction

In the field of robotic-hand manipulation, the study of how to grasp and manipulate deformable objects is still a challenging topic and has been studied during the last years in many contexts, ranging from industry to surgery [1]. Nowadays, grasping and manipulating any type of elastic or deformable object by a service, autonomous or assistive robot, are considered as extra and important capabilities.

Robot hand manipulation of rigid bodies is based on the principles of rigid body motion, where the use of the grasp matrix and fingers' Jacobian lead to mathematically model and track the behavior of the whole system [2]. In this case, control laws can be developed taking into account the well-known dynamics of rigid objects. In contrast, deformable objects are very difficult to model and simulate, and the robot hand-object system cannot be controlled using the same laws as rigid ones. This is mainly because deformable objects' dynamics depends on a large and complex set of parameters, such as deformation, softness and friction.

It is possible to obtain a perfect model of the deformable object using some of the current approaches, such as mass-spring model [3], mesh-less models [4] and the more general Finite Element Method (FEM) [5]. Although these are precise techniques, most of them require a fine discretization of the object and hence, they are time-consuming for on-line manipulation performance. Given these difficulties in this research field, several approaches have been developed to explore manipulation of deformable objects using a simple model or without explicitly modelling the objects [6–8]. In this last sense, the use of tactile data to obtain information about the deformability and softness, and also how to use this information as a reference to control the motion of the fingers is a key issue. This field of study is inspired on the scheme of human grasping and manipulation, which essentially depends on tactile sensation rather than vision or proprioception.

Force Closure Grasping (FCG) is considered a key point in order to perform a correct dexterous manipulation of rigid bodies. Regarding FCG, it is possible to determine the quality of a grasp for a rigid object by its shape and dimensions and the information of the robotic hand. In contrast, when the objects are deformable or elastic, it is necessary to incorporate a contact tactile-based readjustment algorithm on the grasp points to ensure the correct operation of the FCG [9,10] and it is very difficult to ensure a FCG. This paper presents an approach based

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on tactile data in order to obtain important features of the deformable object and to manipulate it in a secure way.

Usually, grasping and manipulating a deformable object needs a multisensory system [11,12], mainly to control the state of the object on each time step. Thus, internal information from the hand (kinematics and dynamics), visual and tactile data are normally used together to control the whole system. In many works, only internal information from the manipulator and tactile data is used to control the manipulation task. In this cases, an accurate tactile sensor is needed to get reliable feedback of how the contacts interact with the objects [13–16]. Using tactile data, servo controllers can be used to maintain a target value of magnitude and position of the applied forces [17]. However, many of them are based on learning algorithms without taking into account objects' features or these approaches use complex models for the objects.

In this paper, a new tactile based grasp and manipulation control system for isotropic elastic objects is described. The basis of the proposed strategy is to develop an integrated framework for the manipulation of elastic objects using tactile data and kinematic information from the manipulation robot. A vision system is only employed to locate the object in the world.

This approach includes three stages of the interaction with the elastic object: exploration, modelling and control. In the first stage, an object recognition to be grasped is carried out in order to obtain an estimation of its softness, i.e the relation of stress and strain in the object (Young's modulus). The extraction of the features allows the robot to create a virtual model of the object (modelling stage), and this virtual model is used later by the robot to control the interaction with the object during a manipulation task. Finally, a tactile-servo framework is employed to maintain contacts with the object and pressure values. This tactile-servo is controlled by a task manager which sends reconfigurations to the finger positions and exerted forces. The servo tactile control depends on the estimation of the rigidity, obtained in the recognition stage, to perform precise control of the caused deformation in the contact points. Once the object is detected and the hand is positioned in the initial configuration, the control and recognition system presented in this paper can work without depending on a vision system, so the processes are more agile than those which use visual processing. Although a complete model of the object is not used, controlling the contact points as well as the exerted forces allows a reliable control of the movements and deformations in the object.

2. System description

The system is basically composed by the Shadow robot hand [18] and a Kinect sensor. Besides, a tactile sensor, the Tekscan grip sensor [19], is attached to the robot hand in order to obtain force and pressure data from fingers. The Kinect sensor is employed to detect and recognize objects in the world. The Shadow hand is mounted on a structure that allows displacements in any direction, and angular movements (roll, pitch and yaw). Only movements of the hand are considered to grasp objects (see Fig. 1).

The Shadow hand is a motor actuated robotic hand with five fingers and 20 degrees of freedom (2 on the wrist, 5 on the thumb, 3 on the first, middle and ring finger, and 4 on the little finger). To make it similar to a human hand, the nearest joint to the finger end effector on each finger except the thumb, is a coupled joint. This is, the hand has 24 degrees of freedom, but only 20 are controlled. Each of the joints is controlled both with position or force control. A kinematic model of the hand is used to compute both forward and inverse kinematic solutions. To model and simulate movements of the hand, the Gazebo simulator and MoveIt software in ROS are used. However, due to the deformability of the objects, these software platforms cannot give realistic simulations of how the system hand-object will behave. Thus, real experimental are necessary to show the veracity of the presented approach.

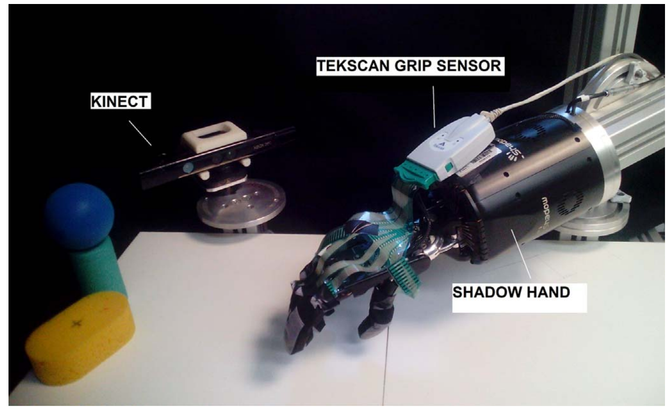

Fig. 1. System used for the experiments: the Shadow robot hand with the Tekscan Grip sensor, and the Kinect sensor.

Regarding the Tekscan grip sensor, is a hand shaped sensor that can be attached to human or robotic hands. It is used to extract a pressure and/or force map of the whole hand. The sensor is divided in 18 regions that cover the palm of the hand and its fingers. Each region is composed by an array of cells with different sizes depending on the position in the hand. For example, the region situated in the finger tips is an array of 4 by 4 element cells. For this paper, only the regions of the finger-tips are used, which are the common parts of the hand to use when a grasp has to be done. The region of each fingertip covers 1′7 by 1′7 cm. The response in pressure and force is calibrated in an initial stage before the sensor is used in real experiments. After this calibration, the response of each region is defined by a calibration curve. This hand was calibrated so that it has a linear response on each region between 0 and 7 N. The sensor is connected to a computer with a local Ethernet connection, and the sampling rate is about 850 Hz. The sensor values are stored in array structures which store the whole pressure map, pressure map for a single finger, or pressure map for the fingertips.

3. Object recognition stage

In order to make this approach adaptable to different deformable objects with different degrees of softness, a recognition stage is performed during the first grasp of the object. The contact points are selected after the object is detected by a vision system, and they are chosen using quality measures. Both visual recognition and grasp metrics are open issues in robotics research, but are not discussed in the presented approach. Basically, the vision system obtains the position of the object and an approximated shape using 3D recognition techniques [20]. With the information about position and size of the object, and using quality measures for the grasp based on geometric properties (distance and angles between contact points and area of the polygon formed by the contact points), the fingers are positioned in an initial grasp configuration from which the recognition algorithm is carried out. During the performance of the recognition algorithm, visual information is not needed.

The idea of the recognition stage is to get a relative value of how the object is deformed relatively to the finger positions and applied forces. For elastic objects, Hooke's law may be used, because it relates stress and strain on the object. After getting values for pressure and strain on each finger, a relative stiffness degree is obtained, which is an approximation of the Young's modulus. For isotropic bodies, the Young's modulus should be the same independently of the points of contact. Fig. 2 shows the algorithm which is executed during the recognition stage to obtain the values of stress and strain.

As shown in the algorithm, the recognition stage starts at the configuration of the hand in which the fingertips are positioned in the selected contact points. The recognition stage is based on the human