A Tactile-based Grasping Strategy for Deformable Objects' Manipulation and Deformability Estimation

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Abstract: Grasping and manipulating deformable objects with a robot hand has several interesting challenges. Deformable objects, due to its texture and deformability, present different features from rigid ones and that issue can cause uncontrolled movements during grasping and/or manipulation. The paper presents a control strategy for grasping deformable objects, focused on elastic foams, based on tactile information. An adaptation at different elastic properties of the object is achieved, because the deformability degree is estimated during the grasping process. Several experiments are shown in order to demonstrate the reliability of the tactile-based strategy.

1 INTRODUCTION

Multi-fingered robotic hands allow both the execution of robust grasping tasks and dexterous manipulation (Melchiorri, 2008). These features enable multi-fingered hands to be controlled not only for holding the object with a firm grasp but also for generating trajectories of the object with the movements of the fingers. Therefore, tactile information plays a very important role for both grasping and manipulation (Yousef, 2011). For that end, tactile sensors are usually employed to measure the force or pressure exerted by the fingertips in order to reach and/or maintain a desired value.

Force Closure Grasping (FCG) is considered a key point in order to perfom a correct dexterous manipulation of rigid bodies (Yoshikawa, 2010). In contrast, when the objects are deformable, it is necessary to incorporate a contact tactile-based readjustment algorithm on the grasp points to ensure a secure grasp (Corrales, 2013) (Kien-Cuong, 2013).

Tactile sensors share a common property in robotics: they analyze the direct contact between the robot and the objects of the environment in order to adapt the robot's reaction to the manipulated object. Tactile information is processed according to two different aims: object identification and manipulation control. On the one hand, the properties of the objects extracted from the robot's tactile sensors can be used to categorize the objects into different classes. On the other hand, the measurements obtained from the tactile sensors can also be applied to control the interaction force (Han, 1998). In this paper, a new tactile-based algorithm is presented in order to perform a secure grasp and for the estimation of the deformability degree of the object.

Some works have been developed to use multisensory systems to plan the forces to be applied to grasp deformable objects. Most of this works use both visual and tactile data (Khalil, 2010) (Luo, 2001) (Bimbo, 2013). A vision system is needed to get a whole map of the object deformation, usually a stereoscopic system, to get information in the three dimensions (Khalil-Payeur-Cretu, 2010) (Gil, 2015). Some works use the information provided by a visual system to compare it with deformable object's models to validate the deformation (Khalil-Curtis, 2010). In this paper, there is not any visual system and only a tactile-based algorithm is applied in order to perform the grasping and deformabilty estimation.

The paper is organized as follows. Section 2 describes the system architecture of the robotic manipulation system. Afterwards, the whole grasping strategy is described in Section 3. Section 4 describes the experimental results obtained. The final section reports some important conclusions.

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2 SYSTEM DESCRIPTION

The robotic system used in this work is based in two articulated robots Mitsubishi PA10 of 7 degrees of freedom each one. One robot has a Kinect range sensor at its end, whereas the other one position a Shadow Hand including Tekscan Grip tactile sensor.

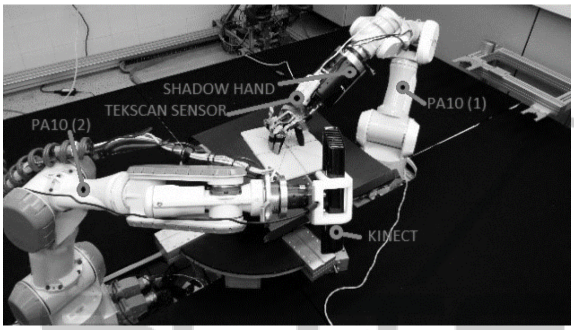

Figure 1: General view of the system that includes the robot Mitsubishi PA10 and the Shadow hand.

2.1 Robotic Manipulation System

The Shadow hand (Shadow Robot, 2015) has five fingers with 20 actuated degrees of freedom and a further 4 under-actuated movements for the total of 24 joints. First, middle, ring and little finger have 2 coupled joints on the end of the finger. Regarding the control, two different approaches are used: position and effort control for each joint.

To get tactile pressure data, the Tekscan Grip sensor (Tactile Sensor Tekscan, 2015) is attached to the hand. This sensor was chosen because of its easy adaptation to different kinds of robotic hands, and the possibility of getting a complete pressure map of the whole hand. The tactile sensor is divided in eighteen sensing regions which are individually positioned on the finger sections and the palm. Considering the morphology of the Shadow hand (quite similar to a human hand), the adaptation of the sensors is easy.

For the experiments developed in this paper, only the information given by the regions of the finger tips is used (see figure 2). For each region, the tactile pressure value is stored in a 4x4 matrix. Thus, the pressure and force value for each cell can be obtained, and then, the total force and pressure on the whole region of the finger covered by the sensor.

In regard to the sensor features, the sensor has a high sampling rate (850 Hz) very useful for feedback control. A pressure service is used to get tactile pressure data asynchronously. This service is called from the main grasping-manipulation process.

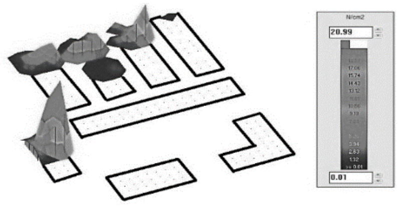

Figure 2: Visualization of the pressure map distributed over the regions of the sensor.

3 GRASPING STRATEGY

3.1 Grasp Planner

The grasp planner algorithm is based on the human hand grasp system (Mira, 2015). In this way, the contact points are chosen after the object is recognized and selected the task to perform. This is the only way to assure a correct grasp for deformable objects. In order to achieve this, a learning algorithm is used with a database filled with the data acquired in previous iterations. This allows determining the best contact points to achieve the correct completion of the task.

3.2 Tactile-based Grasping Strategy

In this section, the tactile based strategy for grasping tasks is explained. The first part of the strategy is the grasping process which starts at the positions given by the grasp planner that was mentioned previously. The grasp planner determines the number of contacts and the position for each one. In this initial configuration, there are contact points between the fingers and the objects. However, this configuration is not suitable to begin a secure grasp, so the steps that are explained in this section are carried out to achieve a secure and force-closure grasp. Figure 3 shows the flow diagram of the tactile based strategy.

The first time the steps are executed for an object with a known shape after visual recognition, the process grasps the object executing position steps until a minimum force value is reached by any finger. After this, a force readjustment process is executed. In this part, a torque control is directly applied to each finger used in the grasp process. Each force is increased and the applied force for each fingertip is read. The process continues until an initial maximum threshold is achieved for the force values.

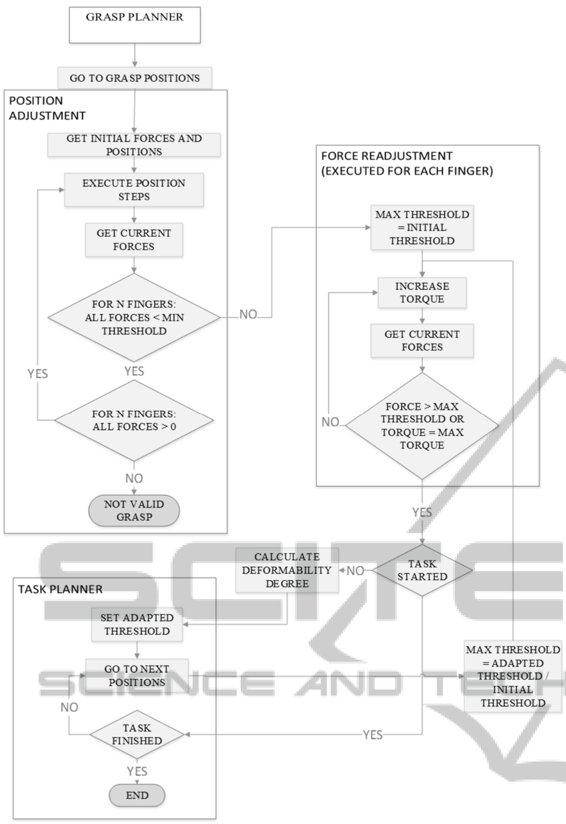

Figure 3: Flow diagram of the tactile based strategy.

Initial minimum and maximum force threshold values are set after experimentation with different objects which have different mass densities and shapes. The minimum initial force threshold value (MIFT) represents the necessary force to be applied to the object in order to be grasped, and the maximum initial threshold value (IFT) indicates a value in which the fingers are applying a high pressure to the object.

After the grasp finishes, a deformability degree is estimated. This estimation is a relative value, between 0 and 1 (where 1 represents no deformation), used to adapt the maximum force threshold to be applied in successive fingers redistribution, during in-hand tasks, and replaces the constant initial value with the maximum value computed. For objects with a high deformability degree, the maximum threshold can be lower because the initial maximum could cause undesired deformations, not necessary due to the object is correctly grasped.

In the position adjustment stage of the strategy (see figure 3) the object is grasped using specific position trajectories of the fingers. The thumb stays in the same position, while the rest of the fingers are moved in parallel trajectories towards the point where the thumb is placed. At the end of the grasping process, fingers are placed in a final position. For objects with a low degree of deformability, this final position will be almost the same as the initial position. For objects with a high degree of deformation, the final position will be different from the initial ones, defined by a known displacement.

As commented before, deformability degree is set after the readjustment, and is related to the relationship between position displacement and the applied forces after the grasping process. For deformable objects, the coefficient of deformability is set as:

$$p = \left[\left(\frac{MD - d}{MD}\right) + (f/IFT)\right]/2 \qquad (1)$$

The value *MD* represents the maximum possible displacement. This value is set as the module of the vector that goes from the first finger's initial position to the thumb's initial position, which is, the maximum distance that fingers can move before they collide. The value *d* represents the current displacement, and is set as the biggest displacement for all the moved fingers after the force readjustment. The value *f* is set as the maximum of the forces applied by the fingers after the force readjustment. The value IFT represents the Initial maximum Force Threshold. Then the maximum Adapted Force Threshold, AFT, is set as:

$$AFT = p * IFT \qquad (2)$$

The initial maximum threshold is multiplied by the coefficient that is directly proportional to the deformability degree. If the obtained AFT value is lower than the minimum threshold value (MIFT), then AFT is replaced by the MIFT.

For the next position steps of the manipulation task, each stage is defined by a position to be reached by each finger. In addition, a condition of the movement must be followed: step to be executed with the maximum force, which ensures a secure grasp but may cause uncontrolled deformations, or basic grasp, to prevent uncontrolled deformations. Each finger is moved to the next position defined by the task algorithm, and the force readjustment stage is executed with the related maximum value, depending on the task conditions. The task planner sets the condition (using maximum or adapted force), depending on the task that is going to be developed. For example, for elastic foam, if the task needs to grasp the object and move or rotate it, the adapted force threshold will be used. On the contrast, if the foam needs to be deformed in order to introduce it in a box or cylinder, the initial threshold will be used.

4 EXPERIMENTATION

In this section, the experiments developed to test the strategy are explained. Three different objects are used. The first object is foam with dimensions of 26x10x1 cm, and a continuous mass density of 0.038 g/cm^3. The second object is foam of dimensions 22x9x4 cm, and the same mass density as the first object. The third object is foam with dimensions of 29x11x1 cm, and lower mass density, 0.015 g/cm3. These objects where chosen to test the strategy with deformable objects, and to study how changes of mass density and volume affect the results.

Next, the tactile strategy is executed, and the results are explained in more detail, to demonstrate the validity of this method to estimate the deformability degree of an unknown object and to adapt the forces applied during the manipulation tasks. For these experiments, an initial maximum value (IFT) of 5 Newton and an initial minimum value (MIFT) of 1 Newton are used. These values are set after experimentation with different objects which have different mass densities and shapes.

4.1 Case 1: Elastic Foam (26X10x1 Cm, Density 0.038 G/Cm^3)

Figures 4 and 5 show the evolution of the positions of the finger tips and the forces applied by each one using five fingers. The reference frame for the positions is situated in the forearm of the hand. According to the orientation of the reference frame, high variations in the 'y' and 'z' axis and little variations in the 'x' axe are expected. The displacement of each finger can be seen in Figure 4, where F1, F2, F3, F4 and F5 represent thumb, first, middle, ring and little fingers, respectively.

After the first force readjustment is executed, the deformability degree is obtained in each case, using the known displacements of the fingers and applied forces by each one (see Table 1).

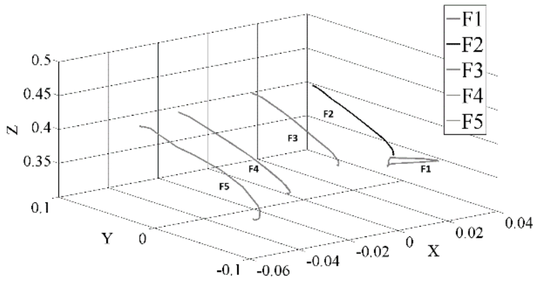

Figure 4: Displacement of each finger during the first experiment.

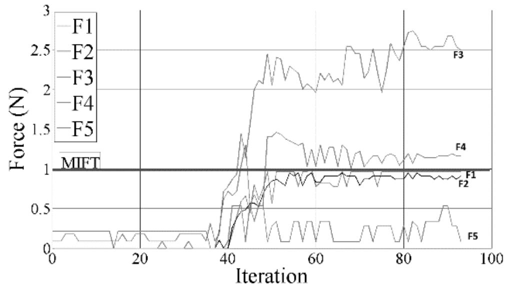

Figure 5: Evolution of the forces applied by each finger during the first experiment.

Table 1: Results of the first experiment.

Maximum final applied force (N)	2.49
Maximum allowed displacement (m)	0.13
Maximum current displacement (m)	0.12
Deformability degree	0.28
AFT (N)	1.42

Figure 6: final positions using initial maximum threshold (left) and adapted threshold (right).

4.2 Case 2: Elastic Foam (22X9x4 Cm, Density 0.038 G/Cm^3)

The results obtained for the second foam (same density as the first, but different dimensions) are shown in Figures 7 and 8. In these pictures, it can be seen the evolution of the finger positions and the forces applied. Table 2 shows the data obtained about the deformability degree of the second foam.

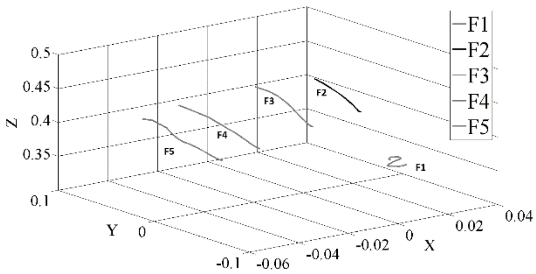

Figure 7: Displacement of each finger during the second experiment.

In this case, the displacement is not as big as in the first case, which indicates that for objects with the same mass density, the deformation degree depends on its shape.

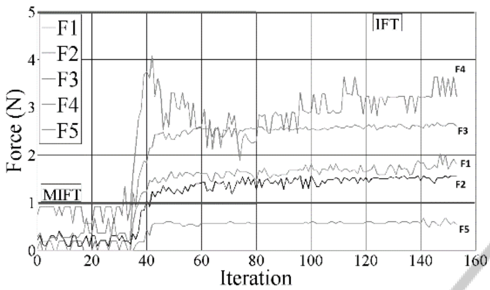

Figure 8: Evolution of the forces applied by each finger during the second experiment.

Table 2: Results of the second experiment.

Maximum final force (N)	3.22
Maximum allowed displacement (m)	0.12
Maximum current displacement (m)	0.07
Deformability degree	0.52
AFT (N)	2.60

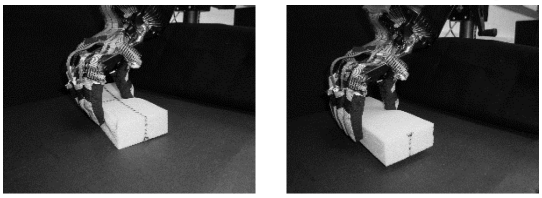

Figure 9: final positions using initial maximum threshold (left) and adapted threshold (right).

4.3 Case 3: Elastic Foam (29X11x1 Cm, Density 0.015 G/Cm^3)

Figures 10 and 11 show the experimental results obtained in the experiment. The shape of this object is similar to the shape of the first foam, but with lower mass density. The results obtained demonstrate that mass density affects the deformability degree and the required forces to be applied.

The values of deformability and adapted force threshold are calculated (see Table 3). If we compare the results with the results obtained for the first foam, it can be seen that the deformability degree and the adapted maximum threshold decrease. There is a direct relation between mass density and deformability degree for objects with similar shape.

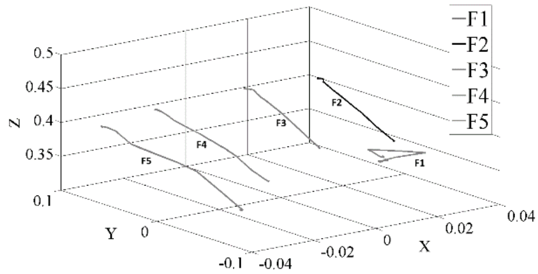

Figure 10: Displacement for each finger during the third experiment.

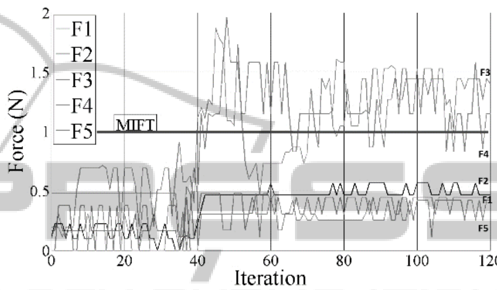

Figure 11: Evolution of the forces applied by each finger during the third experiment.

Table 3: Results of the third experiment.

Maximum final force (N)	1.40
Maximum allowed displacement (m)	0.13
Maximum current displacement (m)	0.12
Deformability degree	0.17
AFT (N)	0.88

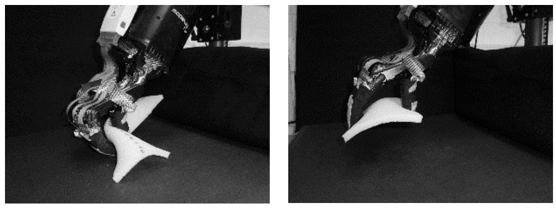

Figure 12: final positions using initial maximum threshold (left) and adapted threshold (right).

5 CONCLUSIONS

The strategy proposed in this paper allows recognizing and classifying the deformability of objects in a fast way. It gives a relative information that is useful for other modules that control in-hand manipulation tasks. The strategy does not require either a model of the object or a visual recognition to get a reliable estimation of the deformability. The visual information is only needed by the grasp planner to reach the object, so the processing load is smaller.

This work is developed as a previous stage for a tactile servoing system that is currently in progress. The classification of the objects that are grasped is useful for the adaptation of the movements of the fingers in order to get a safe hand-object configuration in which nor the joints of the fingers nor the object are suffering high pressures that could cause undesired results.

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