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Towards autonomous soft grasping of deformable objects using flexible thin-film electro-adhesive gripper and online capacitance measure

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***Abstract*—Grasping fragile or deformable objects is a more complex task with respect to the traditional pick and place of solid objects. In such cases, a retention action is typically preferred over a compression force in order to avoid damaging the objects. The proposed work presents a robotic manipulation grasping system that leverages a gripper realized with the flexible thin-film electro-adhesive (EA) devices technology and a vision pipeline based on an RGB-D camera to detect the grasp pose configuration and track the target during the holding phase to check whether the task has been successfully completed. Several tests have been done to assess the capabilities of the proposed robotic system, picking and placing deformable objects, comparing the EA gripper with a traditional parallel jaw gripper. Furthermore, a self-sensing circuit capacitance has been developed for measuring the variation of the capacitance between electrodes of an EA device during the adhesion providing useful information to automatically detect the successful grip of an object and the possible loss of adhesion during manipulation.**

***Index Terms*—electroadhesive grippers, autonomous grasping, deformable objects, self-sensing**

Autonomous robotic grasping is a topic of great interest in the research community since it is fundamental in many applications like service robots, pick and place in manufacturing and logistics, and others. Most of the approaches in the literature rely only on visual cues since vision is useful to get global information from the scene, needed to compute the grasping points. On the contrary, vision is not suited to detect local information regarding the contact phase and the gripper-target interaction, especially in terms of the forces exerted during the grasping.

Grasping fragile or deformable objects is a more complex task with respect to the traditional pick and place of solid objects relying only on visual information. Even though the research in that field is progressing fast, robots typically do not have a reliable sense of touch, and traditional robotic grippers are designed to grasp specific types of objects. In the case of fragile or soft objects, a retention action is typically preferred over a compression force in order to avoid damaging the objects. In this work [1] we propose a robotic grasping system that employs a gripper realized with the flexible thin-film electro adhesive (EA) pads technology (Fig. 1) that is controlled through a vision pipeline based on an RGB-D camera to detect the grasp pose configuration. The advantage of using such kind of system is that vision is the only perception cue needed to successfully grasp the target without damaging it, thanks to the properties of the EA gripper. Indeed, the gripper can automatically adapt its shape to the surface of the target delicately wrapping its two fingers around the object. The grasping action of the gripper relies on the electrostatic force induced by an electric field generated applying a voltage across a couple of electrodes embedded between dielectric substrates.

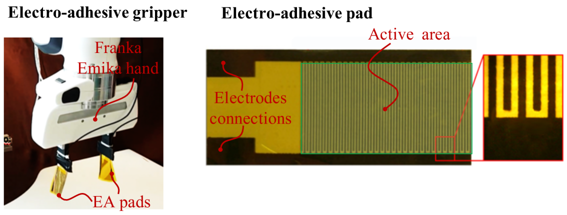

Fig. 1. Gripper equipped with two ED pads (left). Geometry of the EA pad showing the electrode shapes and the active area (right).

Several tests have been done to assess the capabilities of the proposed robotic system, picking and placing deformable objects, comparing the EA gripper with a traditional parallel jaw gripper. In particular, we use compliant single layer cardboard boxes that are typically employed in medical and pharmaceutical packaging. Figure 2 gives a close up of one of the attempts using a box medicine and shows that even if the manipulator successfully accomplished the task with both grippers, the parallel-jaw gripper deformed the box, squezing it at the picking phase and during the whole task. The EAD gripper is also able to grasp objects that have an asymmetric barycenter. In order to show this property, some boxes of medicine have been modified, putting some extra weights inside them in a non-uniform way. In this case, the manipulator successfully accomplished the task only with the EAD gripper. The parallel-jaw gripper failed every attempt for each target. Such results could be explained by the fact that the EAD gripper gently attaches the internal face of the finger on the surface of the target and generate a distributed force over the whole contact surface. Instead, the contact between the parallel-jaw gripper and the target object can be modeled as two contact points where the interaction forces

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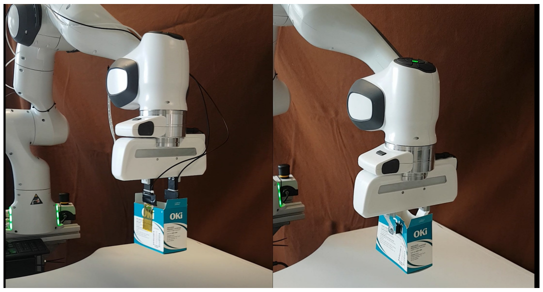

Fig. 2. Grasping of opened medicine box. On the left, the EAD gripper successfully grasp the box without altering its geometry. On the right, the classic parallel-jaw gripper deforms the box during grasping.

are concentrated. Furthermore, the parallel-jaw gripper closes the fingers between the two contact points until current return feedback is detected, and usually, this principle is not suitable for deformable fragile objects.

We also propose a novel low-cost sensing architecture that makes it possible to detect the successful creation of EAD adhesion force and detect the possible loss contact with the adhering objects [2]. The proposed principle leverages on the intrinsic variation of capacitance that is associated with the capacitive coupling established between the elector-adhesive device EAD and the adhering object. Thus the measurement of capacitance during the operation of the EAD allows to identify several important adhesion parameters without any additional sensors and can be used as a checking mechanism that the grasping task has been successfully completed. Such a variation is dependent upon the material of the adhering object, the surface quality, and the presence of remaining air gaps at the interface.

The manipulation system has been realized as a component-based designed architecture. In particular, the vision and planning pipeline run in the ROS (robotic operating system) Noetic environment containerized in a docker machine with Ubuntu 20.04 LTS. The gripper controller executes on a Speedgoat Baseline real-time target machine, and the capacitance analysis runs on another PC with Windows and MATLAB Simulink 2021a. All the computing units are interconnected by employing a switch: the Speedgoat talks directly with the Windows PC, which sends the closing information to the main Ubuntu PC via ROS messages from Simulink.

The vision system uses a Realsense D435 RGB-D camera positioned on top of the working table, looking down at the object to be manipulated. In order to show the grasp capabilities of the electroadhesive gripping system and to demonstrate the possibility of recognizing instant in which electradhesion become effective, single object scenarios have been considered. The vision pipeline exploits the registered depth information for segmenting the scene and detecting the pose of the target. In particular, the algorithm extracts the principal axes, the centroid, and builds the bounding box. As a first step, the RGB image is converted to grayscale to perform a thresholding operation to get the mask of the target object. Then, the Suzuki algorithm is used to find the contour, and the Principal Component Analysis (PCA) is applied to that contour to return the two eigenvectors that represent the principal components of the data and are used to identify the object orientation. The size of each eigenvector is encoded in the corresponding eigenvalue, which indicates how much the data vary along with the principal component or, in other words, it represents the length of the side of the enclosing 2D bounding box. The beginning of the eigenvectors is the center of all points in the data set, a.k.a., the centroid. Then, the vision pipeline builds the 3D cuboid of the object deriving the height, width, and depth of the object. In particular, the height and the width can be obtained from the magnitude of the eigenvalues and the depth can be computed by reading the depth information provided by the camera as the difference between the depth value of the centroid and the depth of the working table. Finally, the algorithm searches for the two smallest parallel surfaces that are below the gripper clearance to compute the grasping pose of the robot. The grasping happens with a purely vertical movement, with the gripper opened at its maximum clearance, in order to minimize possible causes of errors. The grasping phase is a closed-loop signal procedure. During the grasping, the main Ubuntu PC commands the gripper to close until it receives feedback from the Windows PC that the capacitance has surpassed a threshold which has been calibrated empirically on the used objects. Fig. 3 and 4 show two grasping attempts using the self sensing mechanism. In particular, 4 depicts the possibility to understand if the object drops down during the transportation phase.

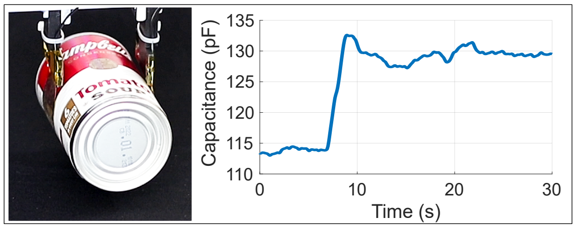

Fig. 3. Capacitance variation during the adhesion of the pads onto a curved surface of a metallic can.

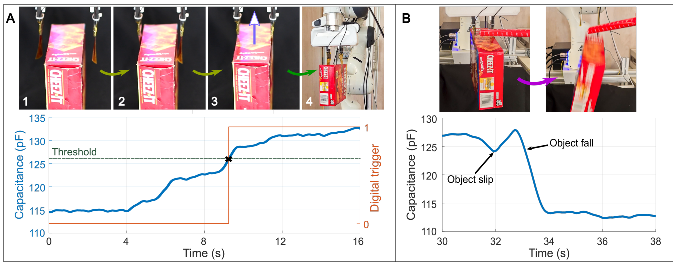

Fig. 4. Capacitance variation during manipulation of a cardboard box

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