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Sensorless model-based object-detection applied on an underactuated adaptive hand enabling an impedance behavior

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ABSTRACT

This paper introduces a sensorless object-detection control strategy designed for an underactuated three fingers hand. The proposed algorithm achieves a very accurate object-detection, through a simple joint impedance control scheme combined with a state-observer. The joint impedance control adapts the position set-point of each finger according to the estimated kinematics state computed from the kinematics model of the finger. The additional control loop is applied as external controller w.r.t. the standard one. The object-detection is obtained without any external sensors using only the measures of position and current provided by the fingers actuators. A friction compensation strategy based on a probabilistic approach has been implemented. An impedance control algorithm avoids the tuning of grasping parameters (i.e. grasping velocity and holding force). In this way developed controller provides adaptive behavior enabling the manipulation of objects made by unknown materials, without producing damages on their surfaces.

This approach represents a step ahead to the flexibility of the grasping devices, in particular in manufacturing production, where the variability of manipulated pieces, in terms of shape and materials can be very high.

An experimental campaign demonstrates the feasibility of the proposed method.

1. Introduction

The importance of manipulating objects is a matter of fact in robotics. Objects manipulation covers a fundamental role in industry, especially in manufacturing sector where the increasing number of robots, the high variability of productions and the tight reconfiguration time impose the use of flexible and easy adaptable grasping systems. In particular, two paradigmatic examples are assembly and, more and more often, disassembly due to the increased importance of products end of life.[1]

Over 3 decades of researches have consolidated the knowledge in robotic hands design giving birth of many commercial products. Different efforts have been made mainly in two directions: at one side by creating complex devices mimicking the human hand structure [1], on the other side by designing hands with a “minimalist” approach [2].

Multiple kinematics schemes with different number of fingers and phalanges have been proposed over the years. The most sophisticated hands present multiple electrical actuators (e.g. some of them are motorized in every joints) increasing the complexity and the price [3–5]. Other devices are equipped with tendon driven transmission systems [6] ensuring: light structures, high level of flexibility and adaptability, with the only limitation in the maximum payload.

Concerning industrial applications, the complexity of anthropomorphic hand is often not required, in fact, most of the industrial robots are equipped with two fingers grippers, usually customized on a specific object. However, a flexible device, capable of adapting to a large variety of objects [7], could be a suitable solution in order to reduce the set-up time and the costs related to the adoption of customized grippers for each specific task.

The study of the minimal number of fingers to guarantee stable and safe grasping began in the early 1980s. A pioneristic work on this topic has been presented in [8]. In general it is possible to assert that three is the minimum number of fingers required to reach a stable grasp [9].

The interest in three finger hands is also confirmed by a large number of new devices presented on the market during last few years, Fig. 1 (a–d) shows some examples that represent the state-of-the-art in this field. These devices are characterized by different design concepts such as: the Schunck [10] and the Barrett [11] hands with 2-phalanges per finger respectively actuated through: a DC servomotor for every joint and through a tendon driven system Fig. 1 (d–a). On the contrary, the Robotiq adaptive gripper [12] and the Kinova JACO Gripper [13] presents an underactuated structure with a transmission system based

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[1] Applying the paradigms of circular economy.

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(a) Barret 3-finger (b) Kinova JACO Hand (c) Robotiq 3finger Gripper

(d) Schunck 3-fingers (e) RightHand robotics 3-finger (f) Sandia 4-finger

Fig. 1. Some examples of commercial three fingers robotic hand.

on a mechanical linkage Fig. 1 (c–b).

Sandia hand and the RightHand robotics hand[2] reported in Fig. 1(e–f) need a special mention. The first one is a 4-fingers modular device where the number of fingers can be changed [14] attaching or removing fingers according to the requirements of the specific task. The second one, even if it is not still a commercial product[3] represents a device with significantly different design respect to the previous ones. First of all, the underactuation is obtained through a tendon driven transmission system, furthermore, joints between phalanges are made with flexible material letting it bend on contact to match the shape of objects enveloping the finger around it. This technique is known as passive adaptation [15]. The main drawback is the payload, limited by the tendon driven transmission system [16].

The emergence of new class of underactuated adaptive grippers represents a further improvements for the flexibility of grasping systems. As described in [9] an underactuated mechanism presents less actuators than degrees-of-freedom (dofs). The underactuation enables the finger to adapt itself to the shape of the restrained object [17,7,18]. In this way, only one actuator per finger needs to be controlled simplifying the control strategy.

The most diffused control strategies are based on position control with force threshold [19], when the threshold is exceeded, the finger movement is stopped even if the final position is not reached. This approach does not guarantee a stable grasp and requires a preliminary knowledge of the object to be manipulated. In fact, the user needs to set a proper restraining force in order to avoid damages on the object. More advanced control algorithms exploit the use of force/tactile sensors placed into the finger phalanges. Unfortunately, force/tactile sensors are not always easily integrable and compatible with the hand controller, furthermore, for industrial applications is preferable to reduce at minimum the number of sensors. At the best of our knowledge, there are no examples of commercial devices equipped with suitable sensorless object-detection strategies, these lacks have therefore provided the motivations of this work.

> On the basis of the state-of-the-art presented above, the herein presented work investigates, verifies, and discusses the advantages introduced exploiting the use of a control strategy designed for a sensorless object-detection applied to a standard underactuated hand. The goal is to recognize the presence of any object, using only the positions and the currents measured from the actuators of each finger, without using any other external sensors but exploiting a joint impedance control scheme combined with a state-observer.

The developed impedance control scheme [20,21] works as external loop according to the standard controller adjusting the position set-point to the estimated kinematics state computed from the kinematics model of the finger. The algorithm allows to manipulate any object without having a preliminary knowledge of their physical characteristics (e.g. materials, stiffness, shape, etc.). Thus, it enables the grasping without setting the restraining force. At the same time it avoided the risk of damaging the surfaces of the objects with a wrong tuning of the restraining force. The platform chosen to carry out the experimental tests is the well-known Robotiq three fingers hand, one of the most important underactuacted robot hands available on the market.

*Remark***.** Notwithstanding the adoption of the Robotiq hand, this work presents a general method and solutions applicable to a wide range of underactuated hands.

[2] The RightHand robotics hand is derived from the prototype realized from iRobot Harvard-Yale (iHY) for DARPA challenge.

[3] A pre-series is already delivered to some universities and research centers.

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