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Stable and repeatable grasping of flat objects on hard surfaces using passive and epicyclic mechanisms

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ABSTRACT

The stable and repeatable grasping of objects lying on a flat hard surface is addressed in this paper. A physical model of an object lying on a flat surface and its interaction with the environment and with a gripper is proposed. The important parameters governing the interaction are obtained. From this model, a grasping procedure is established and a robotic gripper is modified in order to grant the ability to pick up large thin objects lying on smooth hard surfaces. The procedure is implemented to demonstrate its repeatability on a chosen set of objects. It is shown that by sensing the force applied on the object and by taking advantage of the nature of the contact provided by the passive joint of the modified finger, a wide range of previously not directly graspable objects are made graspable via the application of a general approach. The experimental results reported clearly show the benefits of the simple force sensing implemented in the gripper as well as of the use of passive joints when interacting with very stiff environments. The proposed approach, while simple, yields a repeatable solution to a complex manipulation problem.

1. Introduction

Applications of industrial robots are quickly expanding and so is their task definition. In most instances, the key component is their end-effector, either a specialised tool, a gripper or a hand. Industrial grippers are often designed for a single task and are frequently made with tools that need to be replaced if the operation changes [1]. On the other hand, human inspired grippers, or robotic hands, are meant to cover a wider spectrum of tasks, but come at a higher price and are more complex to operate. Simpler and more specialised grippers are present in industries such as food packaging, foundry manipulation, car assembly and are starting to appear in the agriculture industry to harvest vegetables or process them [1,2].

The analytic investigation of grasping is being addressed by many researchers for different finger designs in order to achieve a force closure on the object [3–6]. It was shown that a more stable grasp is achieved by a form closure instead [7,8], i.e., a force closure without considering the friction forces. If human hands inspire dexterous robotic hands, the study of their taxonomy also helps the design of simple grippers [9], sometimes with the use of pattern recognition tools [10,11]. Indeed, 60%–70% of human grasps use only two fingers [1]. It should also be noted that many analytically derived grasps — although theoretically possible — are not achievable due to the potential for ejection of the object [5] or interferences with the environment (occlusions).

This research targets a special case of object grasping that most simple grippers cannot achieve and that challenges dexterous robotic hands. Indeed, the grasping of a flat object on a flat surface is a complex task to perform without taking advantage of a nearby wall or edge. Specific solutions exist, such as electromagnetic grippers [12], which focus on generating artificial friction on a wider range of materials than metals but which are ill-suited for electrically sensitive objects such as electronic components. Other examples of tailored solutions are the use of vacuum grippers [13], which are less effective on uneven or porous surfaces, or the use of the universal gripper [14], which relies on positive and negative pressures to grasp parts with a membrane containing granular material. Soft fabrics in industrial plants can be manipulated with a suction gripper. However more versatile solutions are required in industry, i.e., to extend the abilities of simple two- or three-finger grippers for the grasping of flat objects. According to the most commonly used taxonomy, grasps are often categorised as power grasps, lateral grasps, precision grasps or adduction grasps. The power and adduction grasps are ill candidates for a task, such as picking up a flat object whose bottom face is hard to reach. However, the precision grasp, for instance using the tip of the fingers, is a possible solution, as shown in [15,16]. In the former case, the finger tips flip small objects,

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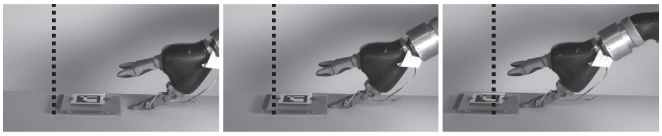
but this solution is quite restrictive regarding the object types and sizes. In the latter case, an underactuated two-finger gripper uses its compliance to transform the grasp in a parallel configuration, which is also greatly sensitive to the object size.

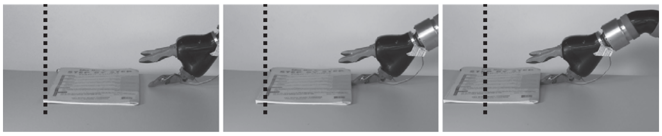
The type of grasp targeted in this study is the lateral grasp. In fact, the lateral grasp is one of the most common ways that humans use to grab objects, as observed in [17]. Following the study reported in [17], the authors introduced a hook finger designed for the lateral grasp showing great performances but restricting the thickness of the objects. An advantage of the lateral grasp is that it can be simplified to a planar grasp, since all forces are acting on a plane perpendicular to the flat surface, in which the fingers rest. It is worth mentioning that other strategies, relying on the environment more than on the finger design itself, can also be used to address this problem. For instance, pushing the object toward the edge of a table to grasp it [18]. Another option is to generate a trajectory of the object to take advantage of its dynamics [19–22]. Obviously, these types of strategies are less versatile because they either rely on specific features other than the flat surface in the environment of require fast moving manipulators. Trivial solutions to the problem include the use of suction cups, which is a well known solution that cannot be used for some objects (e.g. porous surfaces) and the use of spatula-like devices to slide under the object and lift it from the ground [23]. The fundamental issue with a spatula-like device is that it cannot be inserted under objects solely by moving towards them: it is necessary to have a reaction force that act on the object to maintain it in place. Section 2.2 explains mathematically why this happens. This reaction force can be the friction between the object and the surface. However, in most cases this strategy fails due to the surface being too smooth to generate the necessary friction as shown in Fig. 1. Another solution would be to approach the object at great speed so that the inertia of the object maintains it in place to some degree. This, however, could result in ejecting objects in the case of insertion failure. In [23] a finger-like mechanism is proposed that goes around the object effectively pushing the object onto the spatula-like platform. All of these solutions rely on the assumption that the objects fit entirely onto the spatula or at least the centre of mass of the object can be located onto the platform. The advantage of using a system that includes opposing fingers is the ability to hold the objects within the grip and orient them arbitrarily even though the centre of mass of the objects is outside the grip itself.

(a) Original gripper performing pinch grasp (b) Modified gripper performing a pinch grasp

Fig. 2. The same grasping procedure performed by the original and modified gripper to demonstrate the equivalent basic capabilities of the new design compared to the original.



(a) Spatula-like thumb failing to insert underneath a rigid object (Rigid CD case)



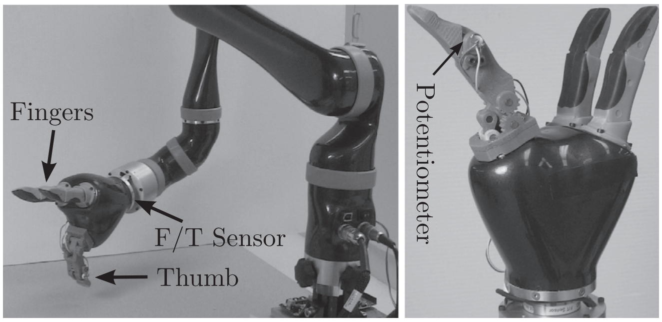
(b) Spatula-like thumb failing to insert underneath a flexible object (Flexible booklet)

Fig. 1. Two examples a manipulator sliding a spatula-like thumb towards two objects (Rigid and Flexible) and failing to perform a grasp because of low friction between the object and the surface. The dotted line represents the initial position of each object.

The goal of this study is to investigate the grasping of objects lying on levelled planes by means of rigid manipulation to obtain a final lateral grasp. A recent study [24] focuses on cases where the gripper exploits the environment constraints to bring the object in a state otherwise unattainable by gripper means alone. It then proceeds to validate these strategies by comparing them to measures of human grasping in controlled environments. This paper instead focuses on the model of the manipulation of a planar rectangular object of unknown size lying on a flat levelled surface and proposes a solution to reach a lateral grasp. The solution is then tested by fitting a custom finger design to the Jaco robot, shown in Fig. 3. The original gripper is considered as a pinch gripper in order to emulate common industrial grippers and the enveloping capabilities of the Jaco hand (underactuation) are not considered. Fig. 2 shows the grasping of a coffee cup with, (a) the original gripper and (b) the modified gripper to show that the basic grasping capabilities of the original gripper are preserved in the modified gripper. Indeed, it should be emphasised that the goal of this work is to get the fingers in opposition on each side of the object and not to study whether the final grasp is optimal or not. The proposed grasp procedure is then automated and performed by the proposed finger mechanism and the grasp process is shown to be repeatable. The contributions of this research are the analysis of the closed-form grasp for a flat object on a flat surface, the design of a novel finger and a closed-loop control experiment for a mechanical gripper. This paper is structured as follows. The interaction model of a finger with a flat object is first described in order to provide insight into the design choices of the novel finger, based on a thorough analysis. The relevant design parameters are then used to justify the design choices that led to the prototype. The results of the many grasping tests that were conducted with the prototype are then reviewed and the performances of the proposed finger and grasping strategy are assessed. Finally Section 4 provides a discussion on the repeatability of the proposed solution.

2. The proposed method

As mentioned above, this work addresses the grasping of a flat object resting on a smooth flat surface. The main motivation for investigating constrained grasping problems is the need for robotic



(a) Manipulator (b) Close-up of the gripper

Fig. 3. The proposed mechanism mounted on a Jaco arm.