A grasp manipulation selection chart to pick-up objects lying on hard surfaces

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***Abstract*—As robotic systems have to solve more and more complex problems, engineers are attempting to create systems that can perform the largest possible set of tasks. To evaluate the needs of the system to be implemented, both the task to be accomplished and the capabilities of the robot must be considered. One critical aspect of the studies is the link between the robot and the environment/object which is the end-effector. Specialised end-effectors are the ones designed with a well defined task in mind and are task specific, as opposed to general purpose end-effectors, which aim to be robust but execute most tasks rather poorly. General purpose grippers are designed to hold a variety of objects but are increasingly required to pick objects in real-world environments in a safe manner. With this in mind, this paper studies grasping methods found in the literature to compare them and emphasize the importance of compliant/soft end-effector compared to the use of force control techniques when interacting with rigid real-world environments.**

***Index Terms*—Grasping, Manipulation, Parallel Grasps, Gripper, Scooping, Workspace, Constrained Environments.**

I. Introduction

The study of object grasping is a very diverse research topic, where the goal of the robotic system is to perform a task. The engineer must determine the needed applied forces on the environment or through a tool held by a robot. The set of forces and torques that can be applied is called the wrench space and is an ongoing research topic [1]–[3]. Because of the complexity of the interaction between an end-effector and an object, simply holding an object with a gripper/robot hand is a complex problem when in presence of external forces like gravity, uncertainties and positioning imperfections [4]. An interesting aspect of object grasping consists of the study of mechanisms that have stable grasp properties [5], meaning that the grasp is robust to external forces to a certain degree. The study of underactuation, which relies on extra degrees of freedom in the hand to mechanically adapt to the shape of objects to obtain form closure [6], [7], is also an ongoing research topic which alleviates the reliance on many motors and complex control.

While previous studies provide an understanding of the quality of the pose of objects within an end-effector, another important research issue is the manipulation processes that can lead to said poses. Some of the references in this area propose tools to quantify the ability of an end-effector to manipulate objects [8]. This leads to the concept of intrinsic [9] and extrinsic dexterity [10]–[12]. In this paper and according to [10], the difference between the methods is that the latter is allowed to use resources external to the gripper, like gravity or a surface, while the former is not. Studies have analysed the human hand, the grasping processes performed by humans [13], and the optimal use of anthropomorphic hands [14]. These all take advantage of extrinsic dexterity to a certain degree. Because of the fact that most objects are resting on a surface under the action of gravity, environment properties can be leveraged into effective grasp methods.

The goal of this paper is first to analyse the grasping methods found in the literature for objects resting on hard surfaces and enumerate the features and algorithms necessary to perform them. Second, the need to interact with the environment for performing grasping in future designs is made clear.

First, the motivation of this paper and the scope of the grasping scenario are presented in Section II. This section aims at clearly stating which cases are considered and why this paper is a proposed starting point for future general purpose grasping algorithms and not a definitive step by step guideline. The methods and the features needed for each of them to work are then summarised in Section III. Section IV then presents a chart outlining each method's steps, a suggested selection guide considering object properties, and examples objects that can be picked up. Finally the crucial features that make each method work and how each can be implemented are discussed in Section V.

II. Motivation

As mentioned above, whether it is in industrial settings or in day to day life, most objects rest on surfaces ranging from the very hard to the very soft. Assuming that enough sensors or vision apparatus are available to detect the pose and orientation of an object, it is not always possible for a robot arm to pick said object. One possible cause for this is simply for the object to be too far away from the end-effector to even be touched. Those cases are not considered in this paper because solutions like using a mobile robot or, for example, a mobile shelve can

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easily resolve this issue. Considering now that the object is in the workspace of the robot, the option of bringing it to the edge of the surface on which it rests to grant access to its side is not considered [15]. However, re-positioning the object in the workspace is allowed in order to prevent failures that would be due to a non-achievable pose of the robot rather than the properties of the gripper. An example of this is an object which can be touched but not approached due to an overhanging obstruction. In that case the robot would be allowed to pull the object to a more suitable area. To prevent the need to specify dimensions, grippers are considered to have an opening of length, *Max opening*, similar to that of the human hand and shown in Fig. 1. With regards to the size of the

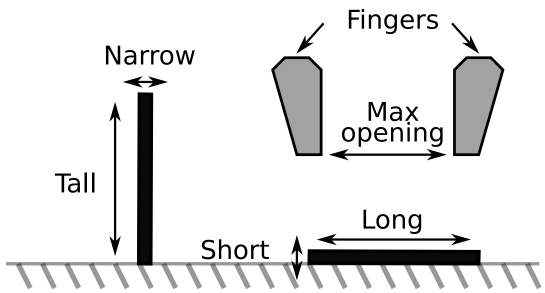

Fig. 1. Primitive of the fingers and object that are used to describe the grasping methods.

objects, the attributes *Long* and *Tall* of Fig. 1 are assumed bigger than *Max opening*. Similarly, *Short* and *Narrow* are assumed smaller than *Max opening*. Finally, the motivation of the paper is to study the methods to pick up an object that is resting on a hard surface which possesses at least one side shorter than the value of *Max opening*.

III. Methods considered

The methods used in this paper are presented in this section. Each subsection summarizes how the method is performed and cites studies where they appeared.

A. Direct Grasping

The direct grasping approach is one of the most common approaches to picking up objects. The basic steps are to approach the object, activate the grasping mechanism and leave with the object as shown in Fig. 2. Examples of direct grasping

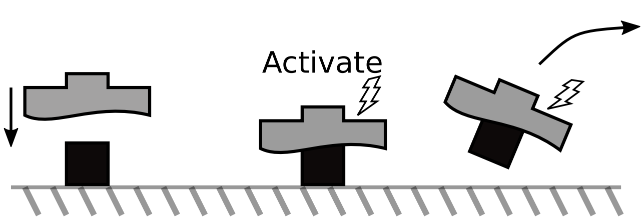

Fig. 2. Direct grasping of an active surface end-effector.

include end-effectors that take advantage of the friction force and the jamming of objects [16], [17], and mechanisms which use suction to lift the objects off the surface [18], [19]. These types of end-effectors may be able to pick a wide array of objects, some of which are larger than the end-effector itself, but are ill-suited to pick porous objects. Furthermore, some applications prohibit these types of grippers for the simple reason that an end-effector power failure would release the objects.

Another solution to this problem is the use of mechanical end-effectors in the form of finger grippers. Some of those being self-locking, which are not susceptible to object release upon power failure. The usual direct grasping approach of these grippers is shown in Fig. 3 where the end-effector

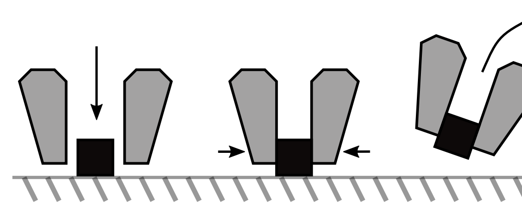

Fig. 3. Direct Grasping of a two-fingered end-effector.

approaches the object, stops before hitting the resting surface, closes the fingers applying pressure on the object then leaves.

The advantage of this approach is that it yields a large area of contact between the fingers and the object and, should there be friction between the object and the finger, both can be easily reoriented together. However, this approach relies heavily on the assumption that the object is *narrow* and that this *narrow* surface is accessible directly. Furthermore, the required distance between the surface and the fingers reduces as the object being picked up is shorter, hence increasing the danger of damaging the equipment or the environment.

B. Contact Grasping

A solution to picking *short* objects by mechanical means is shown that takes into account the contact with the environment in a relatively safe manner [20]. The method, inspired by the human grasp, is shown and outlined in Fig. 4 where a

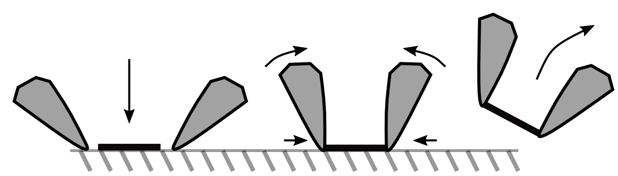

Fig. 4. Contact Grasping of a two-fingered end-effector.

deliberate contact is made by the fingertips with the surface, then the control method implemented applies forces on the surface with the fingertips while closing the fingers until both make contact with the object. This ensures that the fingertips are as close as possible to the surface. Next the gripper rotates the fingertips until their surfaces are parallel to each other, hence granting the maximum contact area between the object and the fingers, then leaves.

The critical aspect of this method is the ability to maintain the contact with the surface via force control. Robots that are very rigid require a high performance control to apply a force on a surface in a safe way and to react to the initial contact with the surface without damaging the equipment and environment. An alternative to using force control is the use of extra degrees of freedom in the form of passive joints at the distal phalanges [11], [12] or to use soft grippers that deform passively after the initial contact [21], [22]. However, the former method introduces complexity in the mechanism while the latter reduces the rigidity possible in a mechanical rigid end-effector.

C. Scooping and flipping methods

The preceding method showed how the direct grasp of a *short* object was possible if the contact with the surface can be managed. In this section is considered the grasping of objects where the final grasp uses the surfaces of the object that yield the most contact area but where such surfaces are initially occluded because they are facing the hard surface. A variation of the contact grasping method shown in section III-B and in [22] is used in [13] to apply pressure on both sides of the object and then lift one finger while maintaining pressure to flip the object inside the finger and hence achieving contact on the previously occluded object surface. A more static method that does not apply pressure on the object until the final contact is proposed in [11], [12] which slides a sharp finger from the side of the object instead of lifting it, as shown in Fig. 5. Other researchers have used a similar concept where a finger scrapes the surface from the side bringing the object onto the sharp finger [23]. This method, however requires the extra finger to do the scraping.

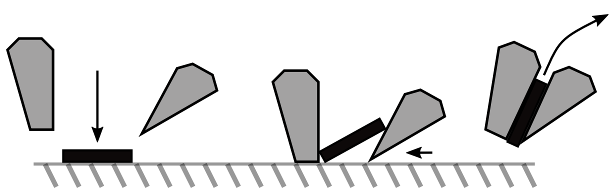

Fig. 5. Scooping a thin, *narrow* object with a two-fingered end-effector.

A variation of the method is used in [12] where the objects are too large for the gripper to create a wall and insert the finger at the same time. Instead one of the fingers applies a force on top of the object which in turn creates fiction maintaining the object in place while the other finger is being inserted as shown in Fig. 6. Like the method proposed in section III-C, to use this approach a robotic system must be able to maintain contact with the surface with force control algorithms or the use of passive mechanisms outlining the compromise of sensing vs. mechanism complexity.

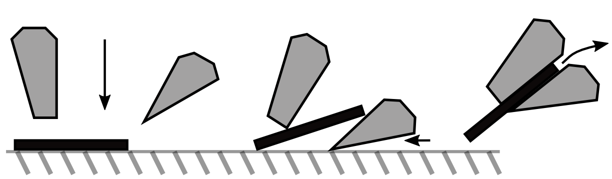

Fig. 6. Scooping a thin, wide object with a two-fingered end-effector.

D. Spatula Grasping

The last method presented is akin to the extrinsic re-grasping manipulation methods [24]. The dynamic approach, called Spatula Grasping, consists of a finger sliding fast towards the object and relying on the inertia of the object to resist it being pushed away as shown in Fig. 7. After the thumb is inserted under the object, the fingers are closed and the end-effector leaves. This method is simple to implement if the contact with the surface can be assured but might be considered dangerous in environments where humans are present. A static version of the method would be to slowly slide towards the object with a sharp finger angled and in contact with the surface. Should there not be enough friction between the object and the surface for it to remain in place, it will simply be pushed instead of being ejected at high speed.

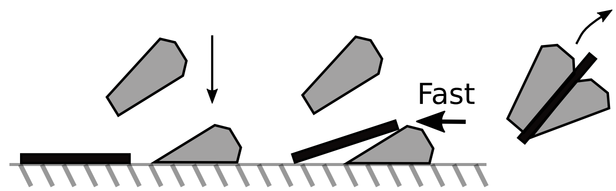

Fig. 7. Spatula Grasping with a two-fingered end-effector.

IV. The Proposed Selection Chart

In this section the flowchart shown in Fig. 8 is proposed to summarise the steps of the methods of section III and the shapes of the objects that would require a certain method to be performed. In the grey boxes are labelled the methods of section III, on the left hand side of these boxes, the decision process with regards to the object at hand is given, and on the right hand side, the steps to be performed. Finally, on the far right, examples of typical objects considered graspable by each method are given. Each method is terminated by what is called and end cap and suggests that something could be connected to it. This paper considers that the picking process was the task to be performed when in fact it is generally just a step in a chain of tasks to be performed. Hence the end cap is where a next step would follow, like to drop the object in a bin in the case of a pick and place task. Finally at the base of the chart are enumerated the critical features of each method without which they cannot be performed.

V. Discussion

By inspection of the chart, it can be observed that the boxes surrounding the example objects represent the methods by which they can be grasped. Hence a coin can be picked up using, spatula grasping, scooping/flipping and contact grasping but not direct grasping. It can therefore be observed that there is a compromise to be made between simplicity and size of graspable objects. In fact, by looking at the chart it can be noted that no thin object can be grasped without taking

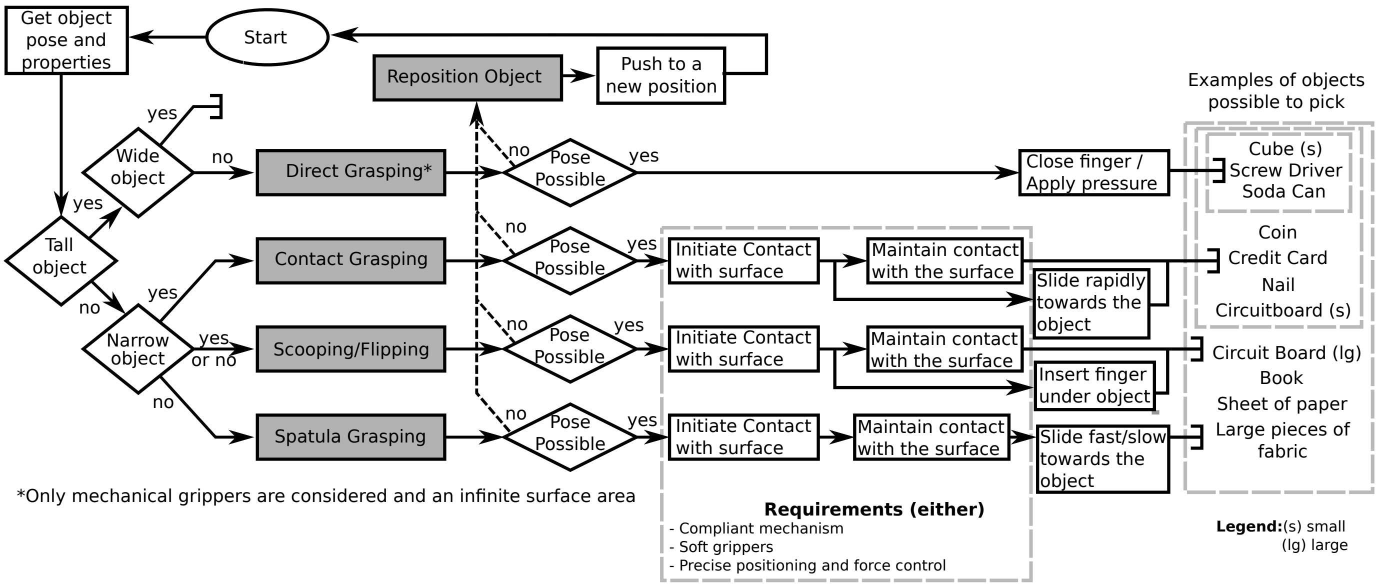

Fig. 8. Flow chart summarising the method selection, methods steps and example objects grasped.

the necessary steps to deal with the interaction with hard surfaces. As robots are becoming more and more effective in a smaller package, their introduction in households has motivated the design of small and safe robots. As their task definition continues to grow, this paper suggests that the use of soft or compliant mechanisms is key in providing safe and capable grasping solutions.

VI. Conclusion

This paper reviewed the main grasping methods proposed in the literature to introduce a study of the grasping of objects and furthermore the grasping involving interactions with the environment. Four methods were reviewed, their execution was studied and the critical features of each method were enumerated. Finally, all these methods were presented together in a chart to compare them and to highlight the fact that the performance and versatility a mechanical grasping process is greatly improved when using force control or compliant mechanisms. Soft grippers are equivalent to compliant mechanism when there is no need for rigid strong end-effectors and safety is of the utmost importance.

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