Designing Ultra-Low Cost Asymmetric Grippers for Human Tasks

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***Abstract*— To manipulate dishes in a human environment requires a variety of skills. This paper examines several gripper designs and proposes an asymmetric pair of grippers to handle common household items. Most approaches for gripping household items involves a single manipulator or symmetric manipulators. Through experimental practise, we have compared a variety of grippers travelling through typical tasks used in the kitchen, and found a pair of grippers that can manipulate the gamut of items.**

I. Introduction

A gripper is a device which enables the holding of an object to be manipulated. The easiest way to describe a gripper is to think of a human hand. Just like a hand, a gripper enables holding, tightening, handling and releasing of an object. There is no dearth of commercially available grippers in the market which have robust design and mechanical features. These grippers [8], [9] have shown significant demand in the industrial sector. However, the limitations posed by these grippers such as heavy weight, high cost, complex operating mechanism and intensive maintenance have aroused the need to develop grippers well suited for household purposes. The following sub-sections shed light on the various properties which are required in a robust gripper and the history of grippers which have been developed recently.

A. Properties of Grasping an Object

While grasping any object with a robotic gripper, the following factors influence the design of any gripper:

1) Friction between the grasping object and the gripper
2) Weight of the grasping object and the gripper
3) Shape and size of the grasping object and the gripper
4) How well the grasping object fits the geometry of the gripper
5) Angle of approach of the gripper
6) Manufacturing and maintenance cost of the gripper
7) Gripper compliance mechanism to minimize the contact forces [1]

B. History of Recent Grippers

As robotics advance along the technology adoption curve, businesses and companies started producing more powerful and efficient robotic grippers. In recent years, quite a few robotic grippers have been proposed and implemented for various industrial and household activities. The focus of research has mainly concentrated on grippers with more than two fingers. One of the important works includes the three fingered dexterous Barrett Hand developed by Bill Townsend in 1988 [8] which can grasp objects of different sizes, shapes, and orientations. Apart from flexing the three fingers individually, the Barrett hand also allows a fourth degree of freedom which permits switching between an enveloping grasp to grasp with an opposing thumb [3].

The three fingered pneumatically-driven underactuated hand developed by Laval University has a behaviour similar to human hand [2]. It is a self-adaptive and reconfigurable hand with gear differential mechanism that provides the underactuation between the three fingers.

The Robonaut Hand developed by NASA Johnson Space Centre in 1999 [10] has a total of fourteen degrees of freedom. A Robonaut Hand is composed of two sections: dexterous work set used for manipulation and grasping set for maintaining a stable grasp while manipulating or actuating a given object.

In 2000, German Aerospace Research Centre produced DLR Hand II [11] with four identical fingers and three degrees of freedom in each finger. There is one additional degree of freedom in the palm making a total of thirteen degrees of freedom in the hand. The three independent joints of each finger are equipped with appropriate actuators.

Another prototype of a human hand was developed by Shadow Robot Company in 2002 referred as Shadow Hand [9]. The twenty four movements of this five fingered hand allow a direct mapping from a human to the robot whereas the forty compliant muscles allow the usage around soft or fragile objects.

A similar robotic five fingered hand closest to the human hand is UB Hand 3 developed by University of Bologna in 2005 [4] where each finger can have up to four degrees of mobility making up a total of twenty degrees of mobility for the hand. In order to obtain the mobility by means of elastic joints, the compliant mechanism is applied for the internal structure of the hand.

The hand by Aaron Dollar [5] is a novel compliant robotic grasper which enables successful grasping and minimizes contact forces in the event of unintended contacts for unstructured environments [1]. The construction of fingers utilizes polymer-based shape deposition manufacturing [6]. This actuator of this hand enables eight degrees of freedom [7], thereby achieving a high level of robustness, adaptability and durability.

This paper illustrates four different designs of a robotic gripper developed by the author for kitchen usage. The paper primarily focuses on the design, mechanics and testing methods for the grippers. The different designs of the gripper are the various types of gripper that could be made at work.

The mechanics of a gripper is the section based on the factors that are taken into consideration when gripping an object. The testing section lists the methods which were used for testing each type of gripper. The testing results are provided in the later section of the paper. Finally, the paper concludes with a brief conclusion on the three gripper types and recommendations for future.

II. Manipulation Theoretical Framework

A. *Problem Space*

To be representative of the sorts of objects encountered in a human environment, we selected the domain of items in the kitchen, and the task of moving dishes from a table to a dishwasher. The objects that we identified as representative are: plate, cup, spoon, bowl, huge dish, playing cards and pen. Some work has been done in this area, with [1] using a CD, wine glass, wood block and volleyball as representative objects. This approach is encouraging, but when we examined that gripper with the target set of objects, some shortcomings appeared. The following gives an overview of our design.

B. *Domain of Investigation*

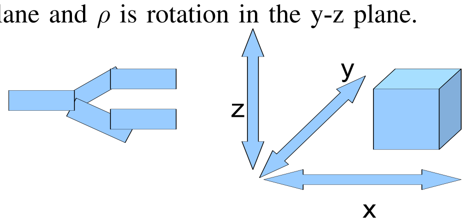
Manipulation of an object goes through three stages which are:

1) the gripper makes a solid grip on the object either unilaterally, or through coordination with a brace
2) the object is carried to the destination
3) the object is oriented for release in the target location

The motions needed will be represented by a 6-tuple

$$(x\ y\ z\ \theta\ \phi\ \rho\ ) \tag{1}$$

where x is forward motion, y is lateral motion, z is vertical motion θ is rotation in the x-y plane, ϕ is rotation in the x-z plane and ρ is rotation in the y-z plane.

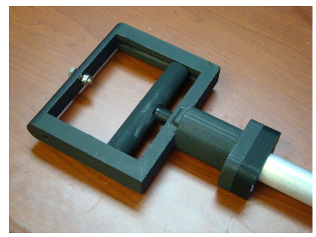


1) Grasp: For an ultra low cost gripper, the feedback of the system will be either based around visual inspection of whether the gripper succeeded or will use low resolution gripper feedback that measure the forces that act upon the grasping mechanism [12]. We will focus on visual inspection for this investigation.

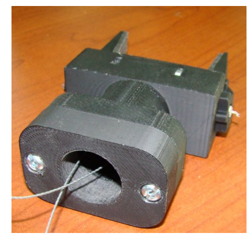
We will be measuring the grip that is made by testing if the object is stably lifted off the table. This is done with a rotationally invariant motion upward. That motion can be represented by the 6-tuple $(0\ 0\ 1\ 0\ 0\ 0)$

2) Carried to Destination: In addition, a carried object which could contain liquids needs to be transported smoothly and stably in the same orientation that it was sitting on the table. The motion representative of this is represented by the 6-tuple $(1\ 1\ 1\ 1\ 0\ 0)$

(a) Assembled Rig



(b) Handle



(c) Gripper Palm Cap

Fig. 1. The assembled test rig with the Blended 4-DOF hand on one end, the actuation handle on the other end.

3) Oriented for Release: Finally a carried object needs to be reoriented to empty it of any liquid or place it in target location such as a dishwasher rack. Modelling human behaviour would suggest that the motion would be normally $(0\ 0\ 0\ 0\ 0\ 1)$ but maintaining a stable grip with this rotation is challenging. We will propose a change in orientation of $(0\ \ 0\ \ 0\ \ 0\ \ 1\ \ 0)$ instead with the gripper designs that are examined.

III. Gripper Design

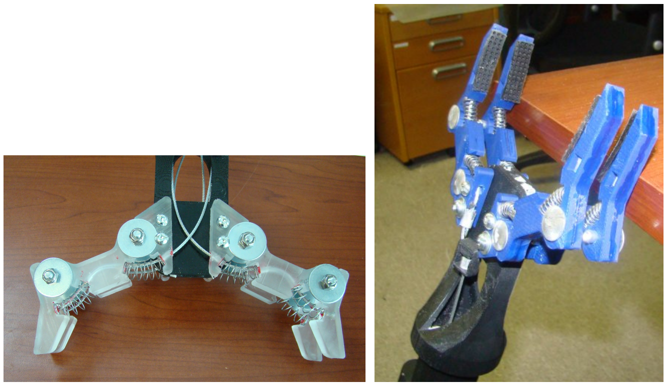
To conduct these tests, six grippers were manufactured on a rapid prototyping machine out of ABS plastic. This plastic allows for testing of the strength properties as well as the functionality of the grasp for each design. In each case we compared each design and took the best of them.

A. *Testing Rig*

To test each of the successive designs of the grippers, it was necessary to build a test rig that allowed for one degree of actuation (DOA) for the manual testing of the different designs of the grippers. This was done with a single tendon wire moving from the actuation handle to one of the six hand designs that were tested.

All of the designs examined had one degree of actuation (1-DOA) even if the joints represented more degrees of freedom (DOF) this is the same notation that is used in [2]. The flexible joints were connected to a single actuation tendon.

When a new hand design needed testing, the gripper palm cap in Fig. 1(c) was replaced and the cable was tensioned.



(a) Protoangular (b) Angular

Fig. 2. The two angular designs that were tested

B. Angular Design

With the protoangular design in Fig. 2(a), in open position the finger tips are 7” apart. For the finger design the first phalanx is 2.5” long, and the second phalanx is 1.5” long. The material in these fingers differ from the rest of the test fingers in that it was made of the polymer mentioned in [1].

With the angular design in Fig. 2(b), in the open position the finger tips are 4.5” apart. For finger design the first phalanx is 1.75” long and the second phalanx is 2.25” long. Also it was supplied with finger pads made from a non-slip iPod car mat. In addition, it was supplied with a much better fingernail that is pointed to allow for better initial grip of objects that are close to the table.

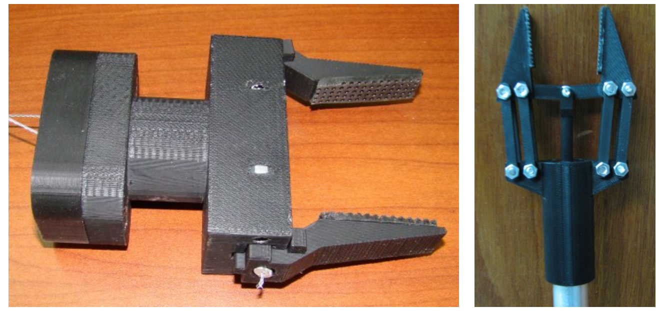
In both cases these are derived from the Harvard style hand described in [5] with 4 fingers and 8-DOF. The fingers in this design return to their natural position with compression springs. When closing the relative strength of the compression spring between the palm and the first phalanx versus the strength of the compression spring between the first phalanx and second phalanx controls which order the joints close in when the tendon in each finger is pulled.

Compliance in both versions are achieved by pulleys balancing the forces between the fingers in two layers. The first layer balancing the force on the top finger or bottom fingers and the second layer combines the pairs of fingers.

C. Parallel Design

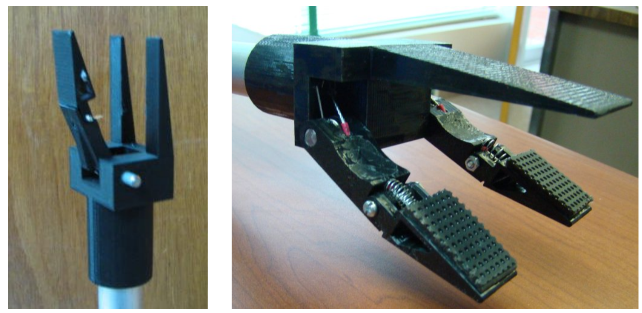
The track parallel design Fig. 3(a) was constructed with a finger length of a at rest spread of 2” and a finger length of 2”. Each finger is attached to a tendon that was attached to the actuation tendon. It uses two compression springs to move the fingers back to the rest position.

The rod parallel design in Fig. 3(b) uses a piston design to transfer the pull of the tendon to the fingers. This pulls on two rods which are in turn connected to the second phalanx. The fingers are kept parallel by eight rods that are attached to the palm and second phalanx. The at rest spread of the fingers is 2” and the length of the second phalanx is 2”.



(a) Track Parallel (b) Rod Parallel

Fig. 3. The two parallel grippers that were constructed.



(a) Blended 2-DOF (b) Blended 4-DOF

Fig. 4. Two grippers with some angular and some parallel fingers. With the 2-DOF finger the thumb bends and the two fingers are a wedge shape in a single pose. With the 4-DOF finger the fingers both bend and the thumb is in a fixed location.

D. Blended Designs

The Blended 2-DOF gripper in Fig. 4(a) has two fixed wedge shaped fingers 2.5” in length to place under large flat objects such as plates with no rubber finger pad, and one two section thumb with a rubberized second phalanx. The first phalanx is 1.5” and the second phalanx is 1.5” long. This design uses a torsional spring to connect the palm with the first phalanx and a compression spring to connect the first phalanx to the second phalanx.

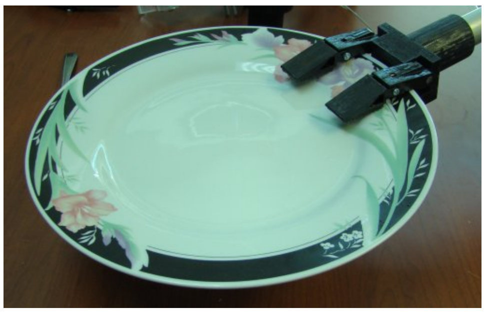
The Blended 4-DOF gripper shown in Fig. 4(b) is an inversion of design 3, with two 2-DOF thumbs and a fixed finger which is wider. The fingers have the same dimensions as the 2-DOF finger, but the thumb is 1.5” wide instead of 0.5” wide from the 2-DOF fixed fingers. This design also used the same combination of a torsion spring near the palm, and a compression spring between the two phalanxes.

E. Experimental Procedure

To carry out the tests, the target objects were placed on a table and the three stages of gripping, moving and orienting were conducted. Five trials were attempted on each item. The results are displayed in Table I. We chose to examine only the best gripper in each category for this paper.

The Angular gripper works very well with curved objects, but does not make enough points of contact on flat objects for a solid grip. With curved objects it contacts the object at 8

(a) Cup



(b) Plate

(c) Spoon

(d) Pen

(e) Bowl

(f) Playing Cards

(g) Huge Dish

Fig. 5. The everyday objects that were tested with the target grippers.

TABLE I

SUCCESS PERCENT FOR GRASPING OF 5 TRIALS

Object	Angular	Rod Parallel	Blended 2-DOF
Cup	100%	0%	0%
Plate	0%	40%	100%
Spoon	80%	20%	40%
Pen	100%	80%	60%
Bowl	20%	40%	40%
Playing cards	60%	60%	100%
Huge dish	0%	40%	60%
Average	51%	40%	57%

points whereas with a flat object like a plate, it makes contact with at most 6 points. This makes it challenging to lift the plate without the plate tilting in the ϕ direction during the grip stage $(0\ 0\ 1\ 0\ 0\ 0)$ motion.

The Rod Parallel gripper two fingered design makes just two to four points of contact on the target objects. Although it works well with objects with parallel sides, the majority of objects found in a human environment aren't designed with that in mind. In addition, plates and other flat objects are especially challenging to keep stably during the carry to destination stage $(1\ 1\ 1\ 1\ 0\ 0)$ with the plate rotating in place, or becoming unstable.

The Blended 2 DOF design works especially well with flat objects. With objects like plates there are 6 points of contact which gives a stable grasp for every motion except for the rotation around ρ. With careful management all three stages can be accomplished without rotating around ρ.

IV. CONCLUSION

Upon analyzing the results of the experimental procedure, the two designs with the greatest coverage are the angular design plus the blended 2-DOF design. By using these two grippers in their areas of strength it raises the overall success rate to be the highest for all of the objects examined as seen in Table II.

From building all of the test grippers there are a number of things that became clear. The dimensions of the target objects need to be grouped so that large objects can be easily grasped by one gripper and small objects can be easily grasped by the other gripper. Flat objects posed a problem for the angular grippers when it was critical to keep the orientation during the carrying stage of the manipulation. Also the finger lengths need to be tuned to make the easiest grip on each object. In addition the finger pads are critical to change a point into an area of grip but can sometimes interfere with the initial grasping stage, unless the object is braced against something else such as another gripper.

This raises the average grasping success rate to 89% which is much higher than any of the individual scores in the trials.

V. FUTURE WORK

The blended design could be further refined to allow for a more stable 8 point of contact grasp. This is especially

TABLE II

ASYMMETRIC PAIR OF GRIPPERS

	Angular	Blended 2 DOF	Combined
Cup	100%	0%	100%
Plate	0%	100%	100%
Spoon	80%	40%	80%
Pen	100%	60%	100%
Bowl	20%	40%	40%
Playing cards	60%	100%	100%
Huge dish	0%	60%	100%
Average	51%	57%	89%

valuable with the problematic angular motion in the ρ direction. Although the trials were conducted without a soft palm, it is possible that this could improve the number of points of contact. The amount of force applied to grasp very heavy objects decreases with the number of contacts that the gripper makes with the object. These relative forces could be measured experimentally. In experiments conducted with these trials, moving or orienting objects with a very tight grip would cause the gripper finger to break or crack at the point of stress.

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Removed for double blind evaluation.

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