Analysis and Comparison for a specified task between the capabilities of a constrained Human Hand and a Parallel Gripper

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Abstract—Achieving the dexterity of the human hand is still a far fetched idea for the robotic and prosthetic hands available today. Nevertheless, there have been attempts to come up with simpler models for constrained tasks to achieve similar results as a human hand for the particular task, if not the same general working complexity as the human hand. We perform a comparison between a simple two-fingered manipulator (parallel gripper) and a restrained version of human manipulation (using two fingers instead of all five fingers) to bring out the differences in their capabilities for the task of sorting 3-D shapes in a shape sorter. We present our observations of the capabilities of these two manipulators and characterize them in different contexts.

I. INTRODUCTION

A highly dexterous human hand allowing for in-hand manipulations along with a highly dexterous arm can possibly perform any task and thus is very complex to model. Dexterity has been defined in the following ways:

1. “(The) process of manipulating an object from one grasp configuration to another, Li et al.
2. “(The) capability of changing the position and orientation of the manipulated object from a given reference configuration to a different one, arbitrarily chosen within the hand workspace, Bicchi
3. “(When) multiple manipulators, or fingers, cooperate to grasp and manipulate objects, Okamura et al
4. “(The) kinematic extent over which a manipulator can reach all orientations, Klein and Blaho
5. “Skill in use of hands Sturges

For our purpose we assume dexterity to refer to all these definitions which in some sense refer to in-hand manipulations as best described by Bicchi and Struges above.

To understand the various capabilities of the human hand, it is important to understand what more it has to offer when compared with a simple robotic hand. We attempt to compare the grasps and motions carried out by a simple parallel gripper and the human hand. We restrict the human subjects to only use two fingers instead of all five fingers so as to better understand the advantages of human hand dexterity with regards to the gripper which also has two fingers. We look at the task of sorting 3-dimensional shapes in a shape sorter by both the gripper and the constrained hand of two experienced and two unexperienced human subjects. Two subjects had experience of using the gripper for sorting shapes for a period of about 7-10 days and two other subjects were novice users who had never used the gripper before. All the subjects were asked to sort the shapes in an unconstrained manner in the following ways:

1. using the parallel gripper
2. using the index finger and the thumb of the hand he/she is naturally inclined to use
3. using the index finger and the middle finger of the same hand
4. freely using all the fingers of the same hand

All the subjects were asked to finish the task as soon as possible by placing all the shapes in their respective slots.

We make observations in two domains - one from the perspective of task completion i.e. placing all the shapes in their respective slots in the shape sorter. Second we observe the different grasps for the gripper and the hand from the perspective of the manipulators. We analyze why certain grasps fail for the gripper and what advantages are seen for

Fig. 1. The hollow wooden shape sorter
the human hand while doing the same task.

II. EXPERIMENTAL SETUP

The experiment that we have chosen to compare restrained hand manipulation and gripper manipulation is to play a game of Shape-sorting. We have a wooden shape-sorter available to us (Fig 1), with blocks of various shapes to be fit in. The task is to pick up these blocks from a cluster and successfully place them in the right position in the shape-sorter. The environment of the experiment is unconstrained, the only change being the manipulator used to complete the task and the only condition being the use of just two-fingers instead of all five for manipulation of the blocks by hand.

The shape-sorter has four faces available, three of them are lateral and one is horizontal on the top. Each face has three different shape-cuts. For successful completion of the task it is required for the blocks to be pushed inside by matching the orientation of the block with that of the shape-cut.

The twelve 3-dimensional shapes available to us are (shown in Fig. 2):

1. Star
2. Parallelogram
3. Diamond
4. Parallelogram
5. Cube
6. Oval
7. Pentagon
8. Hexagon
9. Octagon
10. Triangle
11. Clove/Flower shaped
12. Trapezium

III. TOOLS EVALUATED

We conducted this experiment with three different manipulators.
1. Mechanical Parallel Gripper
2. Opposable Finger Manipulator (Human hand)
   Subjects are constrained to use the thumb and index fingers (as shown in Fig. 4), of their dominant hand to manipulate the various objects. We chose this configuration due to its opposable similarity to that of the simple gripper.
3. Parallel Finger Manipulator (Human hand)
   Finally, we have a parallel finger gripper (as shown in Fig. 5) which doesn’t have opposability support like manipulator 1 or 2, but was chosen because it seemed like a good approximation to the simple gripper constraint of only being able to use the two flat opposite sides to grip onto various objects without any skew.
IV. Observations

For each of the three manipulators, the first task was to put all 3-D shapes in their slots as soon as possible. During this activity every subject approached the task differently starting with the shapes they found more easier first. Table 1 describes the total time taken to complete the task by the two experienced and two novice subjects using all three manipulators.

It is clear from Table 1 that the novice subjects take more time to complete this task with the mechanical gripper as compared to experienced subjects who spent about a week to 10 days practicing with the shape sorter and the parallel gripper. There is hardly any difference in the time taken by all these users to do this task via the two manipulators of the human hand allowed in this experiment (since all subjects are trained since birth to manipulate objects with their fingers!). However, the manipulation of the hand using the thumb and the index finger is relatively easier for all subjects as compared to the manipulation with the index and the middle fingers.

We also describe here some general observations for each of the manipulators in the experiment.

A. Mechanical Parallel gripper

For the precision task of sorting these shapes, this gripper is not very dexterous and does not allow for in-hand manipulations. Thus the manipulation involves grasping the small 3-D shapes with the parallel gripper but the placement into the slots also heavily depends on the dexterity of the human arm which is connected to the gripper. Reorientation of objects within the hand is difficult, if at all possible. The surface area of contact between the gripper and objects is much larger than that available for human fingers. This leads to a higher chance of failure of putting objects inside the sorter as most of the gripper is covering the object leaving very little room for the object to sit in its slot comfortably and be pushed in. However for regular shapes such as the cube, cuboid et cetera this large surface area allows for comfortable grasping. For irregular shapes such as the trapezium and triangular block, the parallel gripper cannot get much surface contact with the non parallel surfaces, hence leading to loose grasps (not enough contact force, hence friction to balance gravity). The task involves placing the objects in their slots and pushing them completely so that they fall in the hollow wooden shape sorter. The subjects subdivided this into subtasks by isolating the object, gripping it, getting it in close proximity to the slot, placing and pushing it in. If held with more area of contact there is not enough scope left for balancing the object in its slot on the lateral side, hence often the object falls and an attempt is made to regrasp and push the object inside its slot. In general the time taken by all the subjects using this manipulator is higher than the other manipulators. Also placing shapes in the lateral surface of the shape sorter was harder and involved maneuvers of the human arm to reach the slot and push it in. Sometimes, subjects used extra force while holding the gripper or using two hands so as to balance gravity while placing the objects in their slots. The gripper fingers can only move closer or away from each other in a symmetrical fashion whereas the human fingers have extra degrees of freedom in this regard.

B. Opposable fingers of the Human Hand - Thumb and index finger

This hand configuration was chosen as it is similar to the opposing nature of the mechanical gripper fingers. Enough dexterity is available with this end effector, thus this manipulator does not use much of arm dexterity. Extra degree of freedoms are available due to the joints in the fingers which allow for bending and more flexibility in applying force to hold the object. The fingers can be bent accordingly to increase or decrease the surface area of contact to grip the object. There is also an extra degree of freedom in being able bring about a skew in the fingers such that they move up and down relative to each other and are not necessarily parallel while grasping the object. This allows the subjects to use the palm area of the fingers (inner) to be in contact with the objects or the edge (lateral) between the palm and the back hand area of the fingers (outer). All the subjects took almost similar and very little time to grasp and place all of the objects. Many a times subjects were seen using the friction between the fingers and object to slide one finger back while pushing the object towards its hole with the other finger. This describes the dexterity of this end-effector. It took much less energy to do this task due to this dexterity as compared to the previous manipulator.
C. Parallel fingers of the Human Hand - Index finger and middle finger

This gripping constraint for the human hand was harder for all the subjects as compared to the previous constraint and thus required more energy as compared to the opposable finger manipulator. It was chosen as it approximates the parallel facing nature of the fingers of the mechanical gripper. But every subject used the extra degrees of freedom available with the joints of the fingers, allowing for bending, thus making the approximation invalid. Here again the fingers can move up and down relative to each other allowing the user to use the lateral, inner and outer side of his fingers to hold the object.

Invariably across all subjects, the insertion of the shapes on the lateral sides of the shape sorter seemed harder than the three shapes needed to be dropped on the top most horizontal surface of the shape sorter, as gravity was in some sense acting against them and not in favour to successfully place and push the object inside its slot. To understand which shapes were harder to grasp for all three manipulators as compared to others, without this bias of placing some shapes at the horizontal surface and some at the lateral surfaces, we simplify the task and ask the subjects to place all objects in their respective slots by rotating the shape sorter to such that each slot is on the top most horizontal surface. This gives room to compare all shapes fairly just for grasping as points going in the sorter is hugely supported by gravity. Table 2 describes the time taken by each subject (subject 1 and 2 are inexperienced and subject 3 and 4 have practice using the parallel gripper) to grasp and put the object (subject 1 and 2 are inexperienced and subject 3 and 4 have practice using the parallel gripper) in its slot on the horizontal surface for the parallel gripper only.

In the end, we observed that different objects and have attempted to compile a summary of different maneuvers which the subjects performed to achieve task completion. We give five different kinds of characterizations in the form of five tables.

1. The different gripping configurations observed while manipulating objects with the parallel gripper (Table III).
2. The various maneuvers (other than just changing the gripper configurations) observed while subjects tried to complete the given task with the help of the parallel gripper (Table IV).
3. The various configurations of fingers observed while holding objects, in effect defining two-fingered grasp types (Table V).
4. The different manipulations (other than object grips) observed while the subjects tried to complete the task with the two-fingered hand manipulation (Table VI).
5. A comparison between the Mechanical Gripper and Two-fingered manipulators depending upon the observations made throughout the experiment (Table VII).

VI. Conclusion

For objects and tasks at scales, where precision grasps are sufficient for force closure, additional hand dexterity can sometimes achieve the goal state entirely within the hand subsystem without any additional action from the arm. By actuating only the smaller finger mechanisms, a dexterous hand can enable increased precision and speed compared to movements from a larger arm. Indeed, in human manipulation, the arm (or wrist) is often braced on a surface to decouple the hand and the arm in precision tasks, such as writing with a pen.

The subjects added their subjectivity to the study, by taking relatively more time to place one shape or the other into the sorter, their seriousness to do the task, their alertness and effort made by them. Different kinds of grasps and
maneuvers were analyzed for all three manipulators. Overall, the dexterity possible even by constraining a hand with two fingers overpowers the simple mechanical parallel gripper which offers larger support area to grasp objects. Significant comparisons, advantages and disadvantages were seen for the human hand and the parallel gripper.

It is important to note that the task that we chose to compare the gripper and two-finger hand gripper can be characterized as a near-distance precision task, which required more near-distance maneuvers and accuracy in terms of placing the shapes within the moderately tight boundaries. The extended arm of the gripper makes it slightly difficult for the subject to complete the tasks, since the accuracy requires the subject to observe the maneuver closely while operating the gripper from an awkward arm angle at the same time.

Moreover, the relative size of the blocks and the gripper wasn’t really comparable. The gripper required a greater area to achieve a good grip on the objects, while on the other hand in order to place the blocks inside the shape-sorter properly it was required for a certain amount of the block to dangle freely which could be pushed in. This wasn’t very easily achievable due to the smaller dimensions of the blocks with respect to the gripper which would sometimes cover more than half the lateral area to grip onto the blocks. The small size of the human fingers along with their dexterous capability of in-hand manipulations on the other hand suited the scale of the task very well.

However, the non-optimal setup of this experiment allowed us to observe the behavior of the gripper in a better manner. The difficulties in grasping allowed a greater domain of configuration space and maneuvers to be available to us which, we believe, helped us characterize and contrast the gripper with respect to human finger gripping in a more detailed way.

ACKNOWLEDGMENT

We would like to thank Professor Matt Mason for his guidance to help accomplish this project.

REFERENCES


Fig. 7. Using minimal area of the parallel gripper to hold the object gives room to successfully place the object in its slot.


### Table III
THE DIFFERENT GRIPPING CONFIGURATIONS OBSERVED WHILE MANIPULATING OBJECTS WITH THE GRIPPER

<table>
<thead>
<tr>
<th>Grasp Configuration</th>
<th>Snapshot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face-to-face Grip</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>Edge-to-Face Grip</td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>Edge-to-Edge Grip</td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
</tbody>
</table>
Table IV

THE VARIOUS MANEUVERS (OTHER THAN JUST CHANGING THE GRIPPING CONFIGURATIONS) OBSERVED WHILE SUBJECTS TRIED TO COMPLETE THE GIVEN TASK WITH THE HELP OF THE PARALLEL GRIPPER

<table>
<thead>
<tr>
<th>Maneuver</th>
<th>Description</th>
<th>Name of Video File</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slide In</td>
<td>While using one of the lower edges of the shape-cut as support to slide up the gripper's inner face to push the block in</td>
<td>gripper_slidein.mp4</td>
</tr>
<tr>
<td>Excess Force</td>
<td>To use excessive force to stabilize the grasp on an object if an optimal hold is not achievable</td>
<td>gripper_excessforce.mp4</td>
</tr>
<tr>
<td>In-hand Manipulation With Extraneous Support</td>
<td>To manipulate an object while gripping it &quot;in-hand&quot; by using the edges or faces of an external surface as support/aid</td>
<td>gripper_inhand_manipulation_using_support.mp4</td>
</tr>
<tr>
<td>Regrasp With Surface Support</td>
<td>To regrasp an object in the right configuration by changing its orientation with respect to the gripper by placing it on an external surface</td>
<td>gripper_regrasp_floor_support.mp4</td>
</tr>
</tbody>
</table>
**Table V**

**THE VARIOUS CONFIGURATIONS OF FINGERS OBSERVED WHILE HOLDING OBJECTS, IN EFFECT DEFINING TWO-FINGERED GRASP TYPES**

<table>
<thead>
<tr>
<th>Grasp</th>
<th>Description</th>
<th>Snapshot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opposable Configuration</td>
<td>Standard Grip: Gripping an object by holding it between the inner faces of thumb and index finger</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>Opposable Configuration Lateral Grip</td>
<td>Grip: Gripping an object by holding it between the inner face of the thumb and the lateral face of the index finger</td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>Opposable Configuration</td>
<td>One-Joint Hold: Gripping an object between the opposite faces of the thumb and index finger but while bending the index finger at upper joint to provide support at the lower faces of the object</td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td>Parallel Configuration</td>
<td>Standard Grip: Gripping an object by holding it between the two lateral sides of the fingers</td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>Parallel Configuration</td>
<td>Gripping an object with the two fingers curved in the shape of a tong</td>
<td></td>
</tr>
<tr>
<td>------------------------</td>
<td>---------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Curved-tong Hold</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Joint Skew Hold</td>
<td>Gripping an object between the inner and outer face of the two fingers with the fingers bent at upper or lower joint</td>
<td></td>
</tr>
<tr>
<td>Extra-contact Hold</td>
<td>Gripping an object in curved tong hold but with the inner faces of the fingers touching it, so as to give extra support to the grip</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parallel Configuration Arc Hold</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gripping an object between the lateral sides with one finger sitting straight on one face of the object while the other curving along with the irregular shape of the object itself</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table VI

THE DIFFERENT MANIPULATIONS (OTHER THAN OBJECT GRIPS) OBSERVED WHILE THE SUBJECTS TRIED TO COMPLETE THE GIVEN TASK WITH TWO-FINGERED HAND MANIPULATION

<table>
<thead>
<tr>
<th>Maneuver</th>
<th>Description</th>
<th>Video File</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opposable Configuration Multiple Object Manipulation</td>
<td>While holding the object to be pushed in by the thumb, the subject grasped the shape-sorter by hooking the index finger inside one of the shape-cuts and tilted the box to make the block fall inside</td>
<td>opposable_multiple_object_manipulation.mp4</td>
</tr>
<tr>
<td>Finger Slide To Push</td>
<td>After placing the object in the shape-cut, using the partial support of one of the edges keeping the object stable with the thumb while sliding the index finger back to push the object inside the box without losing contact</td>
<td>opposable_finger_slide.mp4</td>
</tr>
<tr>
<td>In-hand Manipulation Using Surface Support</td>
<td>While holding the object in opposable grip the subject achieved in-hand manipulation by changing the orientation of the object by using the floor as external support</td>
<td>opposable_regrasp_floor.mp4</td>
</tr>
<tr>
<td>Alternate Finger Change Maneuver</td>
<td>While holding the object in a parallel grasp, the subject uses an edge of the shape-cut as support and brings both fingers alternately to the back-face of the object and pushes it in without losing contact at all</td>
<td>parallel_alternate_change_push.mp4</td>
</tr>
<tr>
<td>In-hand Manipulation without External Support</td>
<td>While holding an object in parallel grasp, the subject changes its orientation to fit the cut-shape by rolling it between the inner face and outer face of the index and middle finger respectively</td>
<td>parallel_inhand_manipulation.mp4</td>
</tr>
<tr>
<td>Squeeze to Push</td>
<td>While holding the object in parallel grasp the subject squeezes out fingers to push the object further inside the shape-cut and then performs a final tap to make it fall in</td>
<td>parallel_squeeze.mp4</td>
</tr>
</tbody>
</table>
Table VII

A COMPARISON BETWEEN THE MECHANICAL GRIPPER AND TWO-FINGERED MANIPULATORS DEPENDING UPON THE OBSERVATIONS MADE THROUGHOUT THE EXPERIMENT

<table>
<thead>
<tr>
<th>Mechanical Gripper</th>
<th>Two-fingered Hand Manipulator</th>
</tr>
</thead>
<tbody>
<tr>
<td>While trying to rotate the blocks to match orientation to the shape-cuts, arm movement is crucial rather than the grip or the gripper</td>
<td>The movement of arm is not very crucial to task execution as the objects are mostly manipulated in-hand by exploiting finger dexterity</td>
</tr>
<tr>
<td>The subjects show apparent difficulty while trying to hold the Trapezium block from its non-parallel sides while using the gripper. This is due to the difference in slants of the two faces of the block and the sides of the gripper</td>
<td>While observing parallel grips it was observed that parallel grip worked well on the Trapezium block due to matching slants of the fingers and the non-parallel sides of the Trapezium. But on the other hand the grip performed pretty poorly with the Triangle block while trying to pick it up from the faces, since here in an analogous case slant of the faces of the Triangle was greater than that of the fingers</td>
</tr>
<tr>
<td>While trying to pick up the Trapezium block, one of the successful grips involved holding it from the sides as the flaps of the gripper held the bottom surface of the block thus stabilizing the hold</td>
<td>While trying to hold the Trapezium block with parallel grip, one of the successful grips involved holding the block from the bottom edges. And just like the flaps of the gripper the fingertips adapted to the shape of the block to provide support from the bottom, like “flaps”</td>
</tr>
<tr>
<td>Observed slide in maneuver to push in the blocks</td>
<td>Observed slide in maneuver to push in the block, very similar to the gripper version</td>
</tr>
<tr>
<td>Required extra surface support to perform in-hand manipulations, with arm movements involved</td>
<td>The opposable grip version also required external surfaces to perform in-hand manipulation of objects, albeit without any arm movements involved relying solely on finger dexterity</td>
</tr>
</tbody>
</table>