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Object Shape Exploration & Recognition Using a Two-Fingered Robotic Hand

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Outline

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- Our Two-Fingered Robotic Hand
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- Generation of the Object Model
- Shape Recognition and Size Estimation
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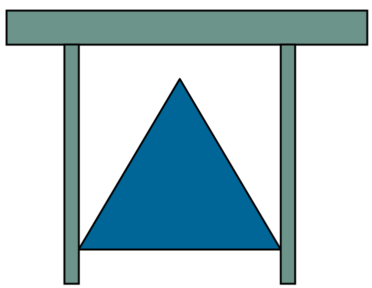
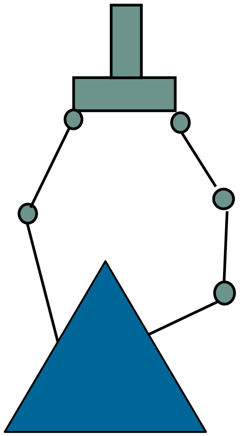
Introduction

- What is exploration?
- Why use exploration?
  - To supplement computer vision info
  - When vision fails (low lighting, highly-reflective surfaces, etc.)
- What can the shape & location data be used for?:
  - Feedback to a haptic interface
  - To model or recognize an object

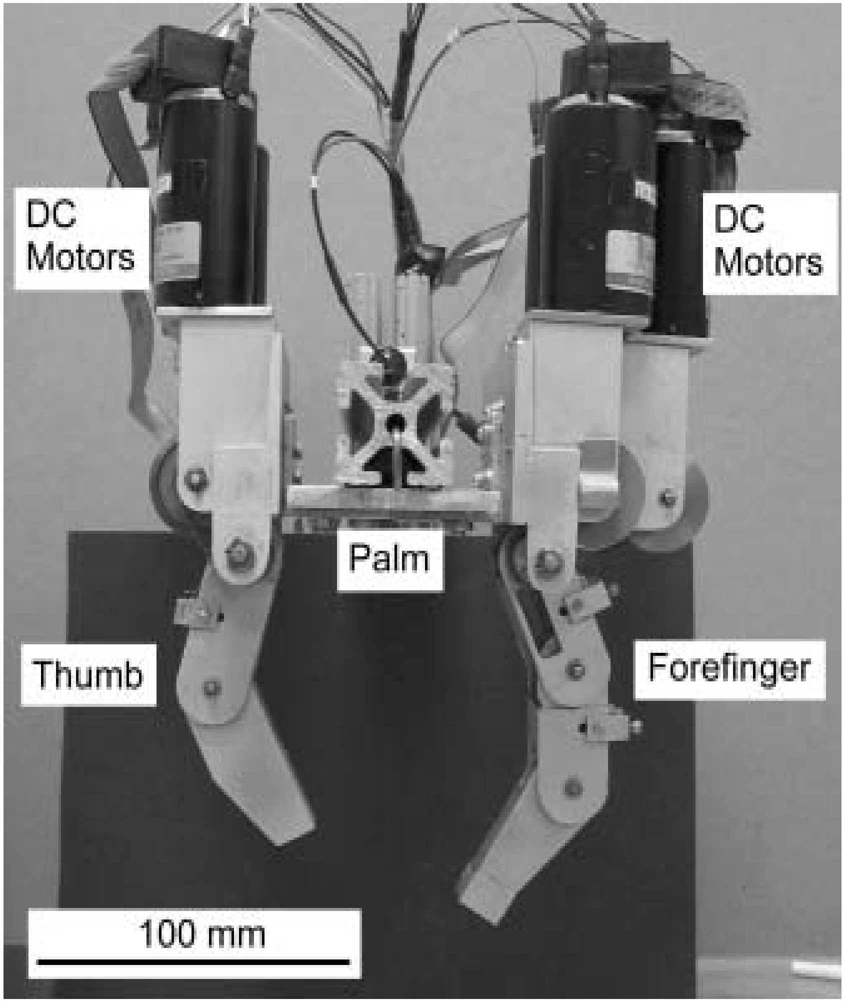
Introduction (continued)

- Previous researchers have explored objects using parallel-jaw grippers and dexterous robotic hands.
- The jaw position or the fingertip positions were used to gather information about the object.
- e.g.





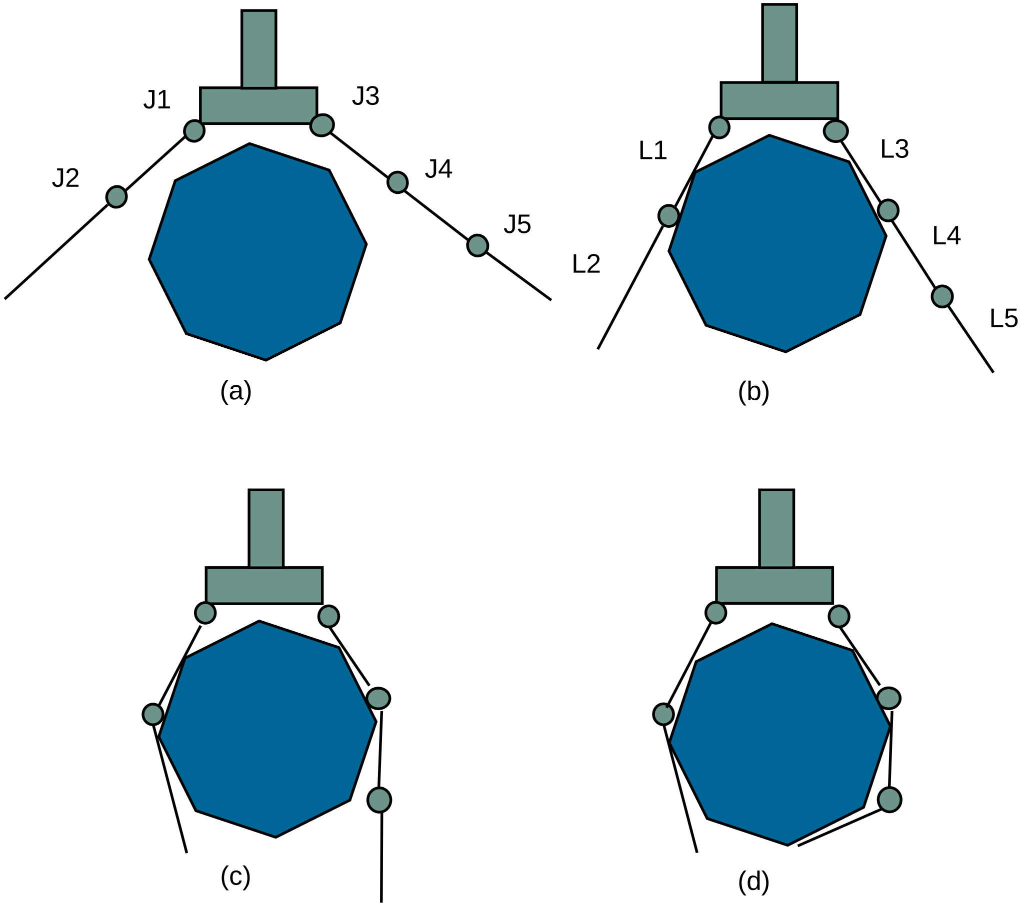
Our Two-Fingered Robotic Hand



- Closed-loop PD control is used for position control of the joints.

Exploration Using Wrapping Grasps

- Grasping strategy:

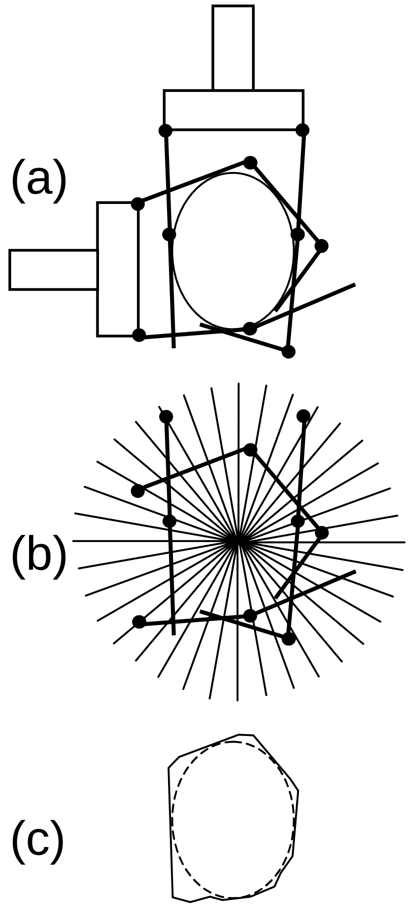


Exploration Using Wrapping Grasps (continued)

- The object is explored in 2D by applying wrapping grasps at multiple orientations in the plane of the hand.
- Finger-object contact is detected by monitoring the position errors of the joint PD controllers.
- This avoids the use of tactile sensors that are costly and unreliable.

Generation of the Object Model

- Objective: To generate an object model from the finger link locations recorded during the set of wrapping grasps.



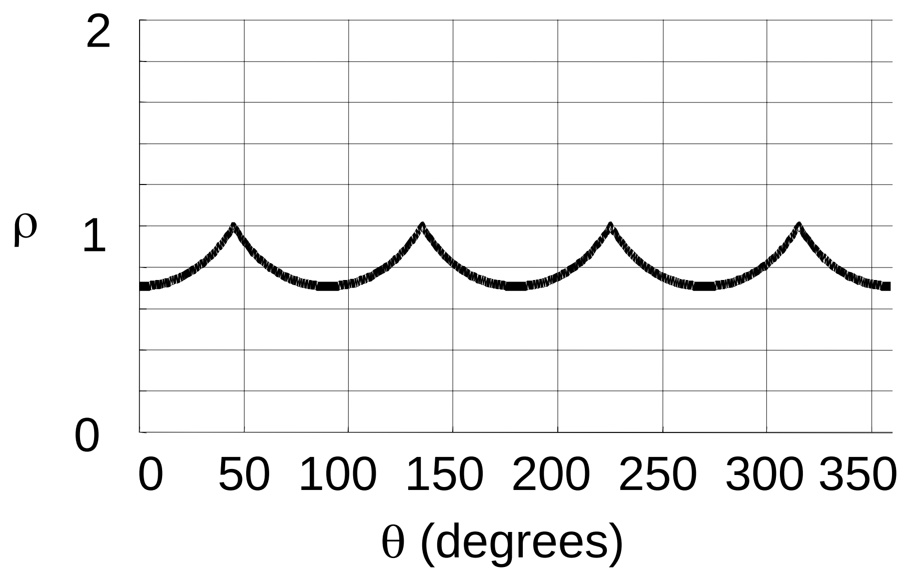
Example using 2 grasps.

Shape Recognition and Size Estimation

- To recognize the object we have adapted a technique from the computer vision field.
- The method is based on a plot of the object contour in polar coordinates.
- This reduces the search space from three dimensions (X,Y and θ) to one dimension (θ).

Shape Recognition and Size Estimation (continued)

- The normalized radius function, $\rho(\theta)$, can be used to recognize an object by its shape, independent of its size.
- e.g. $\rho(\theta)$ plot for a square object



Shape Recognition and Size Estimation (continued)

- Main Steps:
  - $\rho(\theta)$ functions are generated for a set of reference objects, and then stored.
  - A $\rho(\theta)$ function is generated from the experimental wrapping grasp data for the unknown object.
  - The object from the reference set with the closest match to the measured $\rho(\theta)$ is selected.

Shape Recognition and Size Estimation (continued)

- If the reference objects consist of a circle, square and equilateral triangle then their estimated dimensions are simply:

$$\hat{D} = 2\sqrt{\frac{A}{\pi}}$$

$$\hat{l}_s = \sqrt{A}$$

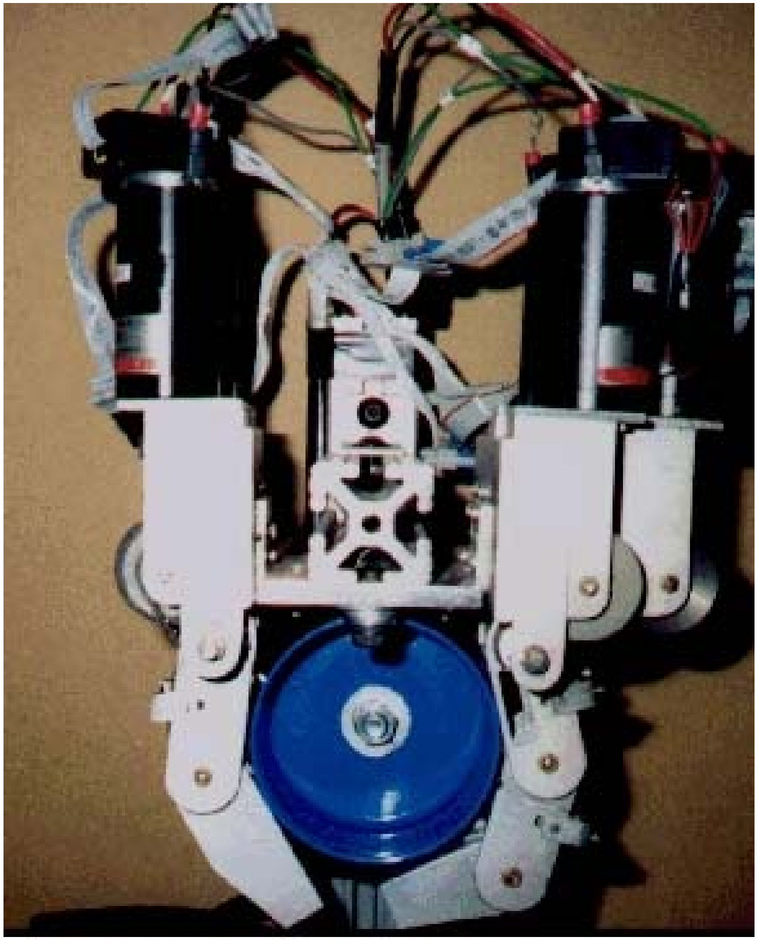
$$\hat{l}_t = 2\sqrt{A/\sqrt{3}}$$

where A is the area of $r(\theta)$.

Experimental Results

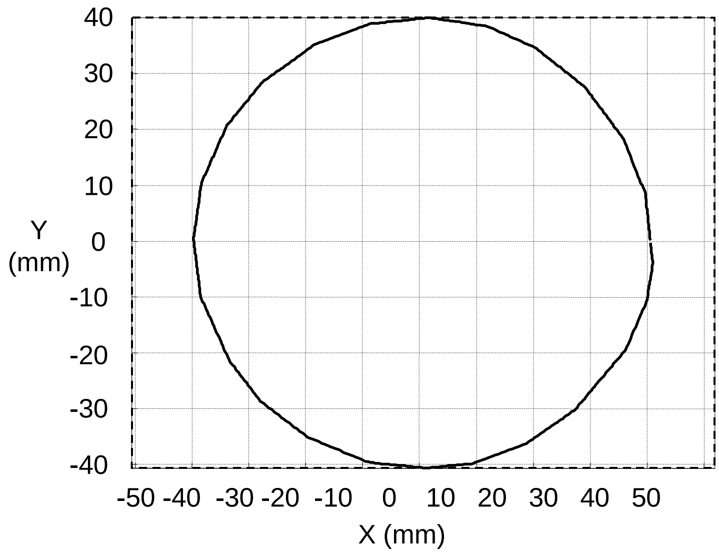
- Procedure
  - Test objects with circular, square and equilateral triangular cross-sections were manufactured from wood and plastic.
  - 24 wrapping grasps were applied to each object at 15° intervals.
  - The changes in orientation were accomplished by rotating the object rather than rotating the hand as the theory intends.

Experimental Results (continued)

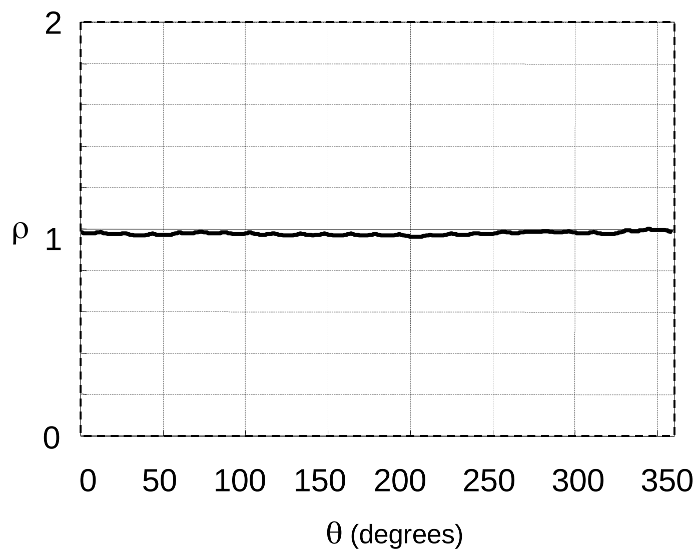


Wrapping grasp experiment with the circular test object.

Experimental Results (continued)

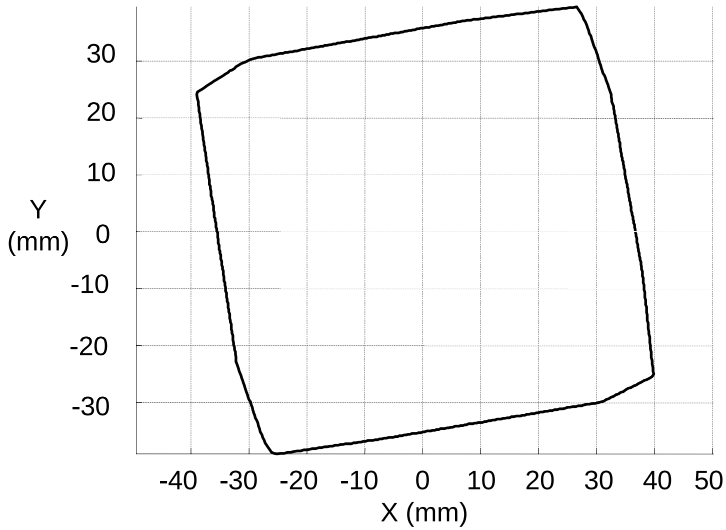


Contour model for the circular test object.

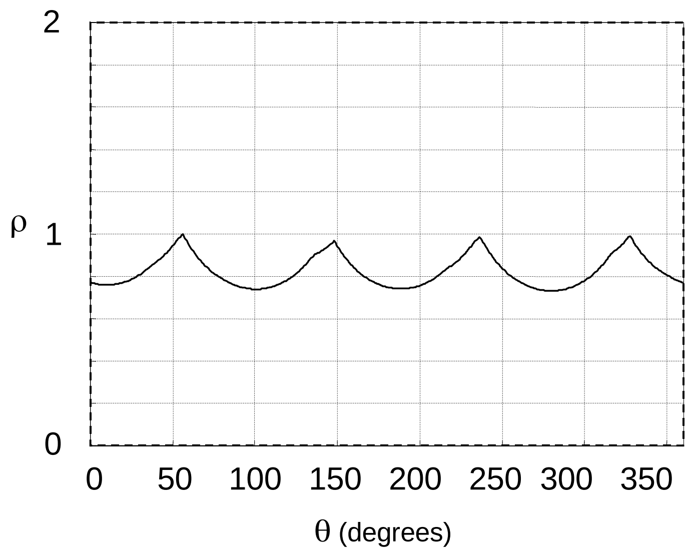


$\rho(\theta)$ plot for the circular test object.

Experimental Results (continued)

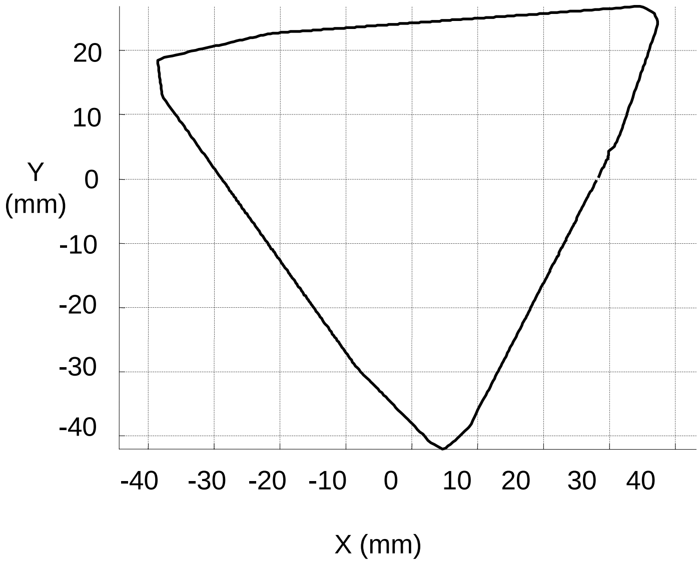


Contour model for the square test object.

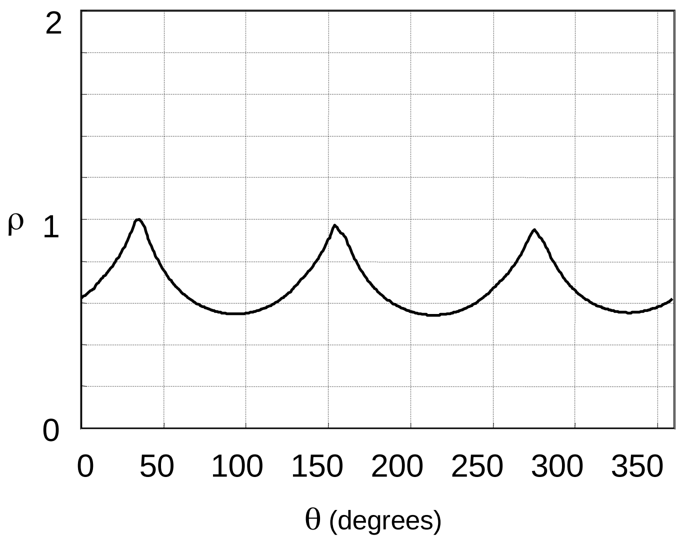


$\rho(\theta)$ plot for the square test object.

Experimental Results (continued)



Contour model for the triangular test object.



$\rho(\theta)$ plot for the triangular test object.

Experimental Results (continued)

- Closeness of fit measures:

Reference shape	**Test object shape**		
	Circular	Square	Triangular
Circle	0.11	2.1	3.4
Square	1.7	0.57	3.7
Triangle	3.0	3.6	0.88

- Dimension estimates:
  - D=80 (true value=85 mm)
  - l_s=70 (true value=75 mm)
  - l_t=82 (true value=83 mm)

Conclusions

- We have developed a novel approach for 2D exploration and object recognition with a robotic hand.
- Employing wrapping grasps extracts shape information more efficiently than prior methods (i.e. parallel-jaw and fingertip grasps).
- 100% recognition accuracy was achieved experimentally with as few as six grasps.

Conclusions (continued)

- The computation time for the modeling and recognition algorithms is less than one second on a standard PC.

- Limitations:
  - Best suited to relatively large objects.
  - Cannot detect concavities (but can still recognize non-convex objects).
  - Belt stretch caused the dimension estimates to be poor. This could be fixed by using non-contact object-finger proximity sensing.