Autonomous Mobile Manipulation for Healthcare

Charlie Kemp

Assistant Professor, Department of Biomedical Engineering

Adjunct Assistant Professor, School of Interactive Computing

Georgia Tech

Robotics@GT & Intelligent Machines

hsi Health Systems Institute

A Georgia Tech / Emory Initiative

Video of the robot EL-E fetching an object for a person with ALS. The user commands the robot using a hand held laser. This video was recorded on October 28th, 2008, and can be found at: http://healthcare-robotics.com/

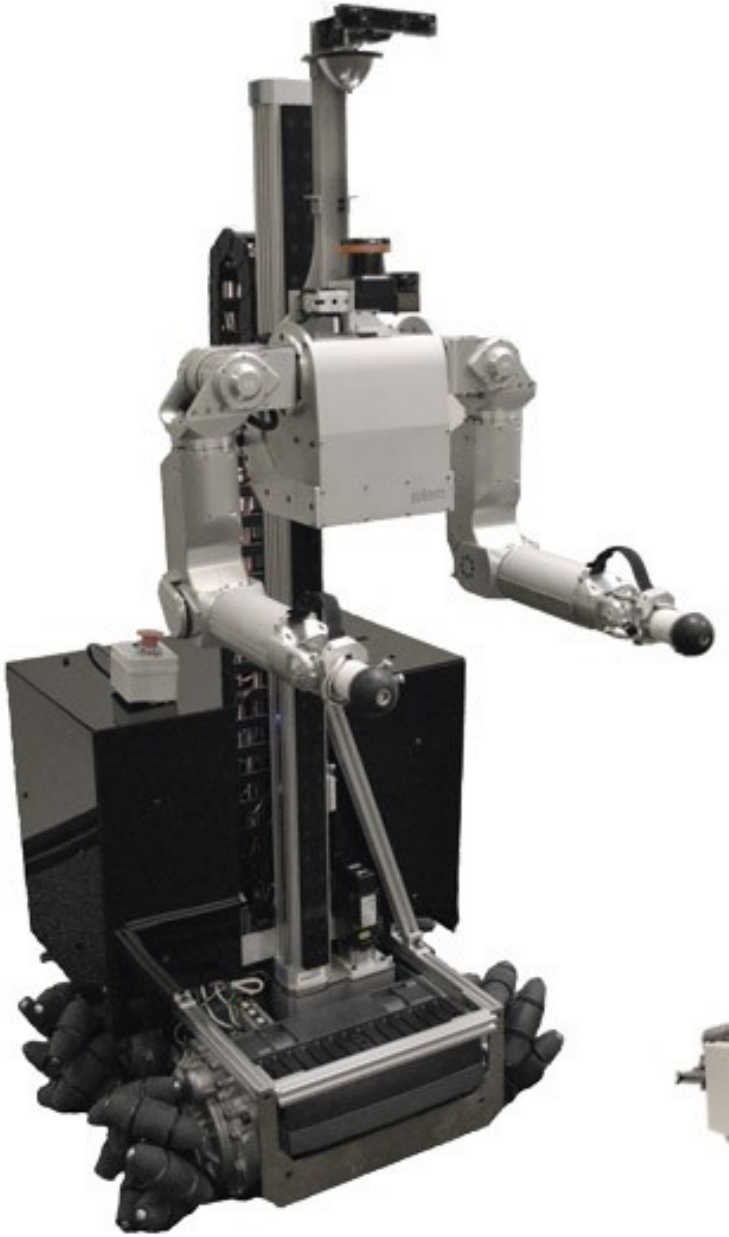
The Healthcare Robotics Lab

- Founded in Sept. 2007
- Members from
  - Biomedical Engineering
  - Interactive Computing
  - Electrical and Computer Engineering
  - Mechanical Engineering
  - Applied Physiology

hsi
Health Systems Institute
A Georgia Tech / Emory Initiative

Robotics@GT
& Intelligent Machines

http://healthcare-robotics.com



Cody **Dusty** **EL-E**

Healthcare Challenges

- Older adults and people with physical-impairments require assistance.
- In the US alone
  - 30,000 with ALS
  - 250,000 with SCI
  - 17,000,000 over 75 years old
    - Estimated that 17% require assistance

Nurse image from: http://blog.soliant.com/wp-content/uploads/stressed-out-nurse.jpg

Healthcare Challenges

- Human assistants and service animals are expensive and in short supply.
  - $15K for service dog and long wait
  - $30K for helper monkey and long wait
  - $24K a year for Certified Nursing Assistant
- Worsening shortages of healthcare workers [1]
- Each additional patient per nurse associated with
  - 7% increase in patient mortality
  - 23% increase in nurse burnout [2]

Nurse image from: http://blog.soliant.com/wp-content/uploads/stressed-out-nurse.jpg

[1] IOM, Retooling for an Aging America: Building the Health Care Workforce. Washington DC: The National Academies Press, 2008.
[2] L.H. Aiken, S. P. Clarke, D. M. Sloane, J. Sochalski, and J. H. Silber. Hospital nurse staffing and patient mortality, nurse burnout, and job dissatisfaction. JAMA. 288(16):1987-1993, 2002.

Robotic Opportunities

- Privacy and independence
- 24/7 personal assistance
- Economies of scale through general purpose technology
- Consistent Performance
- New forms of healthcare services
- Empower healthcare workers

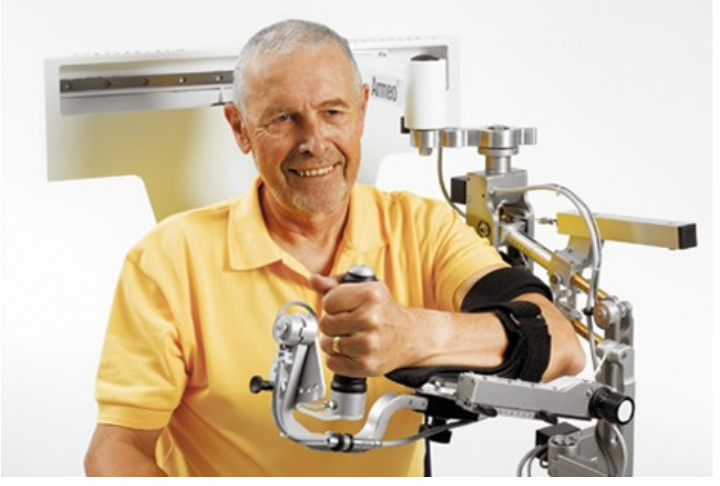
Rosie the robot picture from: http://marissabeck.wordpress.com/2009/09/22/rosie-to-handle-food/

Assistive Robots

- Prosthetics
- Powered Orthoses / Exoskeletons
- Rehabilitation Robots
- Wheelchair Mounted Robot Arms
- Stationary Robot Arms
- ***Mobile Manipulators?***

image removed

Pictures taken from miscellaneous websites. In counter-clockwise order they show: Manus ARM from Exact Dynamics, Armeo from Hocoma, HAL from Cyberdine, unidentified exoskeleton arm for rehabilitation (removed), and the Luke arm from DEKA.



Autonomous Mobile Manipulation for Assistive Applications

- Operate Independently from the User
- No Don/Doff
- No Direct Encumbrance
- Generally Useful
  - Potential for Broad Adoption and Commoditization

A Need and an Opportunity... Now Build Something.

- What tasks would be valuable?
- How can users direct a robot to perform these tasks?
- How can a robot perform these tasks in real healthcare environments?

What tasks are valuable?

Object Fetching

- People with severe motor impairments have consistently given a high priority to the ability to pick up objects from the floor and from shelves.

Stanger, C.A., et al., *Devices for assisting manipulation: a summary of user task priorities.* IEEE Transactions on Rehabilitation Engineering, 1994. **2**(4): p. 10.

Rank	Object Class	Image	Rating Mean	Rating Stdev.	Weight (grams)	Max size (cm)
1	TV Remote		6.64	0.57	90	18
2	Medicine Pill		6.36	1.55	1	2.2
3	Cordless Phone		6.28	1.31	117	15
4	Prescription Bottle		6.08	1.31	25	7
4	Fork		6.08	1.12	39	18
6	Glasses		6.00	1.53	23	14
7	Toothbrush		5.96	1.81	15	19
8	Spoon		5.92	1.19	38	17
9	Cell Phone		5.88	1.69	76	9
10	Toothpaste		5.72	1.84	160	20
10	Book		5.72	1.46	532	24
10	Hand Towel		5.72	1.46	65	58

- Survey of 25 people with ALS
- Likert scale (1-7) ranking importance of robotic retrieval for each of 43 objects

Results

SUMMARY BY OBJECT GROUP

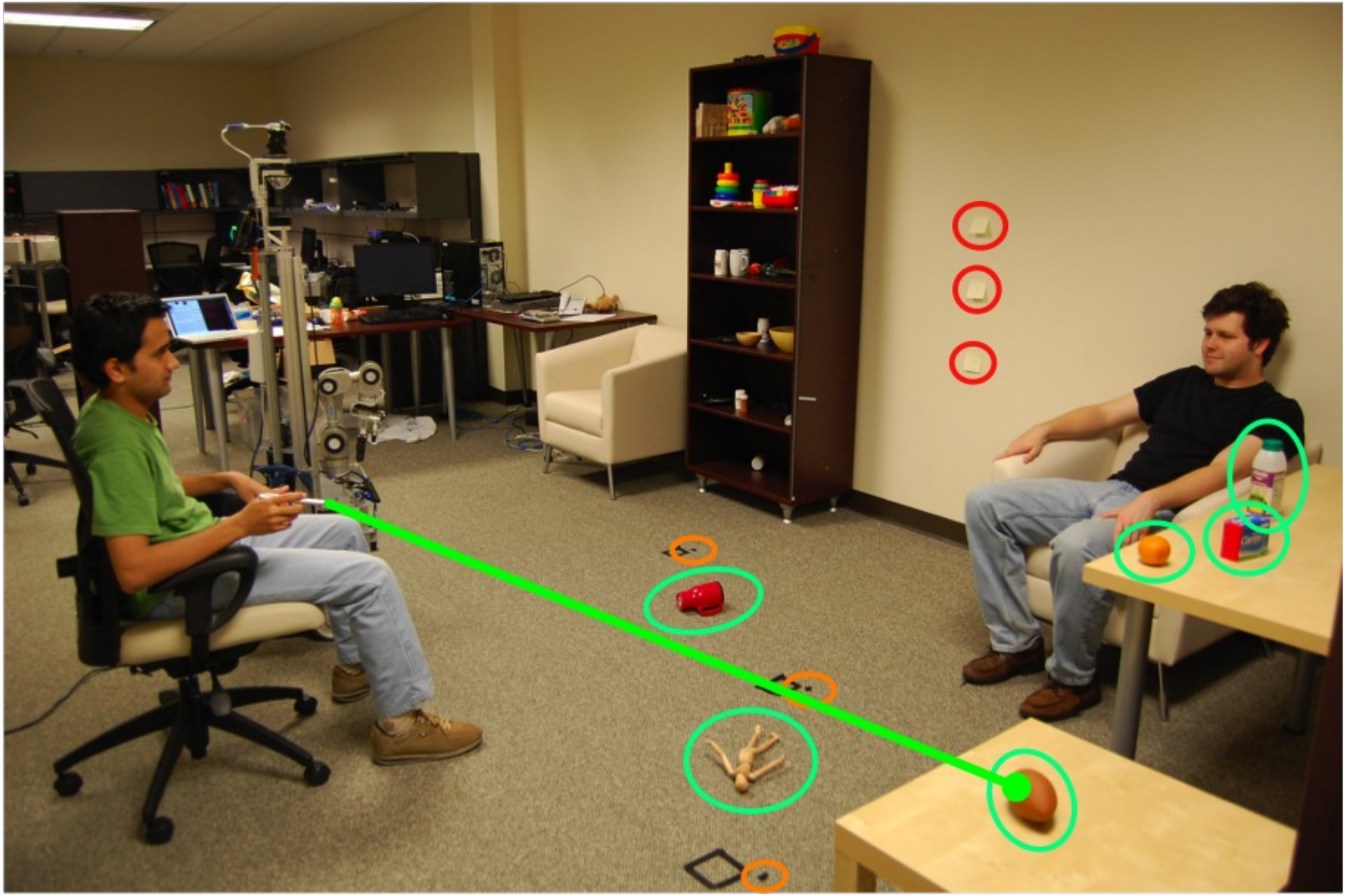
Group	Score	Count	Average Weight (grams)	Average Max Size (cm)
Very important	6 – 7	6	51.2	11.2
Important	5 – 6	15	133.4	19.0
Slightly Important	4 – 5	17	281.7	43.0
Not Important	1 – 4	5	196.5	15.2

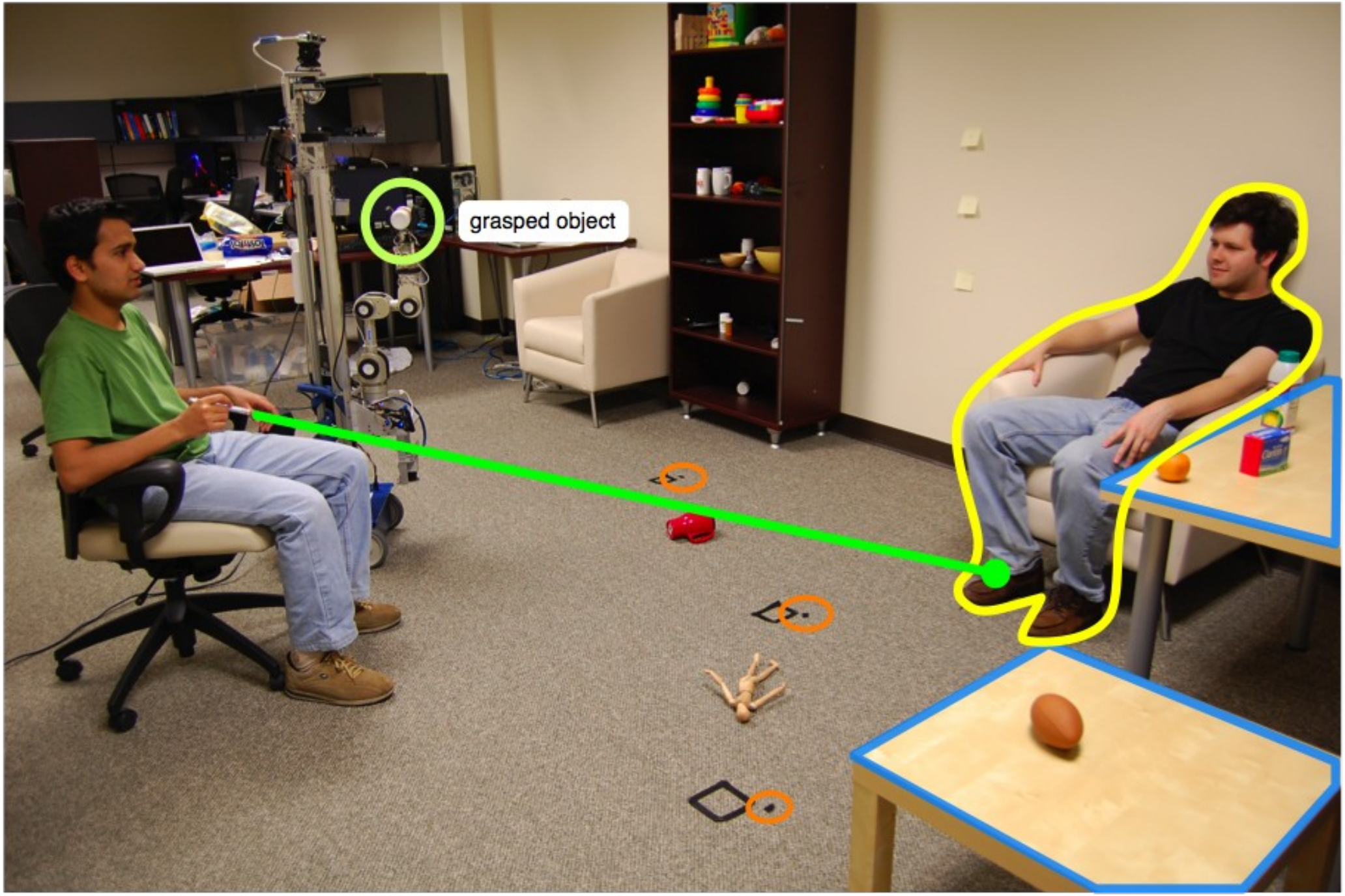
Other Important Healthcare Tasks

- Object Fetching
  - Opening Doors and Drawers
- Lifting patients
  - A top cause of workplace injury for nurses
  - Common requirement in healthcare facilities
- Hygiene
  - Frequently cited as important task for assistive robots
  - Can be an unpleasant job for nurses

How can a user direct a robot to perform these tasks?

Showed video of a helper monkey being commanded with a laser pointer. Information and videos can be found using the following link: http://www.monkeyhelpers.org/




grasped object

User Studies

Three Interfaces

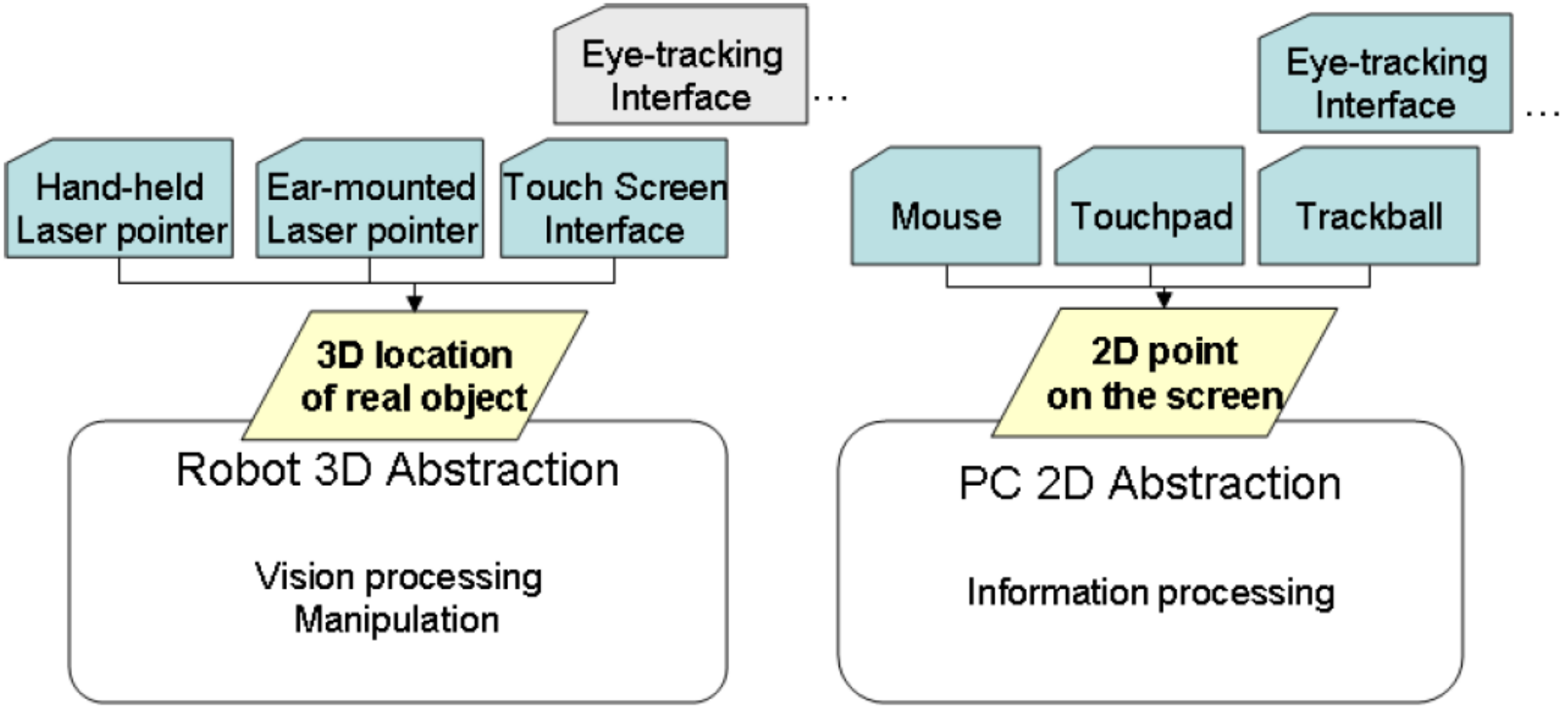
Hand-held laser pointer

Ear-mounted laser pointer

Touch screen

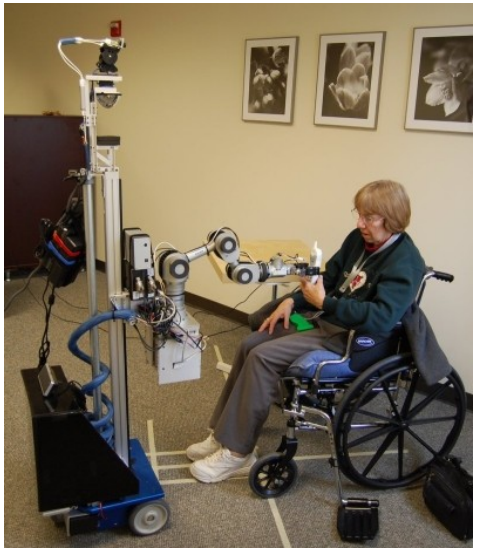
Results

- 8 participants (6 male, 2 female)
- Overall success rate of **94.8% (127 out of 134 trials)**
- All participants learned to use the robot in **less than 10 minutes**
- Laser pointer interfaces were **69% faster** than touch screen
- Satisfaction survey
  - Overall satisfaction was high for all interfaces
  - Variation of preference
  - Ear mounted was more comfortable for people with less upper limb mobility
  - Touch screen was preferred by some, regardless of mobility


Eye-tracking Interface
...
Hand-held Laser pointer
Ear-mounted Laser pointer
Touch Screen Interface
3D location of real object
Robot 3D Abstraction
Vision processing
Manipulation
Eye-tracking Interface
...
Mouse
Touchpad
Trackball
2D point on the screen
PC 2D Abstraction
Information processing

User Study of Object Delivery

Object Delivery Study (n=8)



Direct Delivery

Indirect Delivery

Results

Success rate

- Overall 88 % (126/144)
- Direct 78% (56/72)
- Indirect 98% (70/72)

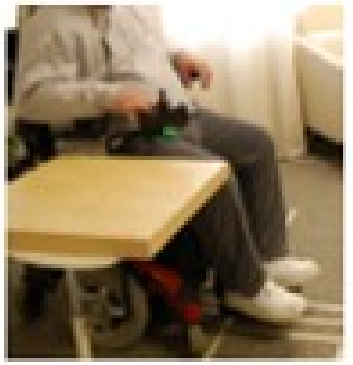
Failures

- 9 out of 16 indirect failures were with one participant
- Body shape and posture appear to be the cause

Delivery method preference was split evenly (5 vs 5)

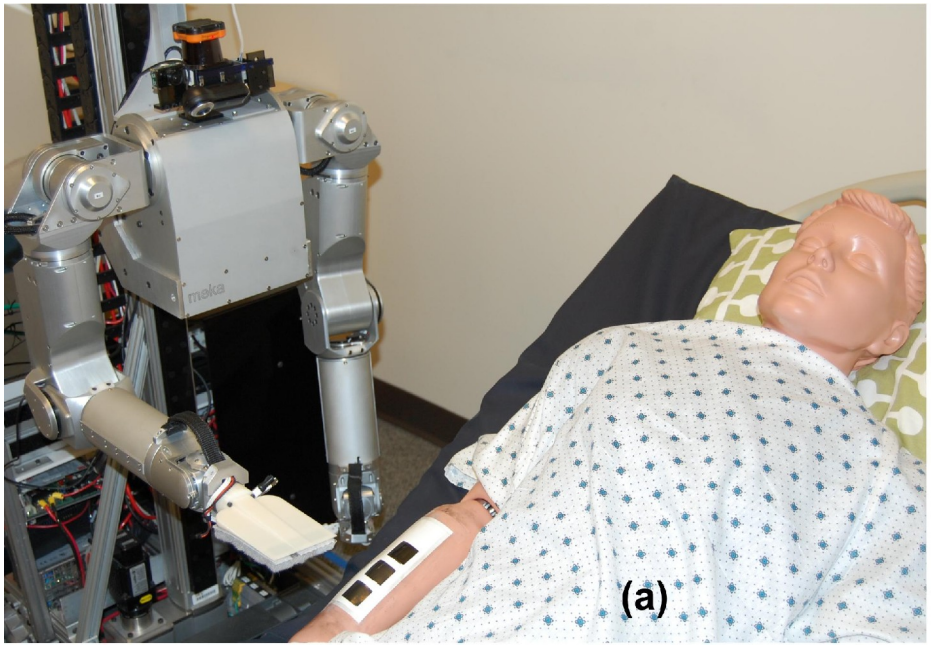
Very high overall satisfaction

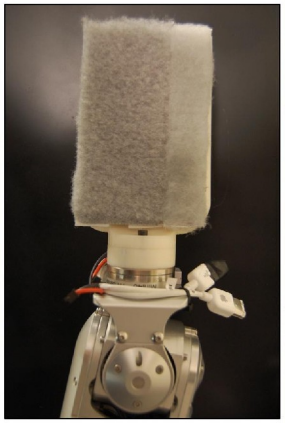


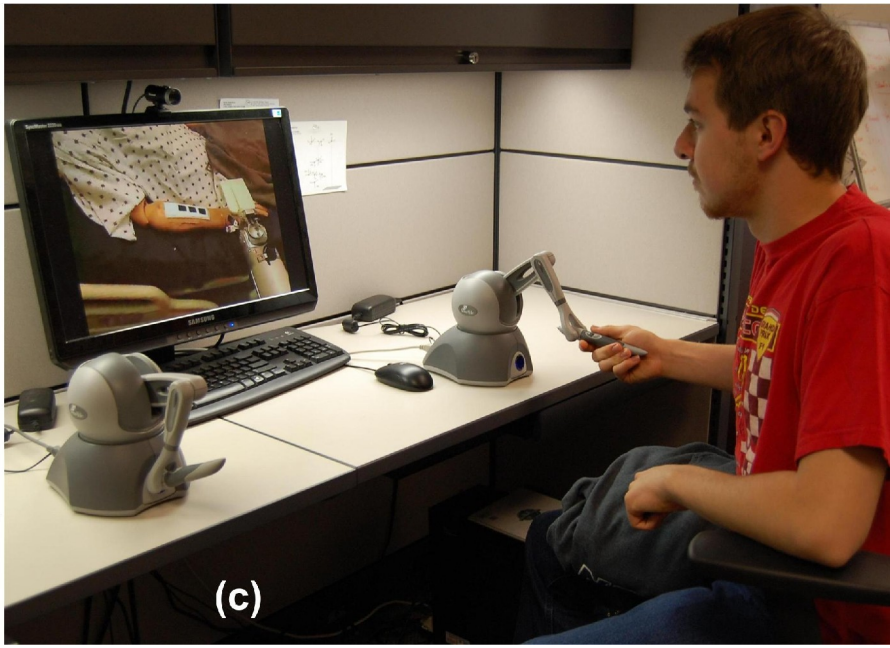



Caregiver Operation of the Robot

Nursing Testing Scenarios







Showed video of our research on teleoperation for hygiene.
More information can be found at this link:
http://www.hsi.gatech.edu/hrl/project_teleop.shtml

How can a robot perform these tasks in real healthcare settings?

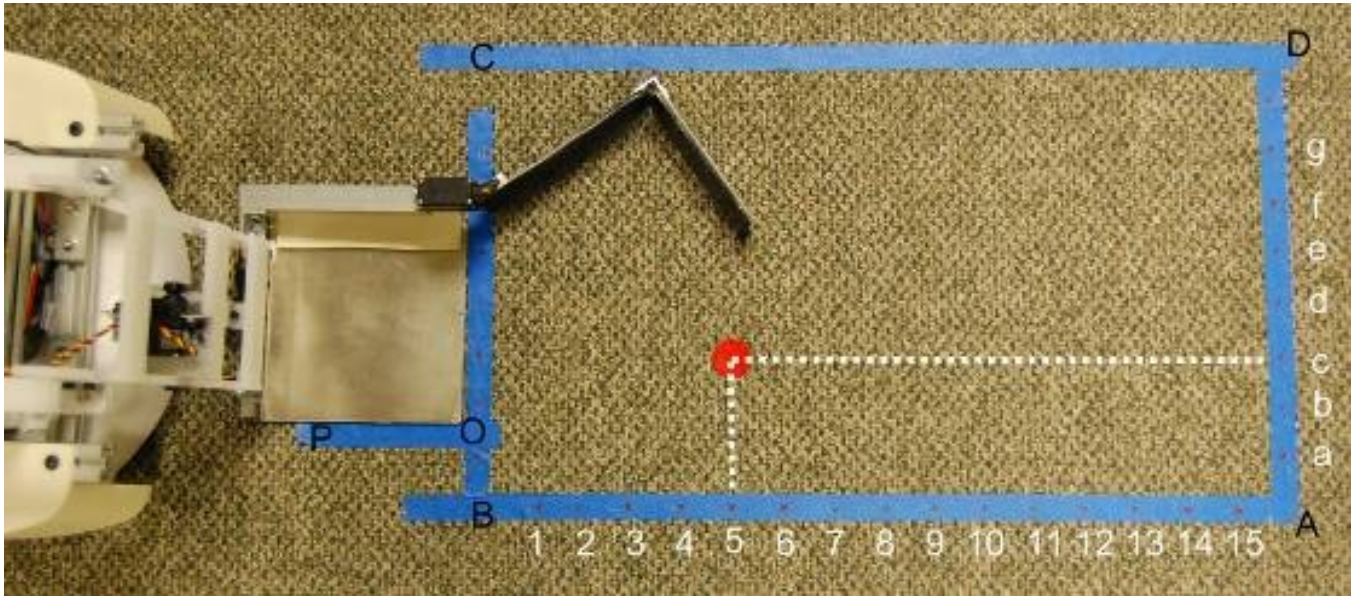
Simplify the Robot by Narrowing the Task

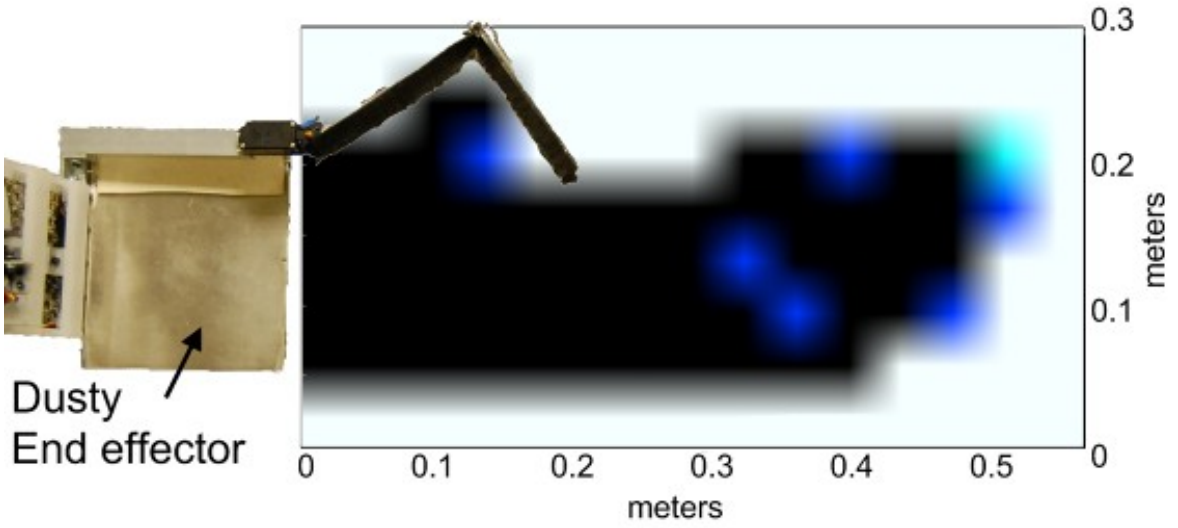
Dusty

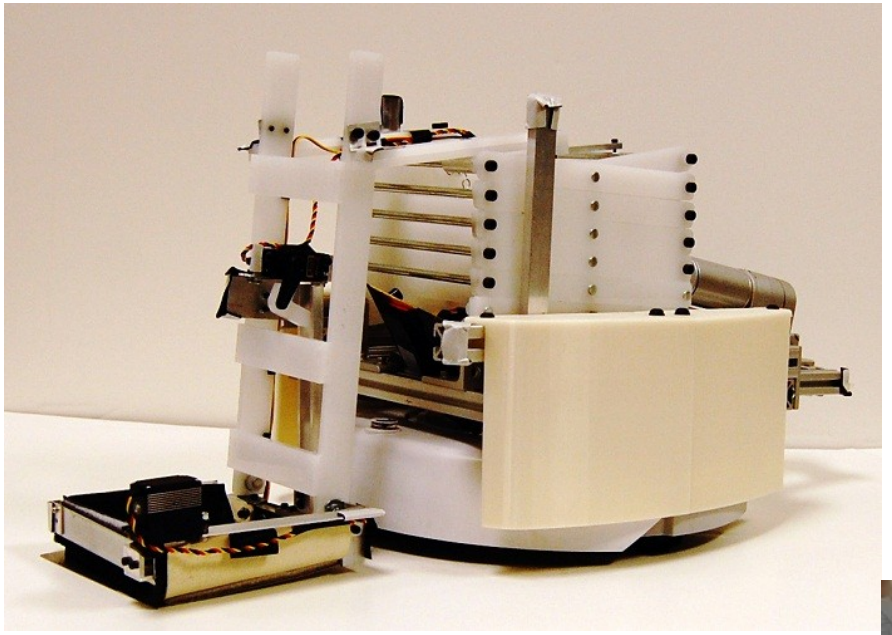
Top 5 objects in the prioritized list

Rank	Object Class	Image	Rating Mean	Rating Stdev.	Weight (grams)	Max size (cm)
1	TV Remote		6.64	0.57	90	18
2	Medicine Pill		6.36	1.55	1	2.2
3	Cordless Phone		6.28	1.31	117	15
4	Prescription Bottle		6.08	1.31	25	7
4	Fork		6.08	1.12	39	18

Video showing Dusty pick up five high priority objects for robotic retrieval.


C
D
g
f
e
d
c
b
a
P
O
B
A
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15


Dusty
End effector
0.3
0.2
0.1
0
meters
0 0.1 0.2 0.3 0.4 0.5
meters



Showed video from in progress user study with latest version of the robot Dusty. Information on the Dusty project can be found at the following website:

http://www.hsi.gatech.edu/hrl/project_dusty.shtml

Make Environments Robot Accessible

Showed video of how service dogs can be commanded, examples of helpful tasks they perform, and environmental modifications used to make them more capable. The video can be found at http://healthcare-robotics.com/

Images taken from miscellaneous websites to illustrate complex environmental modifications people make to improve quality of life.

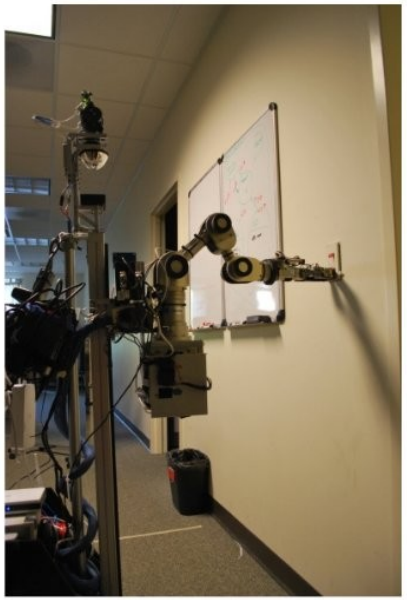
Images taken from miscellaneous websites to illustrate environmental modifications people make that make things easier to manipulate.

Images taken from miscellaneous websites to illustrate environmental modifications people make that make things harder to manipulate.





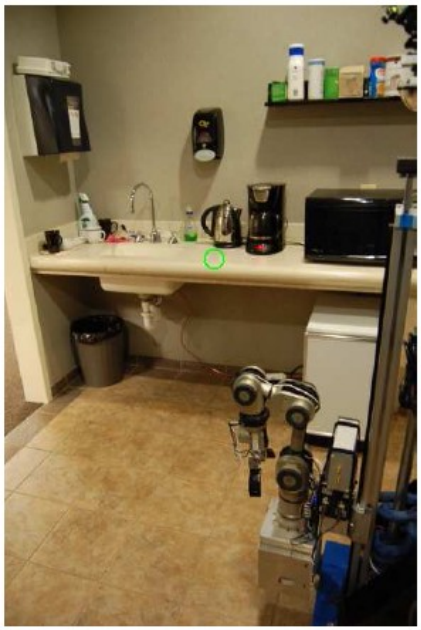


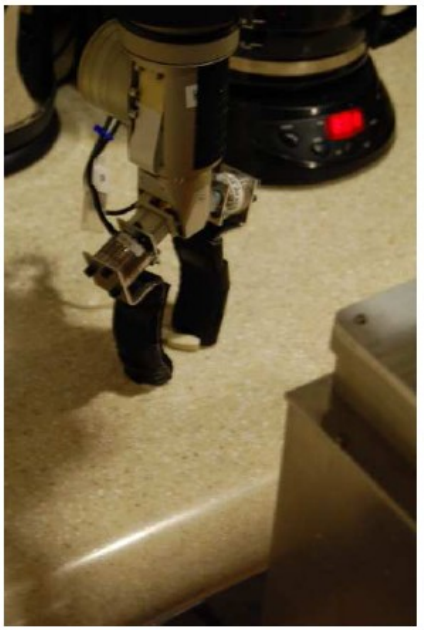


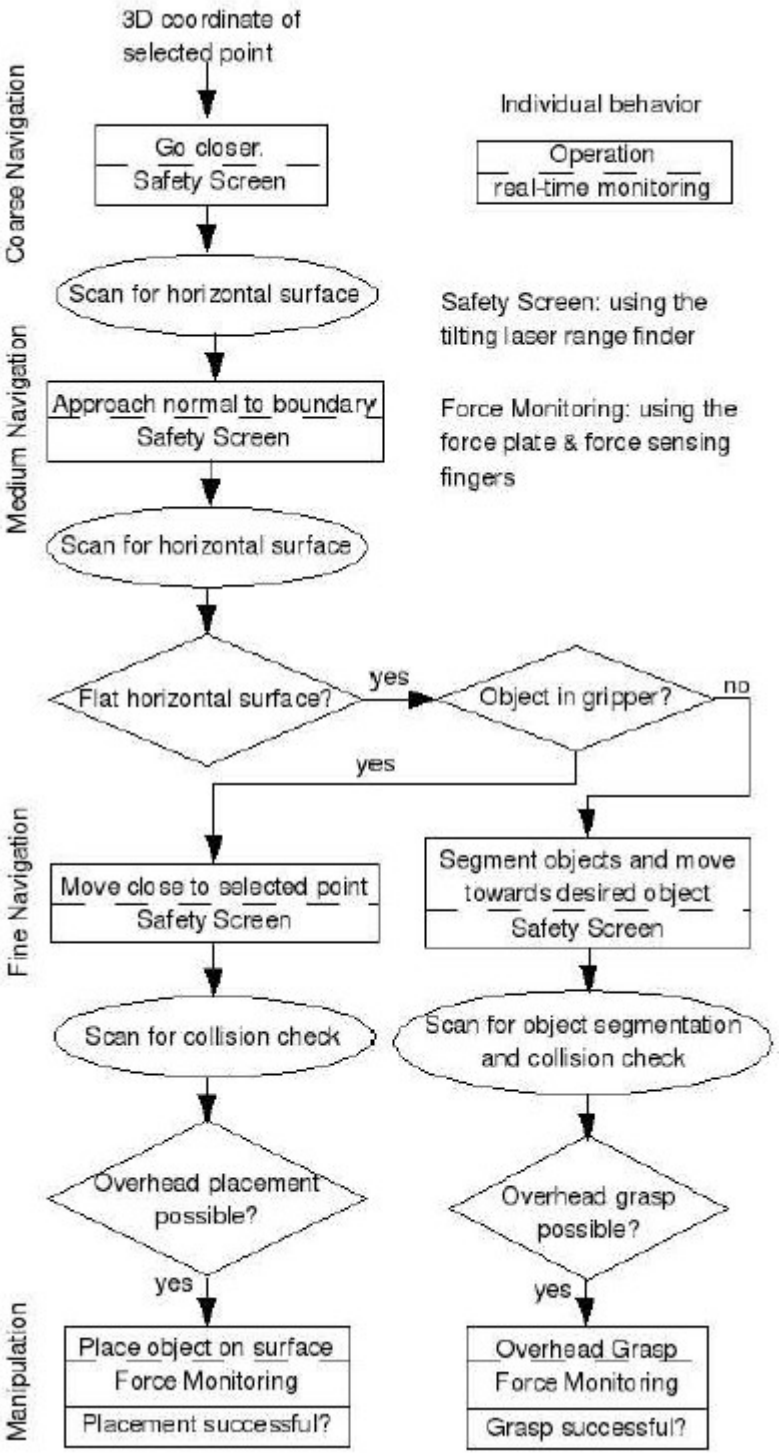

Adapt Robots to The Environment (Make Robots Intelligent?)

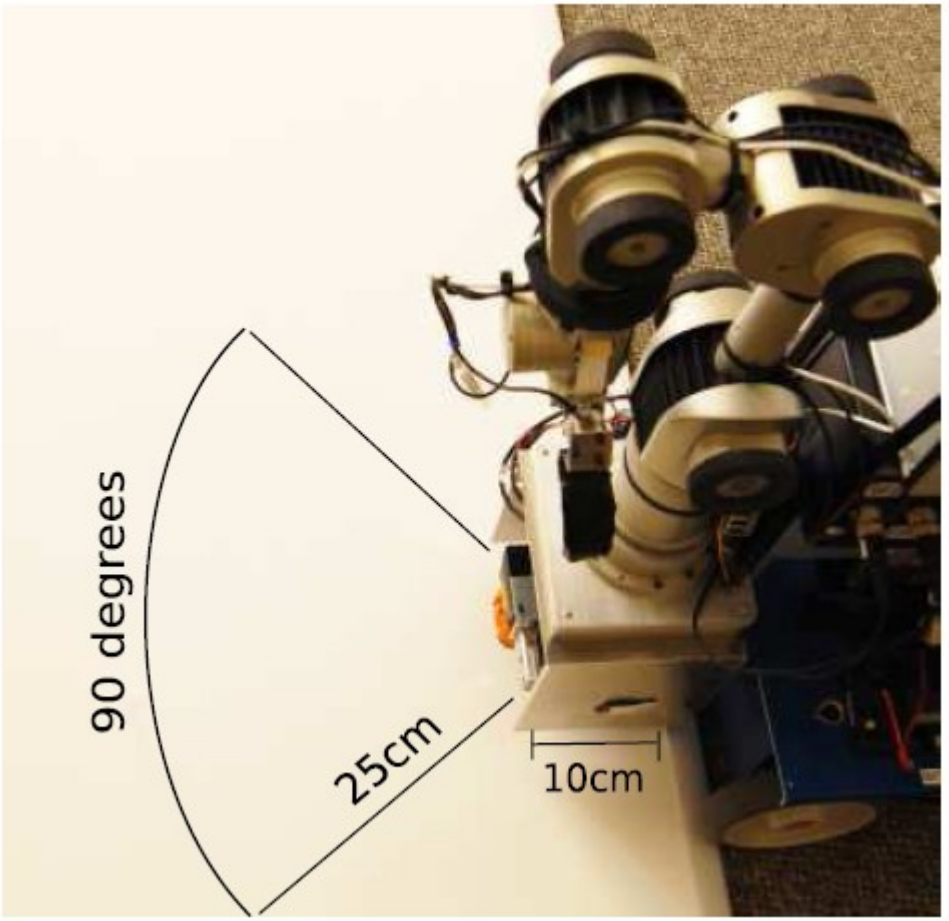
Fetching Objects

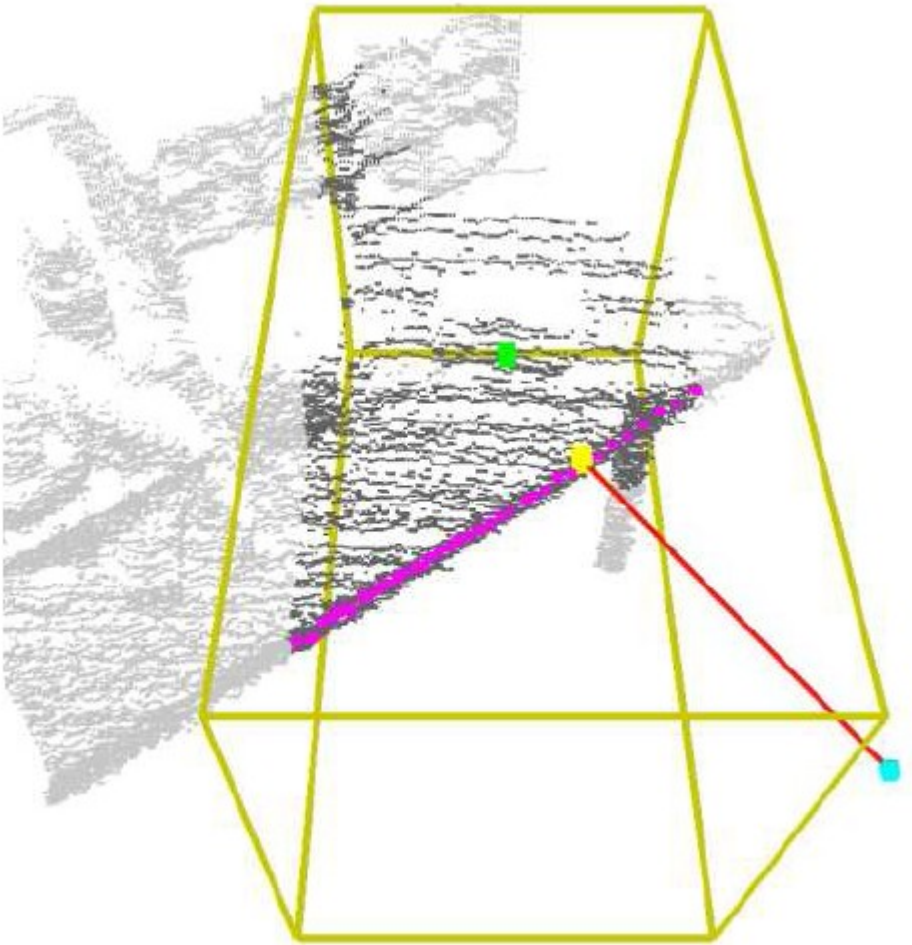
Showed video of EL-E grasping a variety of objects from a table. The video can be found at http://healthcare-robotics.com/

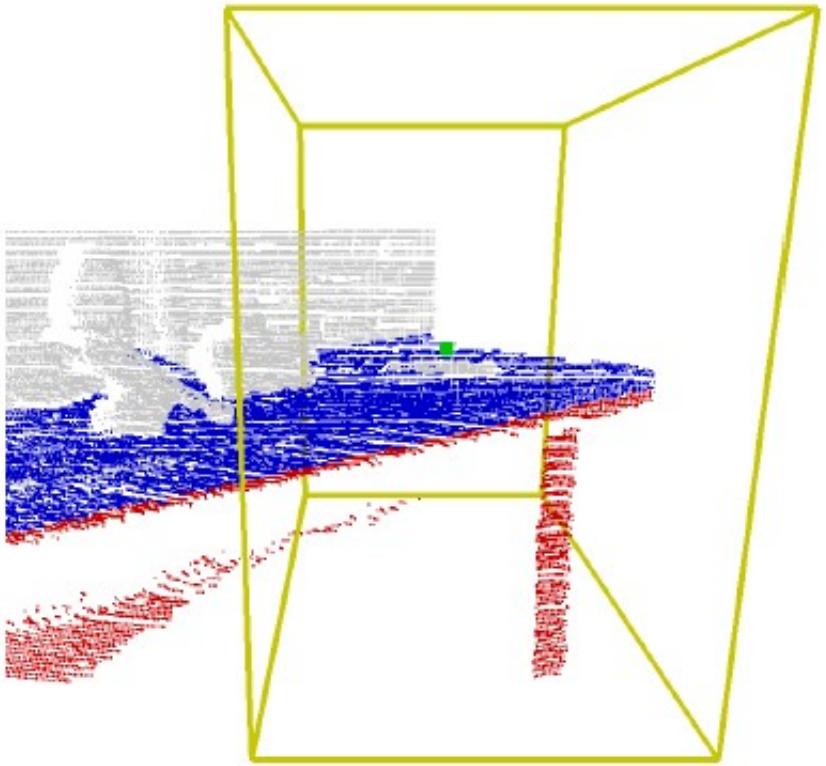


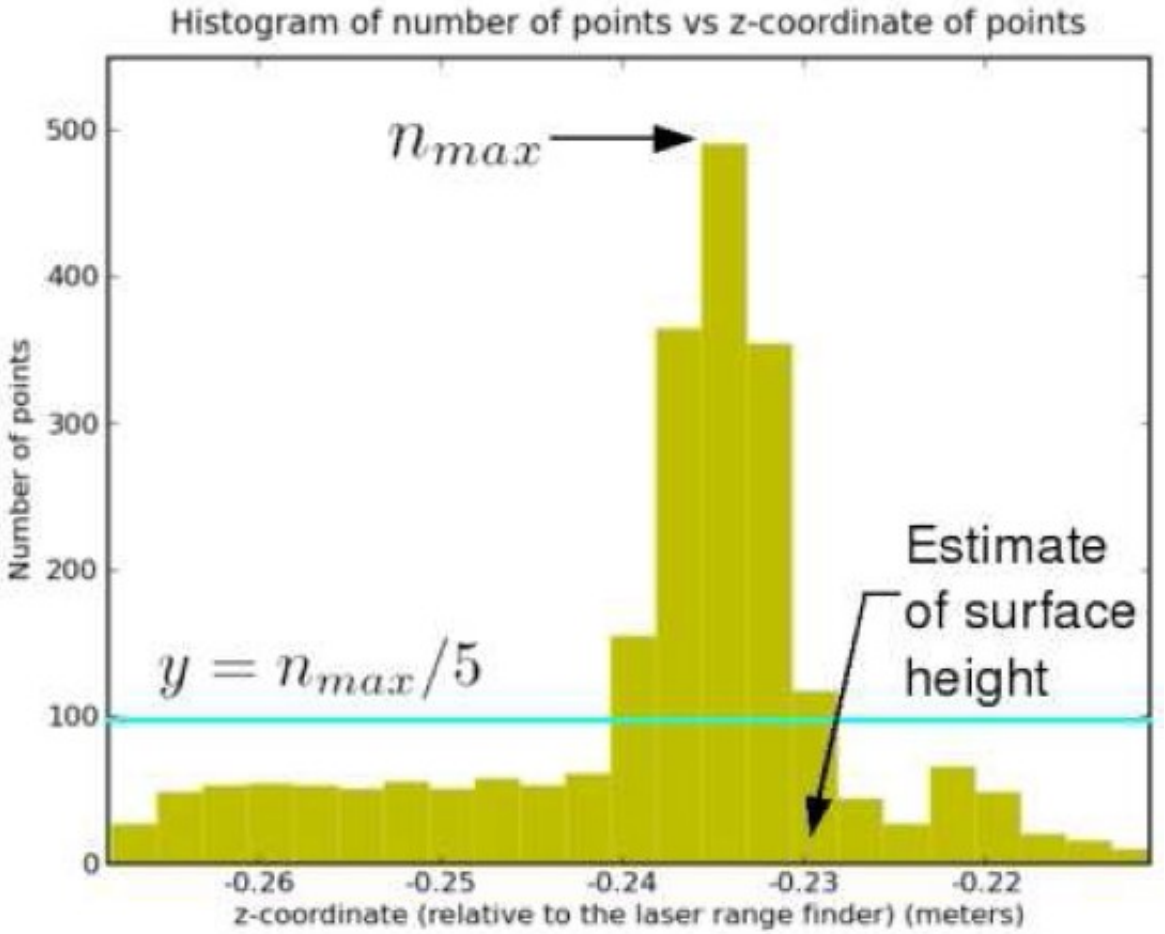



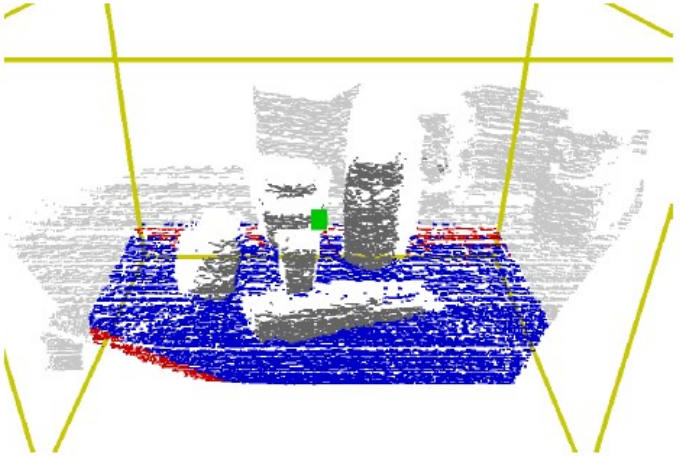


3D coordinate of selected point
Coarse Navigation
Go closer.
Safety Screen
Individual behavior
Operation
real-time monitoring
Scan for horizontal surface
Safety Screen: using the tilting laser range finder
Medium Navigation
Approach normal to boundary
Safety Screen
Force Monitoring: using the force plate & force sensing fingers
Scan for horizontal surface
Flat horizontal surface?
yes
Object in gripper?
no
yes
Fine Navigation
Move close to selected point
Safety Screen
Segment objects and move towards desired object
Safety Screen
Scan for collision check
Scan for object segmentation and collision check
Overhead placement possible?
Overhead grasp possible?
yes
yes
Manipulation
Place object on surface
Force Monitoring
Placement successful?
Overhead Grasp
Force Monitoring
Grasp successful?

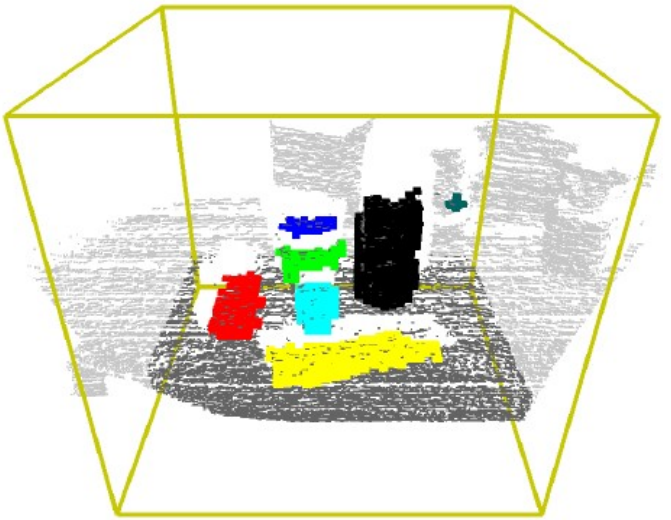

90 degrees
25cm
10cm



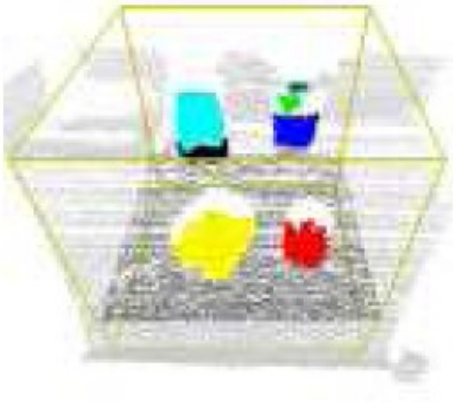
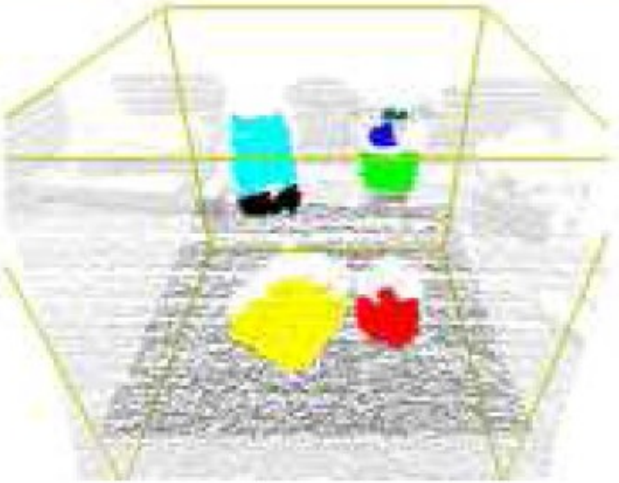
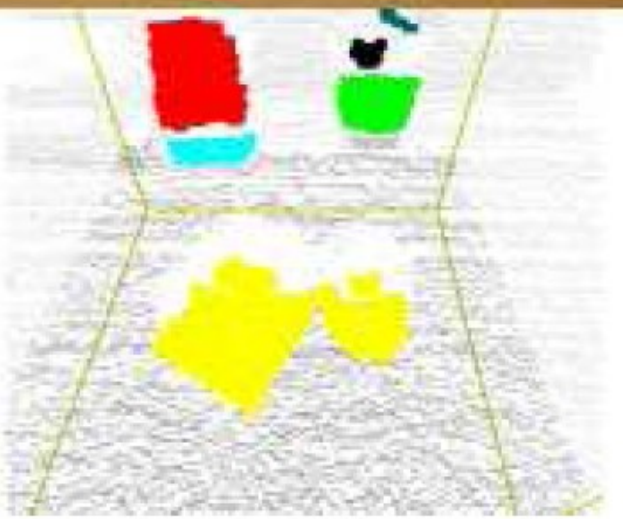


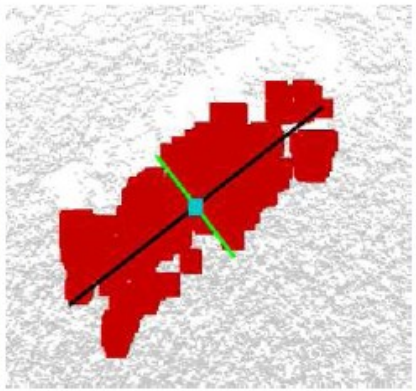
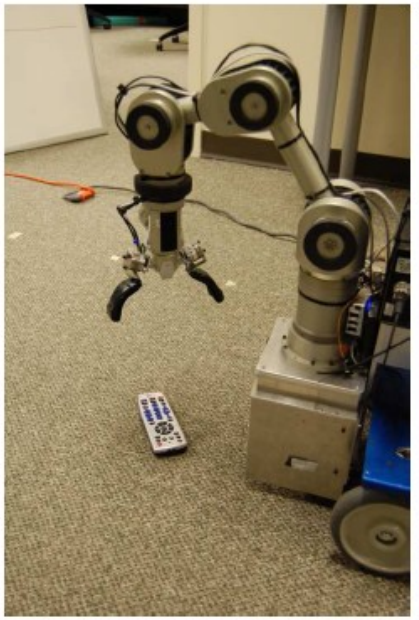
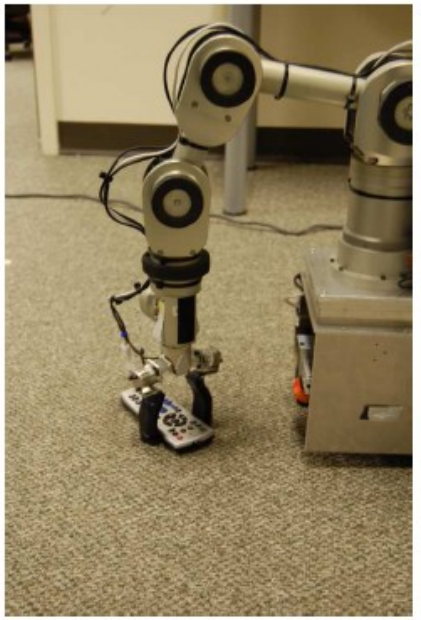

Histogram of number of points vs z-coordinate of points
n_{max}
$y = n_{max}/5$
Estimate of surface height
Number of points
0
100
200
300
400
500
-0.26
-0.25
-0.24
-0.23
-0.22
z-coordinate (relative to the laser range finder) (meters)



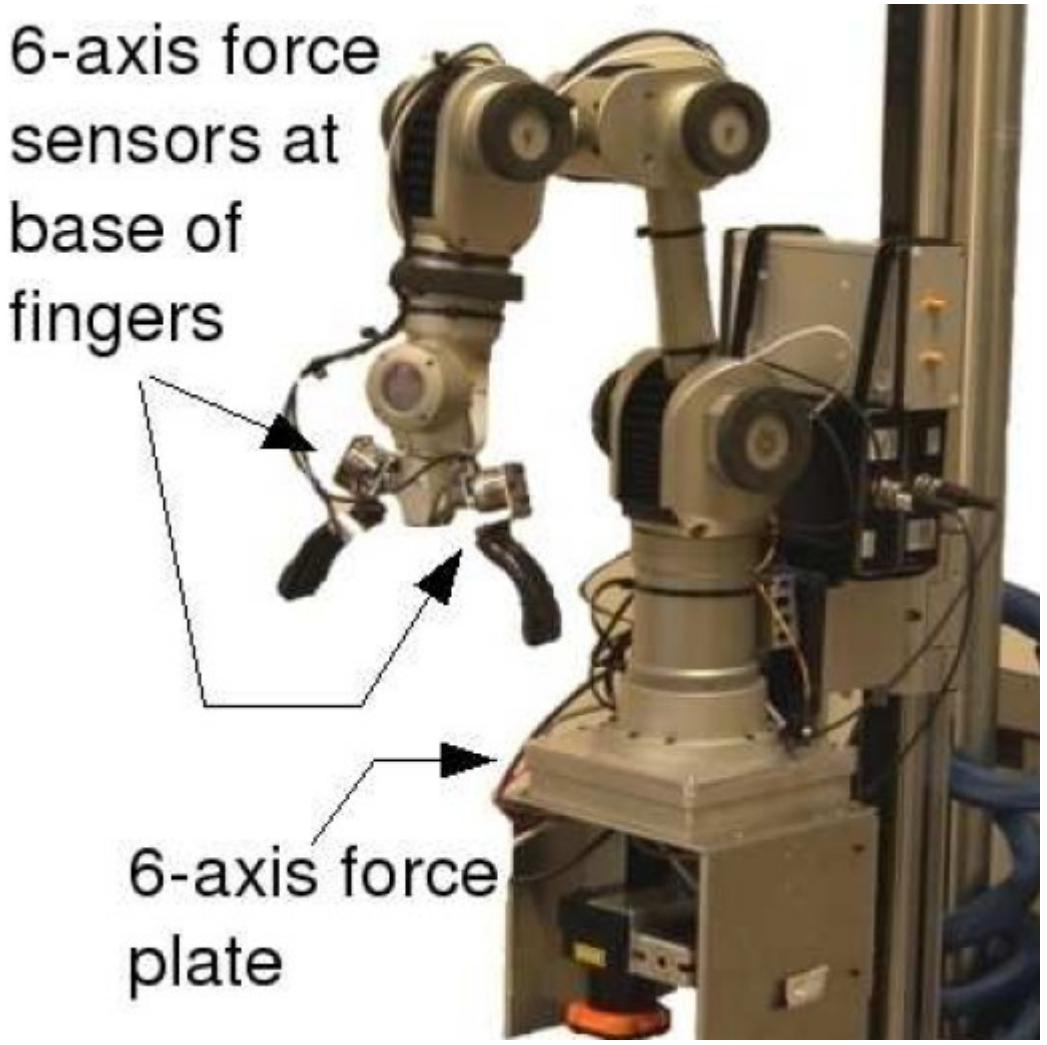


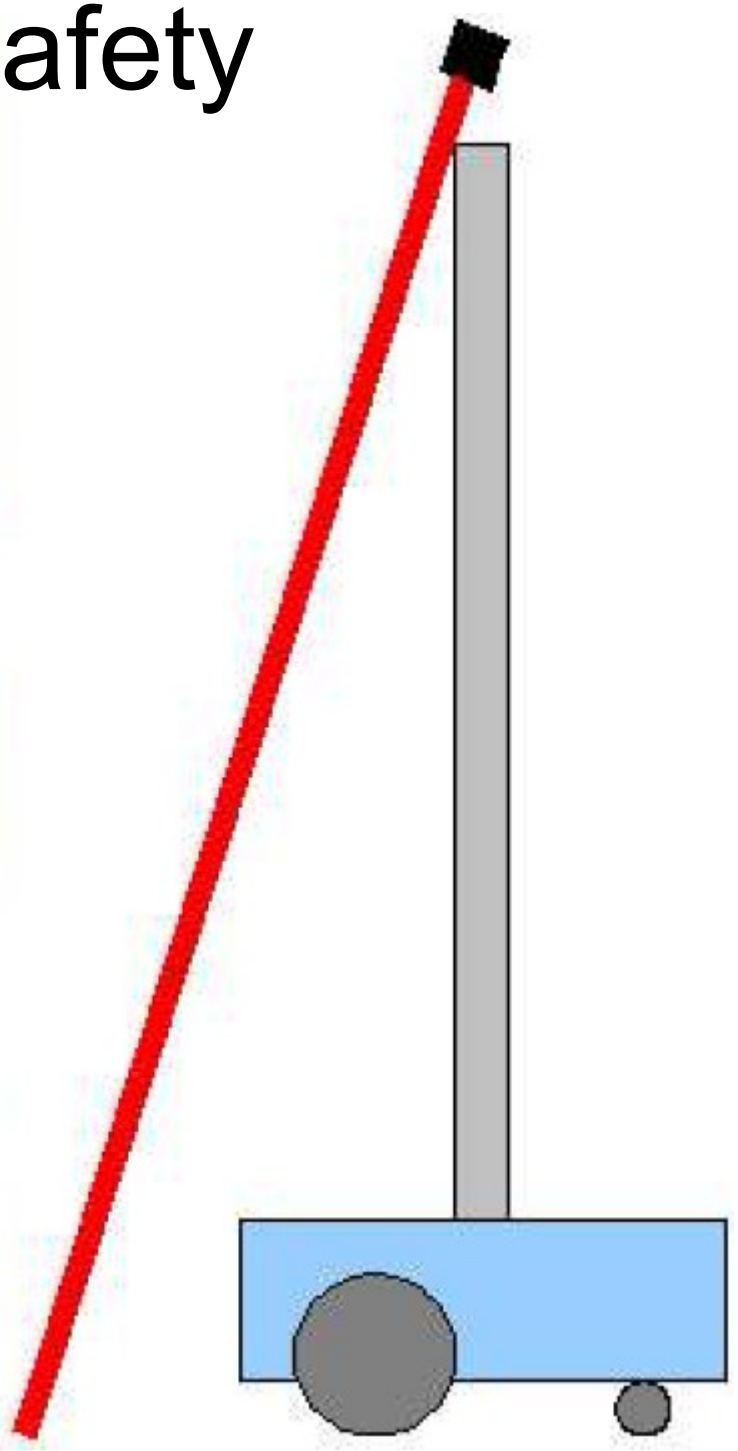


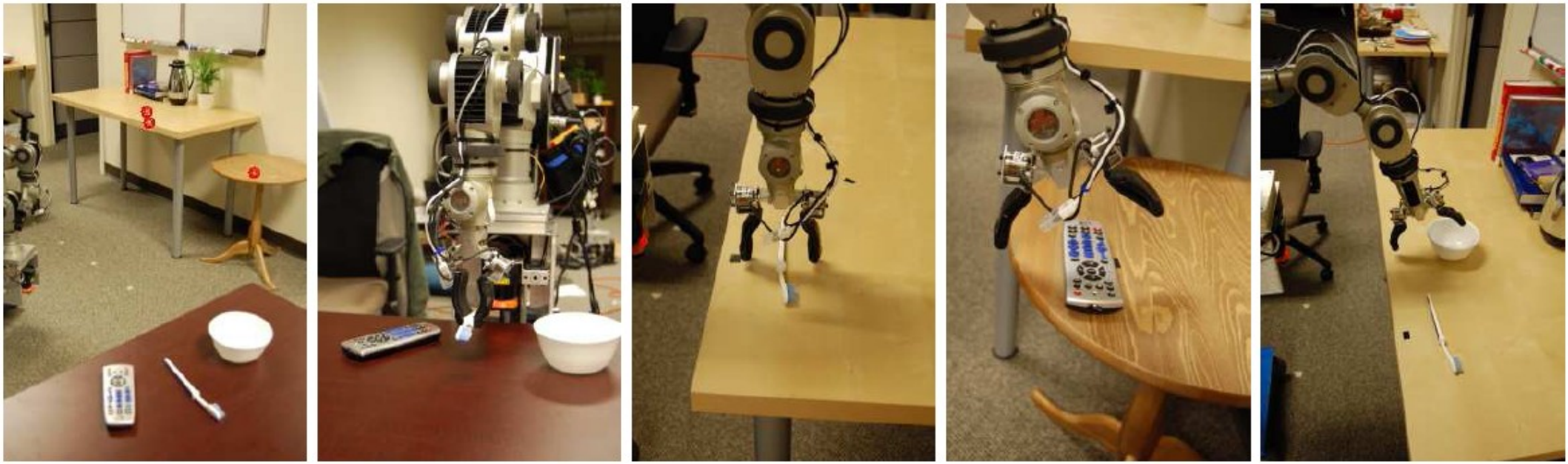






Monitoring Safety







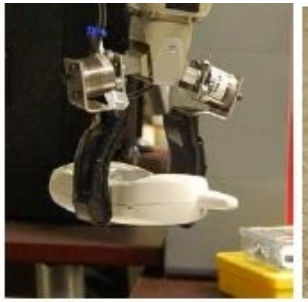
2 objects x 12 surfaces = 24 trials total
Cordless phone → 100% success
Vitamin pill (1.5cm x 0.5cm x 0.5cm) → 58% success

1) TV remote

2) Pill

3) Pill bottle

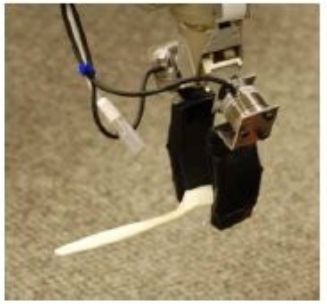
4) Glasses



5) Cordless phone

6) Toothbrush

7) Plastic fork



8) Plastic spoon

9) Bottle

10) Toothpaste

11) Cup

12) Plate

13) Bowl

14) Soap

15) Cellphone

16) Hand towel

17) Book

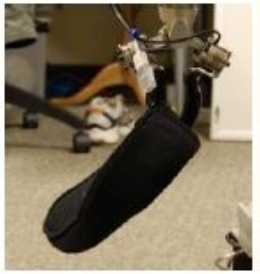
18) Dollar bill

19) Mail

20) Straw

21) Keys

22) Table knife



23) Slipper

24) Pencil

25) Medicine box

Causes of Failure

- Perception
  - Material properties
    - Reflective, Transparent, Noisy
  - Geometry
    - Low profile, Clutter
- Manipulation
  - Clutter
  - Low profile
  - Large
  - Thin and Rigid
  - Semantics

19) Mail

22) Table knife

12) Plate

17) Book

18) Dollar bill

Take Home Message

- Specialized behaviors composed in a simple way
  - Can generalize
  - Can achieve good performance
  - Are predictable
    - Good for Human Robot Interaction
    - Good for Data-driven methods
    - Easier to characterize and monitor for unexpected situations
  - Are modular, composable, and comprehensible
    - Good for system design
- A simple behavior does not imply narrow capability
  → **Performance is an empirical question**

Opening Doors and Drawers

Showed video of our latest research on door opening, which is a collaboration with Wolfram Burgard's group. The video of our older published work can be found at the following link:

http://www.hsi.gatech.edu/hrl/epc-icra10.shtml

Understanding the Requirements (What's waiting for mobile manipulators outside of the lab?)

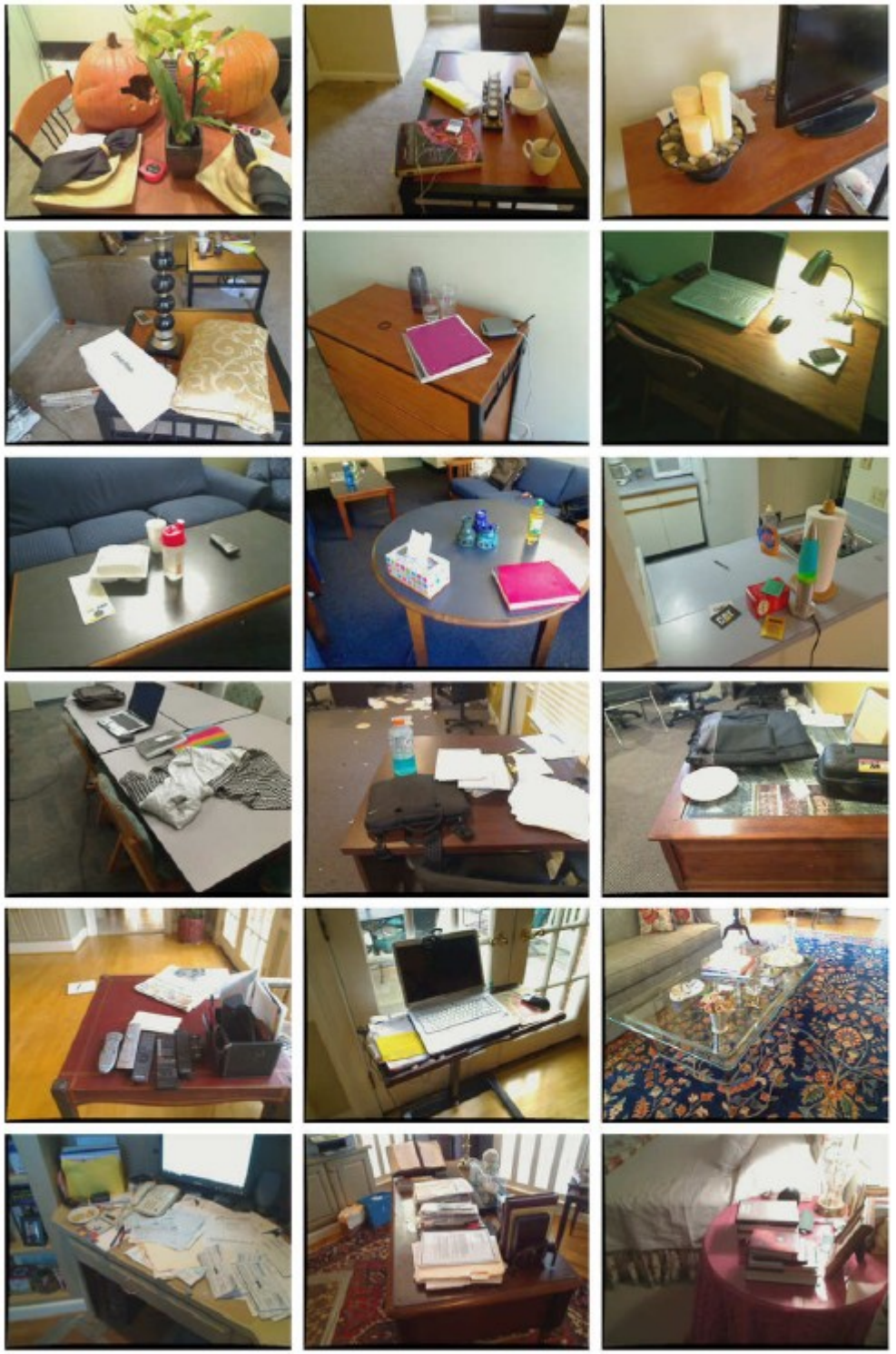
How to design brains and bodies?

- Option 1: Replicate performance of biological systems (e.g., humans or helper animals)
  - Can be a high bar
  - Unclear what to emulate
  - Tradeoffs unclear
  - Good for inspiration
- Option 2: Use knowledge of the task and the world
  - Need to capture and quantify
  - Define necessary conditions for success
  - Make tradeoffs explicit
  - Give robots common sense

Frankenstein picture from: http://www.boston.com/bostonglobe/ideas/brainiac/Frankenstein_monster_Boris_Karloff.jpg

Characterizing Clutter


WHEN GOD INTERRUPTS
BARNES
THE HOPEFUL HEART
Manfrotto



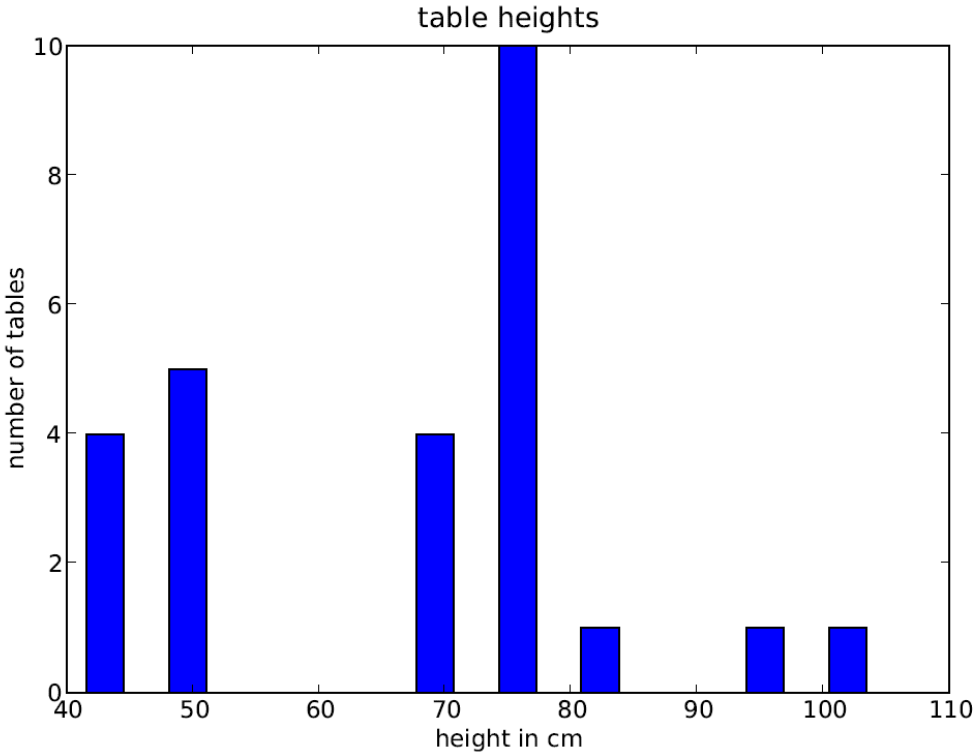
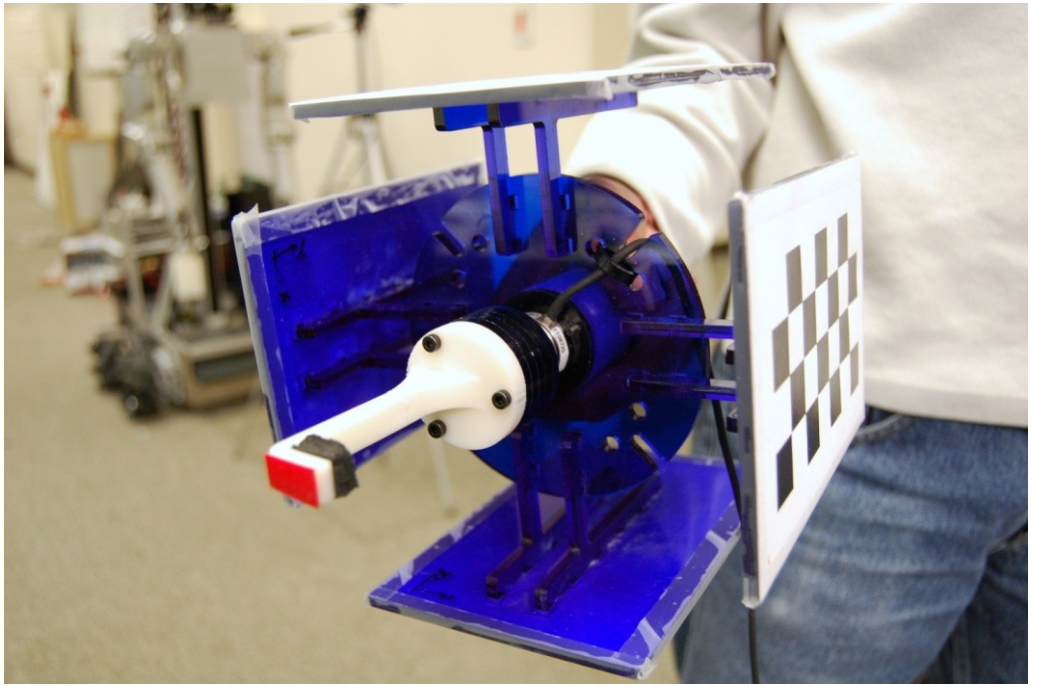
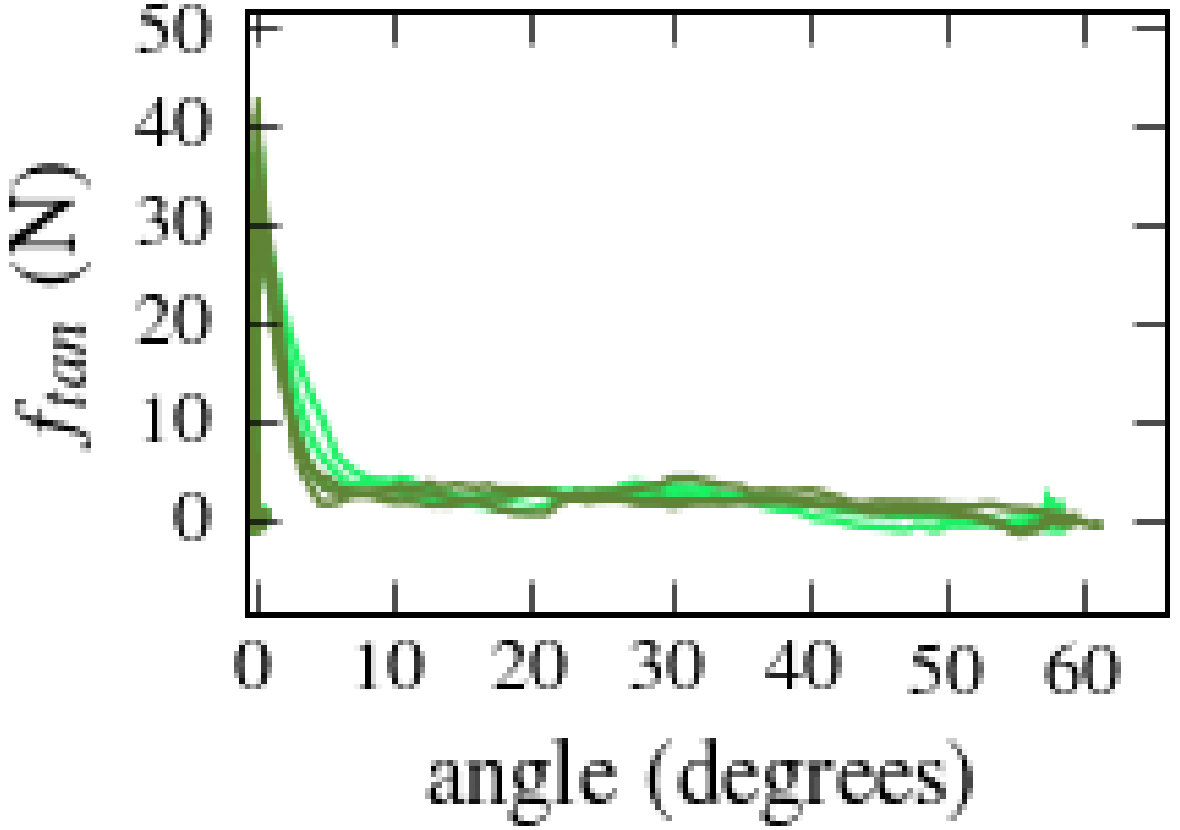


table heights
number of tables
height in cm
0
2
4
6
8
10
40
50
60
70
80
90
100
110

Capturing Everyday Mechanics

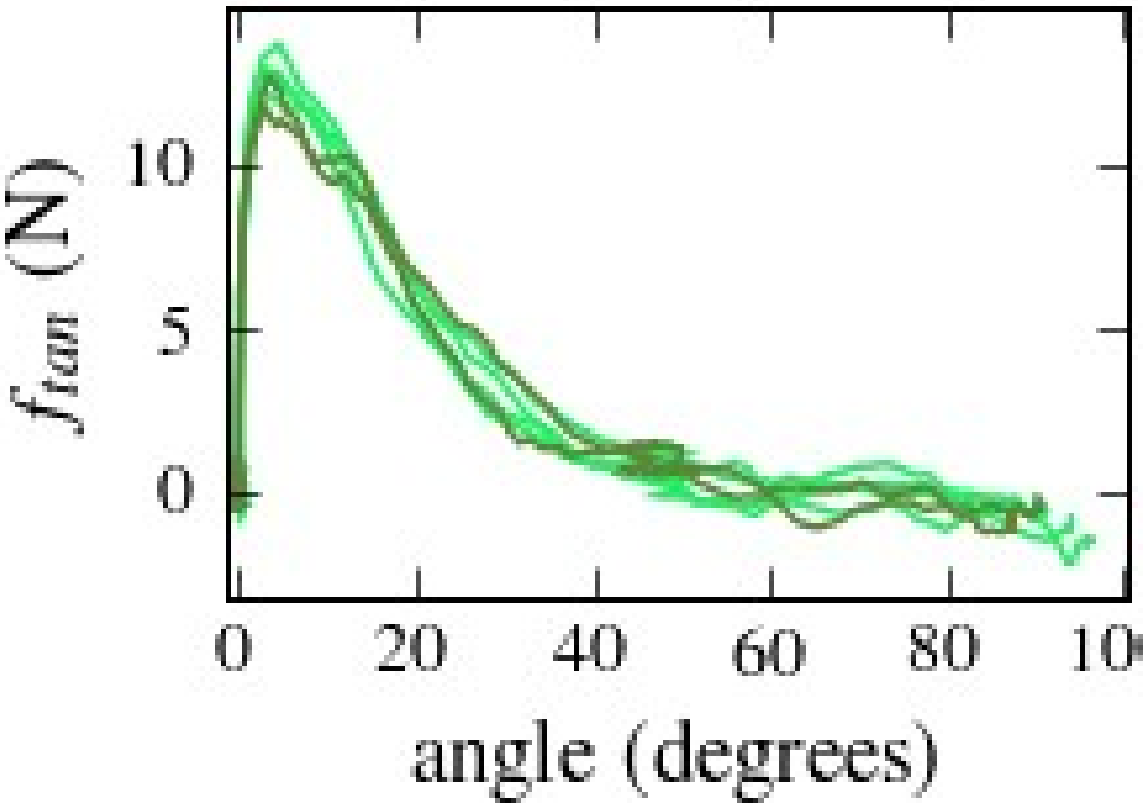


Refrigerator



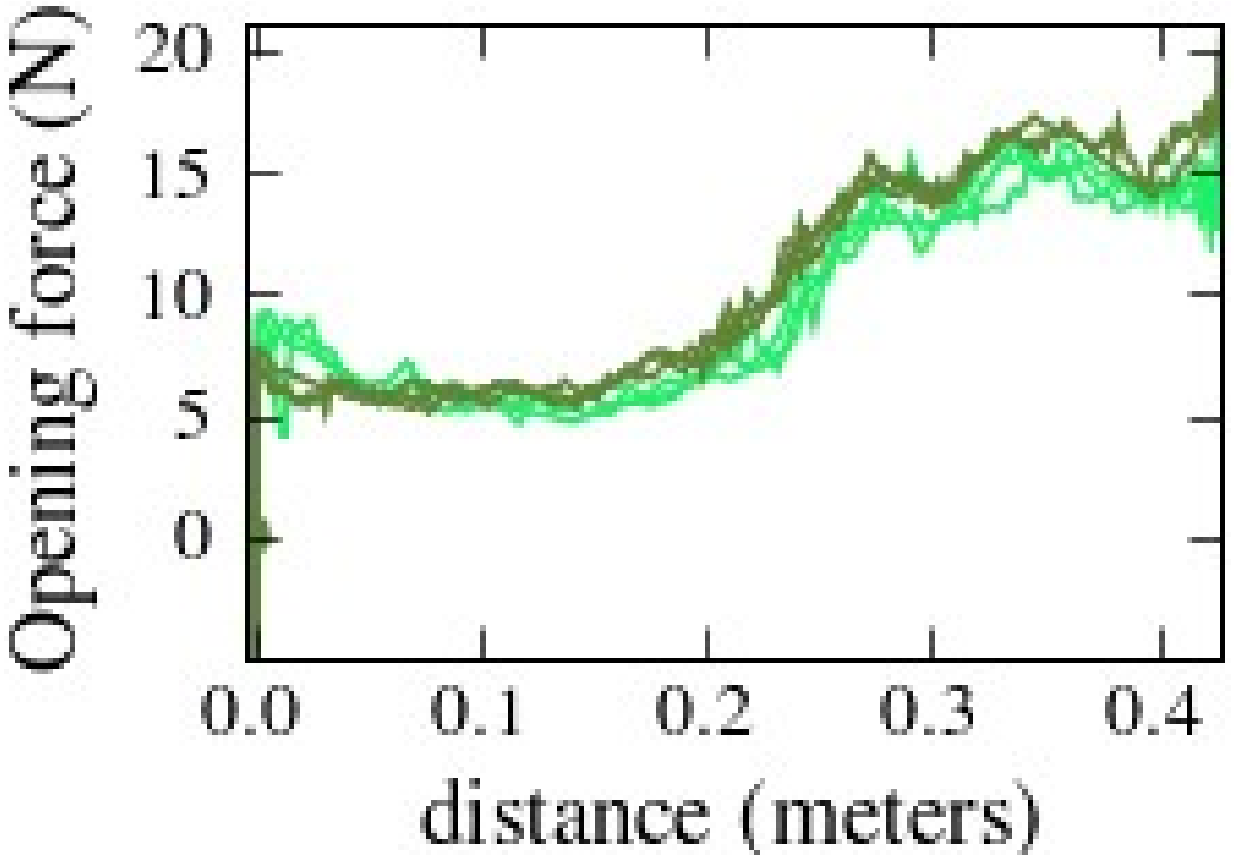
6 recordings
average angular velocities of 17 deg/s to 26.3 deg/s

Kitchen Cabinet



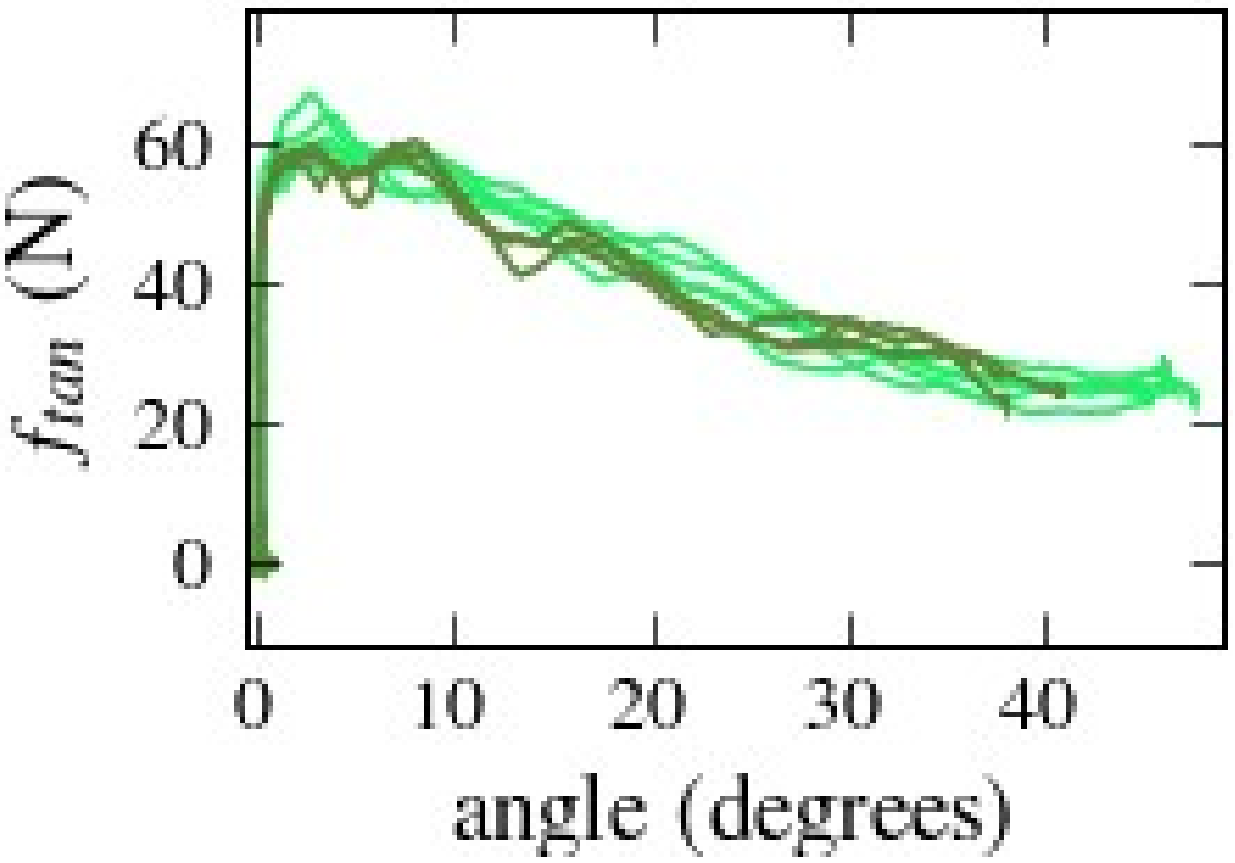
6 recordings
average angular velocities of 22.9 deg/s to 31.5 deg/s

Tool Chest Drawer

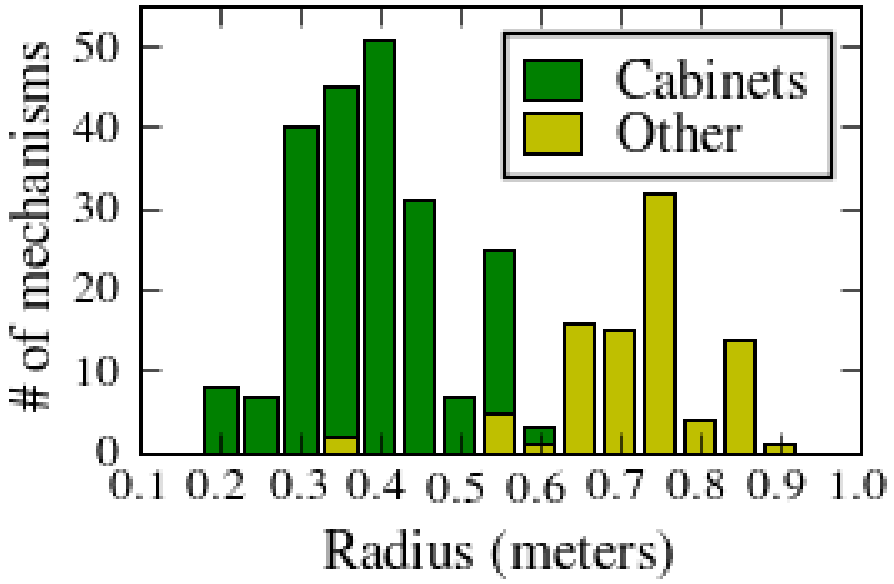


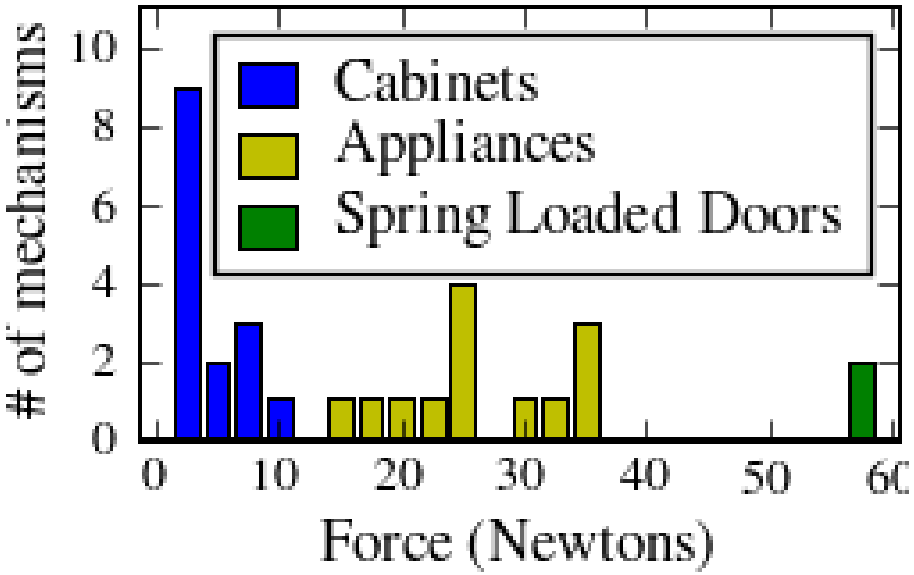
6 recordings
average velocities of 0.07 m/a to 0.2 m/s

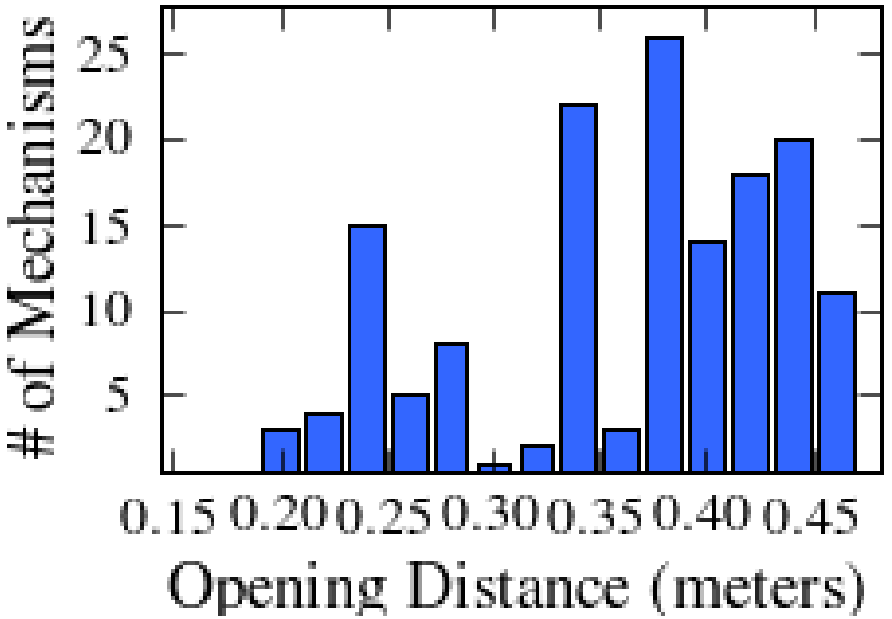
Spring-loaded Door

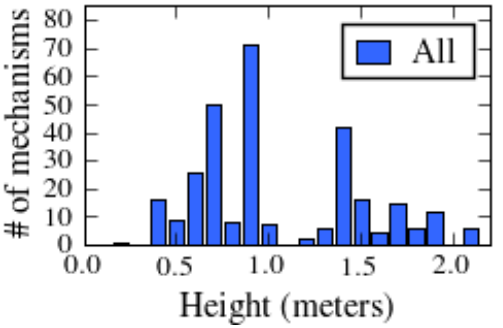


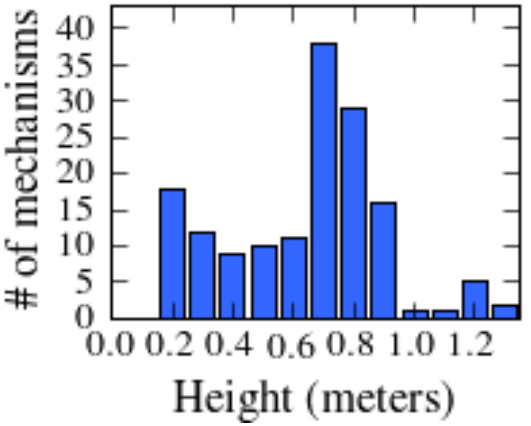
8 recordings
average angular velocities of 6.3 deg/s to 18.6 deg/s


Cabinets
Other
# of mechanisms
Radius (meters)
0
10
20
30
40
50
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0


Cabinets
Appliances
Spring Loaded Doors
# of mechanisms
Force (Newtons)
0
2
4
6
8
10
0 10 20 30 40 50


# of Mechanisms
Opening Distance (meters)
5
10
15
20
25
0.15 0.20 0.25 0.30 0.35 0.40 0.45


All
# of mechanisms
Height (meters)
0
10
20
30
40
50
60
70
80
0.0 0.5 1.0 1.5 2.0


# of mechanisms
Height (meters)
0
5
10
15
20
25
30
35
40
0.0 0.2 0.4 0.6 0.8 1.0 1.2

Outlook on the Future

The Chicken and the Egg

- Ubiquitous mobile manipulators would make these problems easier to solve
  - Lower bar to contribute to research
    - Like digital camera revolution and internet for computer vision research
  - Capture world and capture use
    - Teleoperate 100 robots for 100 days → ~27 years of captured experience
- Selling mobile manipulators is hard until we've solved some of these problems
  - Robots need to be useful enough to justify the cost
    - Is teleoperation enough?
  - High cost of arms may be biggest challenge
    - Mass production would help

Mobile manipulators can really help!

http://healthcare-robotics.com

I'm looking for a postdoc.
Referrals appreciated!