Toward Versatile and Inclusive Mobile Manipulators

Charlie Kemp, PhD
https://charliekemp.com

Associate Professor, Department of Biomedical Engineering

Georgia Tech

Wallace H. Coulter Department of Biomedical Engineering

EMORY UNIVERSITY

Co-founder & CTO, Hello Robot Inc.

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Charlie’s Conflict of Interest Statement

Dr. Kemp is both an associate professor at Georgia Tech and the chief technology officer (CTO) of Hello Robot Inc. where he works part time. **He owns equity** in Hello Robot Inc. and is an inventor of Georgia Tech intellectual property (IP) licensed by Hello Robot Inc. Consequently, **he receives royalties** through Georgia Tech for sales made by Hello Robot Inc. He also benefits from increases in the value of Hello Robot Inc.

Summary: If Hello Robot does well, Charlie does well.

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A Story in Two Parts

- Research on Mobile Manipulators for Personal Assistance
- A Novel Commercialized Robot

Part 1: *Research on Personal Assistance*

1980 - Star Wars: The Empire Strikes Back

2014 - Big Hero 6 (Baymax)

Stretch's Ancestor

EL-E from 2008

- Statically stable
- Small footprint
- Lightweight
- Cameras high
- Reach flat surfaces

A Point-and-Click Interface for the Real World: Laser Designation of Objects for Mobile Manipulation, Charles C. Kemp, Cressel Anderson, Hai Nguyen, Alex Trevor, and Zhe Xu, 3rd ACM/IEEE International Conference on Human-Robot Interaction (HRI), 2008

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Hand It Over or Set It Down: A User Study of Object Delivery with an Assistive Mobile Manipulator, Young Sang Choi, Tiffany L. Chen, Advait Jain, Cressel Anderson, Jonathan D. Glass, and Charles C. Kemp, IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN), 2009.

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Mobile Manipulators Can Provide Meaningful Assistance






research from the Healthcare Robotics Lab (healthcare-robotics.com) at Georgia Tech

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Long-term Disabilities

- In the US, 12,000,000 people with disabilities need assistance with daily activities [1]
- Causes include
  - Disease
  - Injury
  - Aging

[1] Brault, Matthew W. "Americans with disabilities: 2010." Current population reports 7 (2012): 0-131.
[image] found on the internet and used without permission

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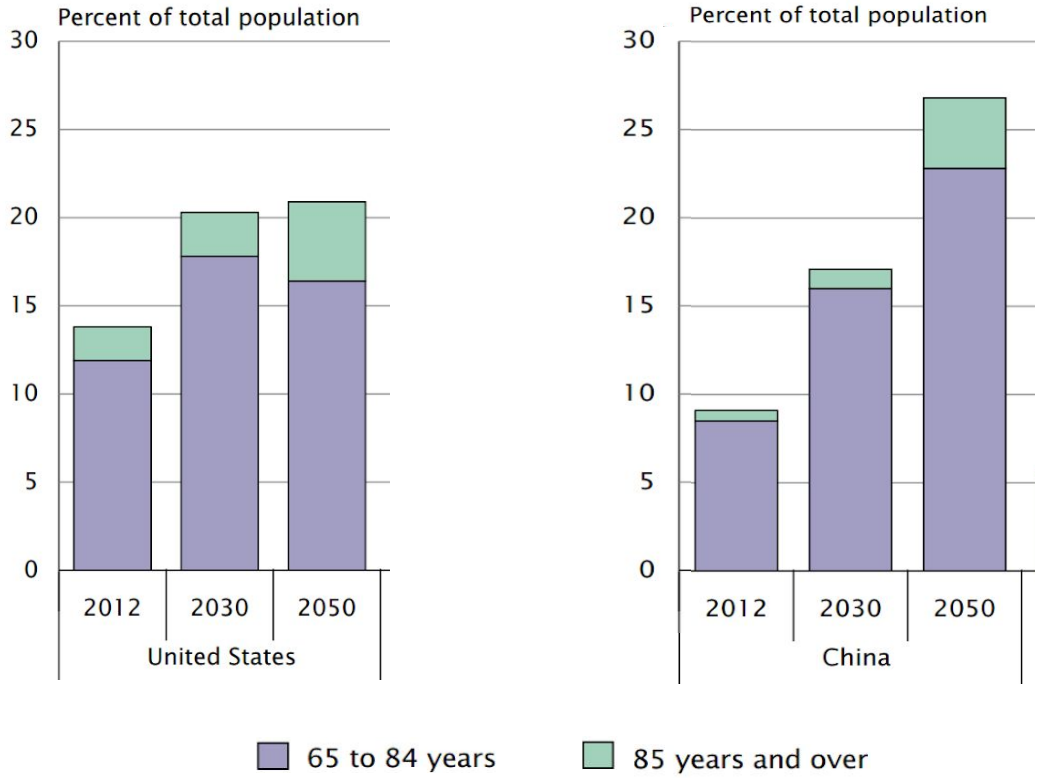
Short-term Disabilities

- In the US by 2030
  - 635,000 total hip replacement surgeries per year
  - 1.28 million total knee replacement surgeries per year

"*The median time to recovery of independence in walking was **12 days** and to ability to perform household chores was **49 days***" [2]

[1] Sloan, Matthew, Ajay Premkumar, and Neil P. Sheth. "Projected volume of primary total joint arthroplasty in the US, 2014 to 2030." JBJS 100.17 (2018): 1455-1460.
[2] Hamel, Mary Beth, et al. "Joint replacement surgery in elderly patients with severe osteoarthritis of the hip or knee: decision making, postoperative recovery, and clinical outcomes." Archives of internal medicine 168.13 (2008): 1430-1440.

Aging Societies will Increase Demand



Ortman, Jennifer M., Victoria A. Velkoff, and Howard Hogan. “An aging nation: the older population in the United States”. Washington, DC: United States Census Bureau, Economics and Statistics Administration, US Department of Commerce, 2014.

Types of Tasks

- **Activities of Daily Living (ADLs)**
  - Feeding, toileting, transferring, dressing, and hygiene
- **Instrumental Activities of Daily Living (IADLs)**
  - Housework, food preparation, taking medications, …

Types of Tasks

- **Activities of Daily Living (ADLs)**
  - Feeding, toileting, transferring, dressing, and hygiene
  - Manipulation near the person's body
- **Instrumental Activities of Daily Living (IADLs)**
  - Housework, food preparation, taking medications, …
  - Manipulation of objects in the environment

[images] found on the internet and used without permission

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Robotic Opportunities

- Provide **independence**
- Robots preferred for some tasks [1]
- 24/7 personalized assistance

[1] *Domestic robots for older adults: Attitudes, preferences, and potential*, Cory-Ann Smarr, Tracy L. Mitzner, Jenay M. Beer, Akanksha Prakash, Tiffany L. Chen, Charles C. Kemp, and Wendy A. Rogers. International Journal of Social Robotics, 6(2):229–247, 2014.
[image] from Willow Garage

Commercial Assistive Robots

JACO by Kinova

- On a wheelchair
- On a table or desk
- On the body

DynamicArm by Ottobock

My Spoon by SECOM

Myomo by Myomo Inc.

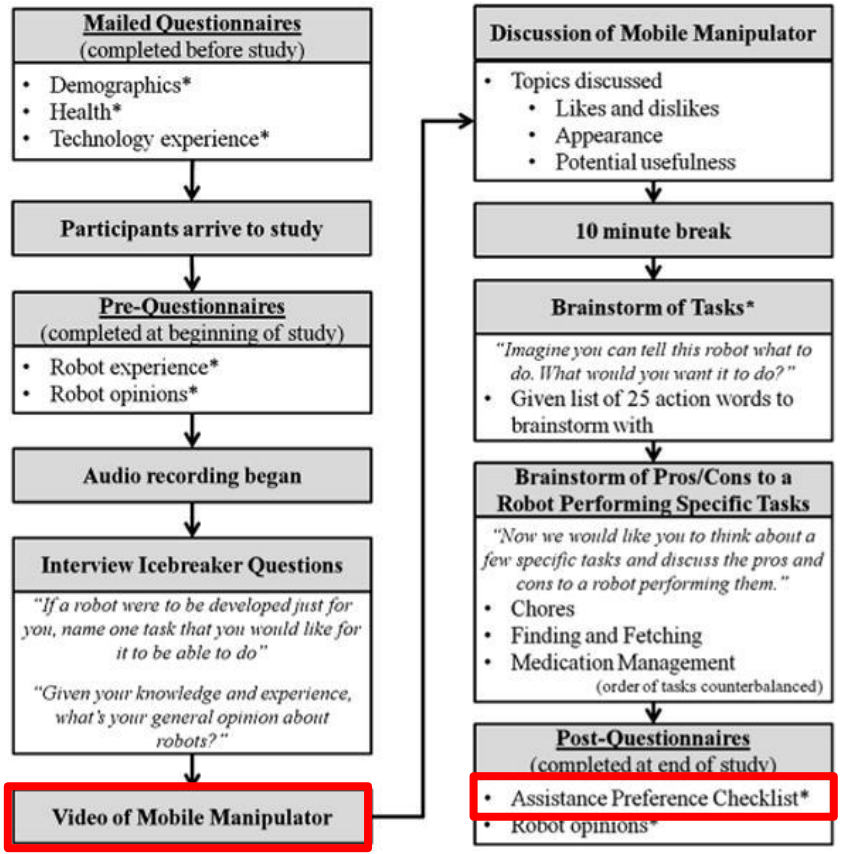
Advantages of Mobile Manipulators

- Operate independently from the user
- No don/doff
- Assist diverse users
- Potential for mass market product

People are Open to Assistance from Mobile Manipulators

- Since 2007, hundreds of participants
  - Older adults
  - Nurses
  - People with disabilities

Structured Group Interview and Questionnaires with Older Adults (N=21)



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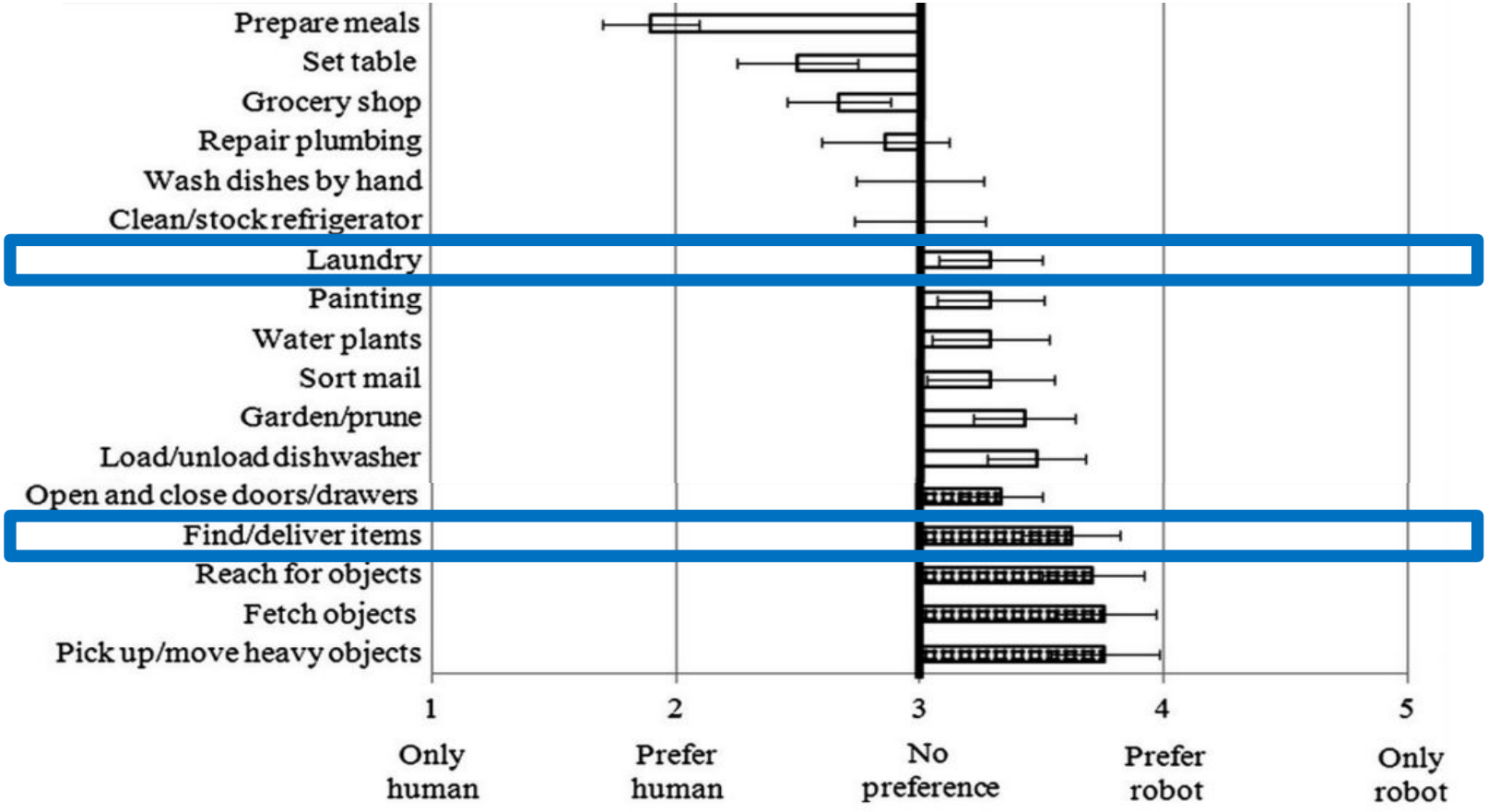
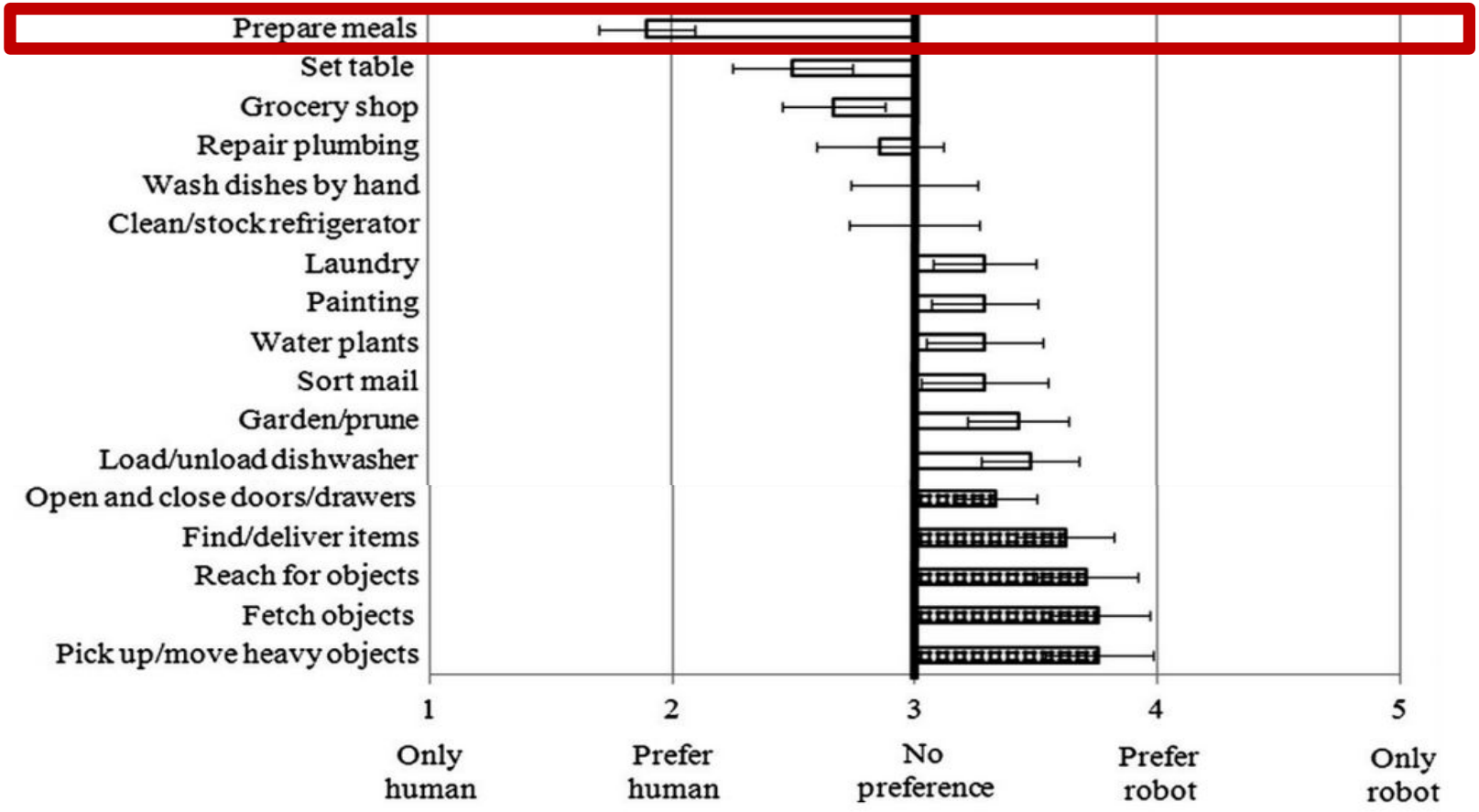
Preferred Robots for Some Tasks

(N=21, results after PR2 video and structured group interview)



Preferred Humans for Others

(N=21, results after PR2 video and structured group interview)



Autonomous Delivery of Medicine to Older Adults at the Aware Home via RFID (N=12)

Older Adults Medication Management in the Home: How can Robots Help? Akanksha Prakash, Jenay M. Beer,Travis Deyle, Cory-Ann Smarr, Tiffany L. Chen, Tracy L. Mitzner, Charles C. Kemp, and Wendy A. Rogers, 8th ACM/IEEE International Conference on Human-Robot Interaction (HRI), 2013

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More Open to Robotic Assistance After Using the PR2

(N=12, POST is after PR2 autonomously delivered medicine to them)

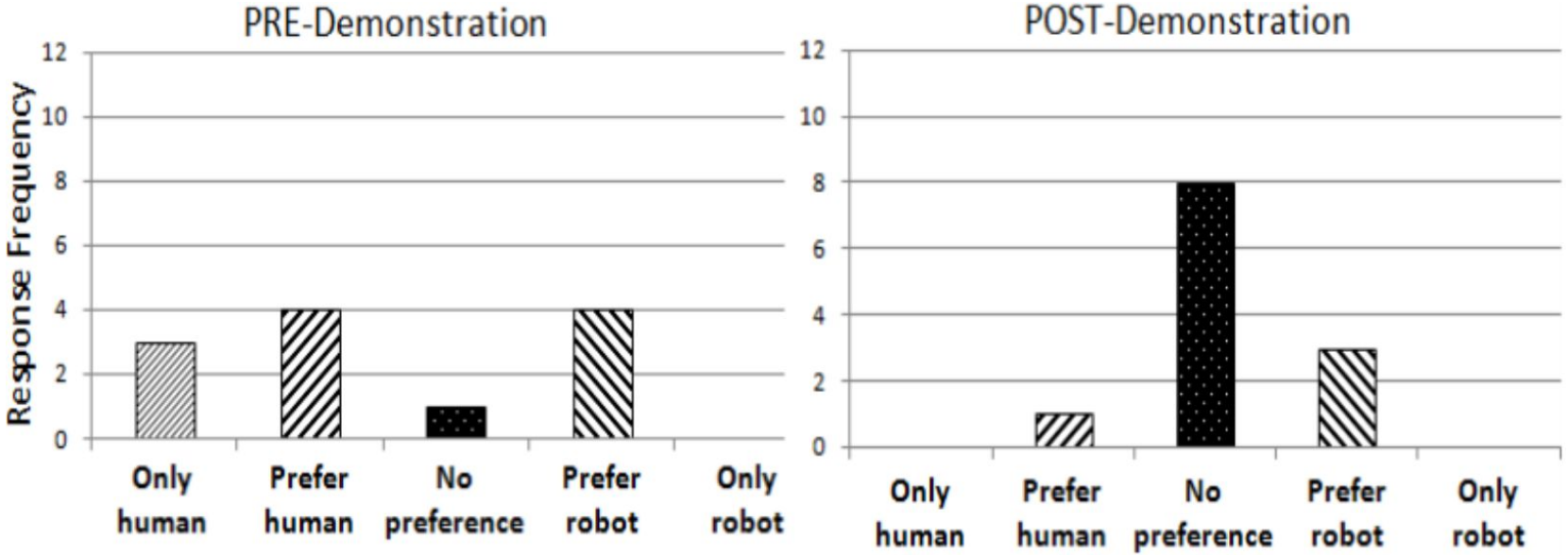

Fig. 4. Human versus robot assistance with delivering medication.

But Not for Everything

(N=12, POST is after PR2 autonomously delivered medicine to them)

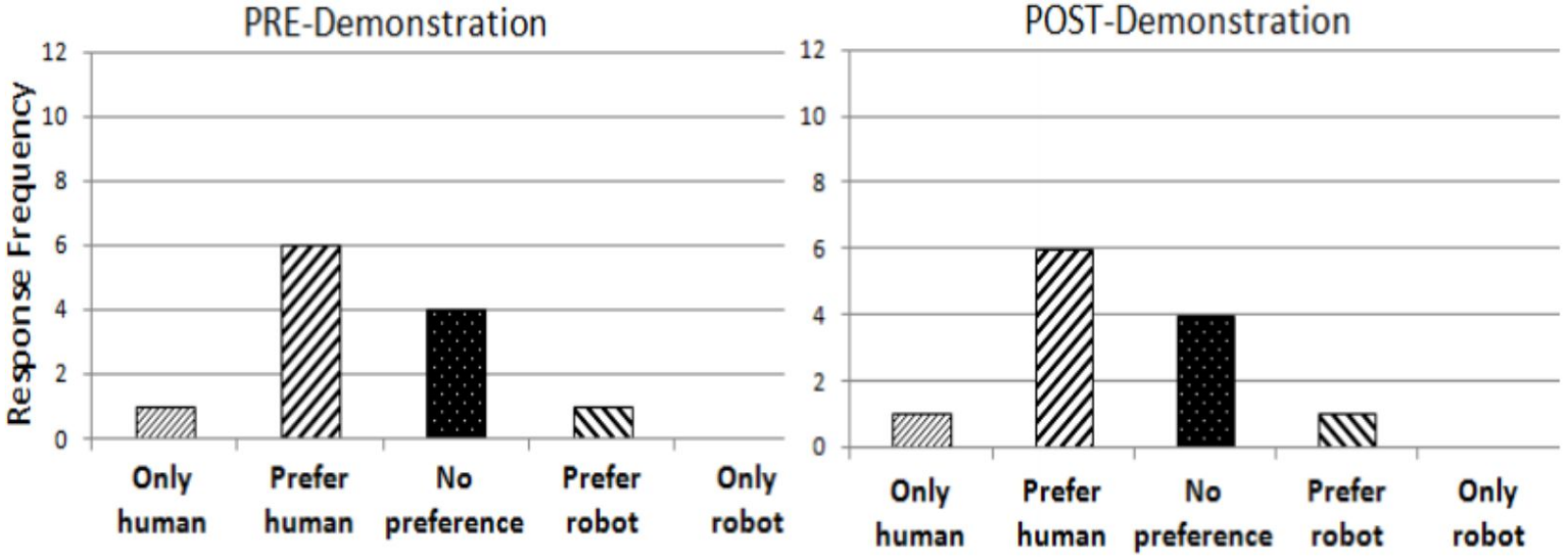

Fig. 5. Human versus robot assistance with taking medication.

Mobile Manipulators Can Provide Meaningful Assistance






research from the Healthcare Robotics Lab (healthcare-robotics.com) at Georgia Tech

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Mobile Manipulators Can Provide Meaningful Assistance

The Robots for Humanity Project

Robots for humanity: using assistive robotics to empower people with disabilities, Tiffany L. Chen, Matei Ciocarlie, Steve Cousins, Phillip Grice, Kelsey Hawkins, Kaijen Hsiao, Charles C. Kemp, Chih-Hung King, Daniel A. Lazewatsky, Adam Leeper, Hai Nguyen, Andreas Paepcke, Caroline Pantofaru, William D. Smart, and Leila Takayama, IEEE Robotics & Automation Magazine, 2013

Photo taken on June 16, 2011 at Willow Garage. Image from https://www.flickr.com/photos/willowgarage/5941309642 .

Assistive Mobile Manipulation for Self-Care Tasks Around the Head, Kelsey Hawkins, Phillip M. Grice, Tiffany L. Chen, Chih-Hung King, and Charles C. Kemp, 2014 IEEE Symposium on Computational Intelligence in Robotic Rehabilitation and Assistive Technologies, 2014.

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In-home and remote use of robotic body surrogates by people with profound motor deficits, Phillip M. Grice and Charles C. Kemp, PLoS ONE 14(3), 2019.

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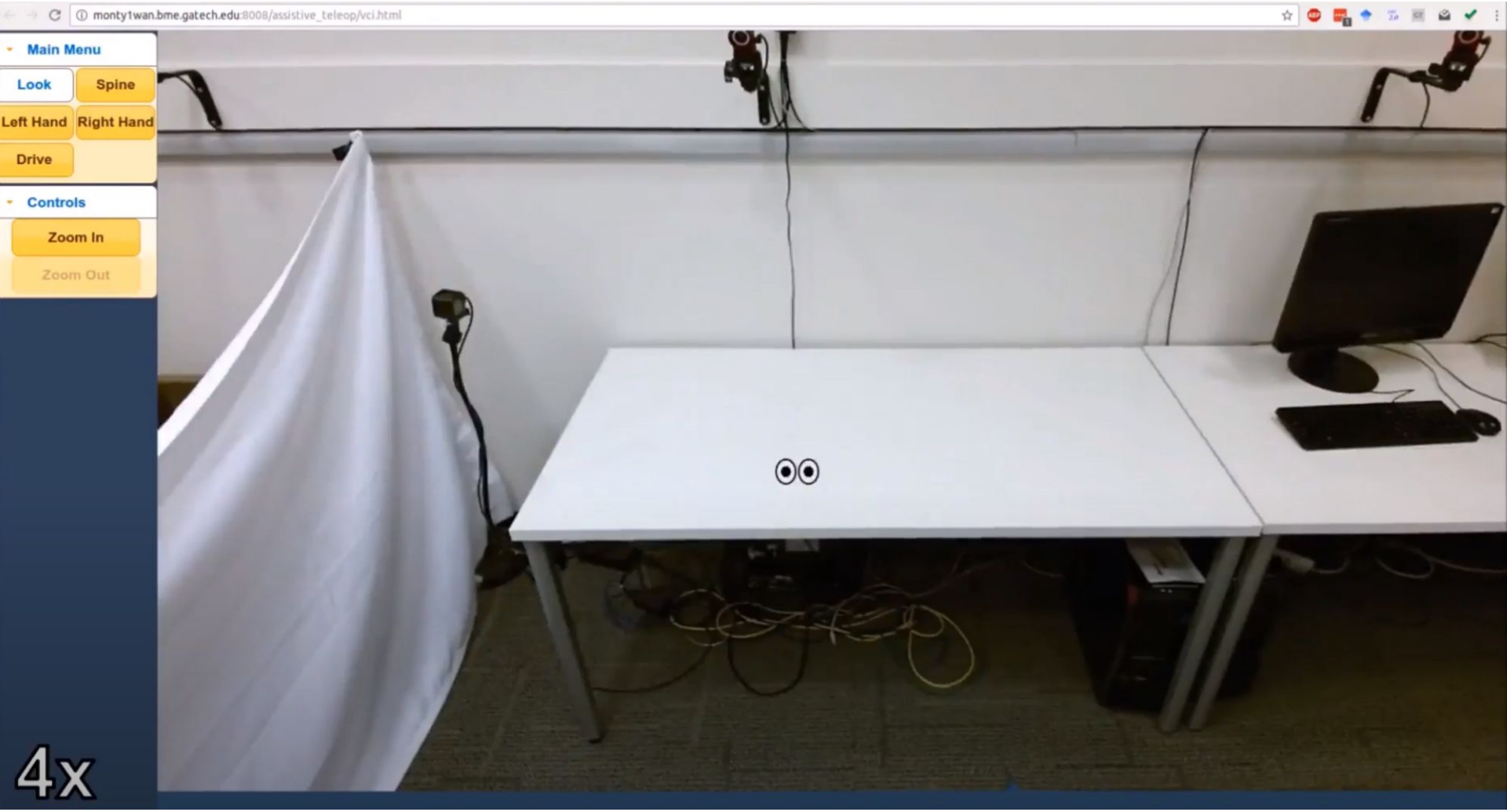
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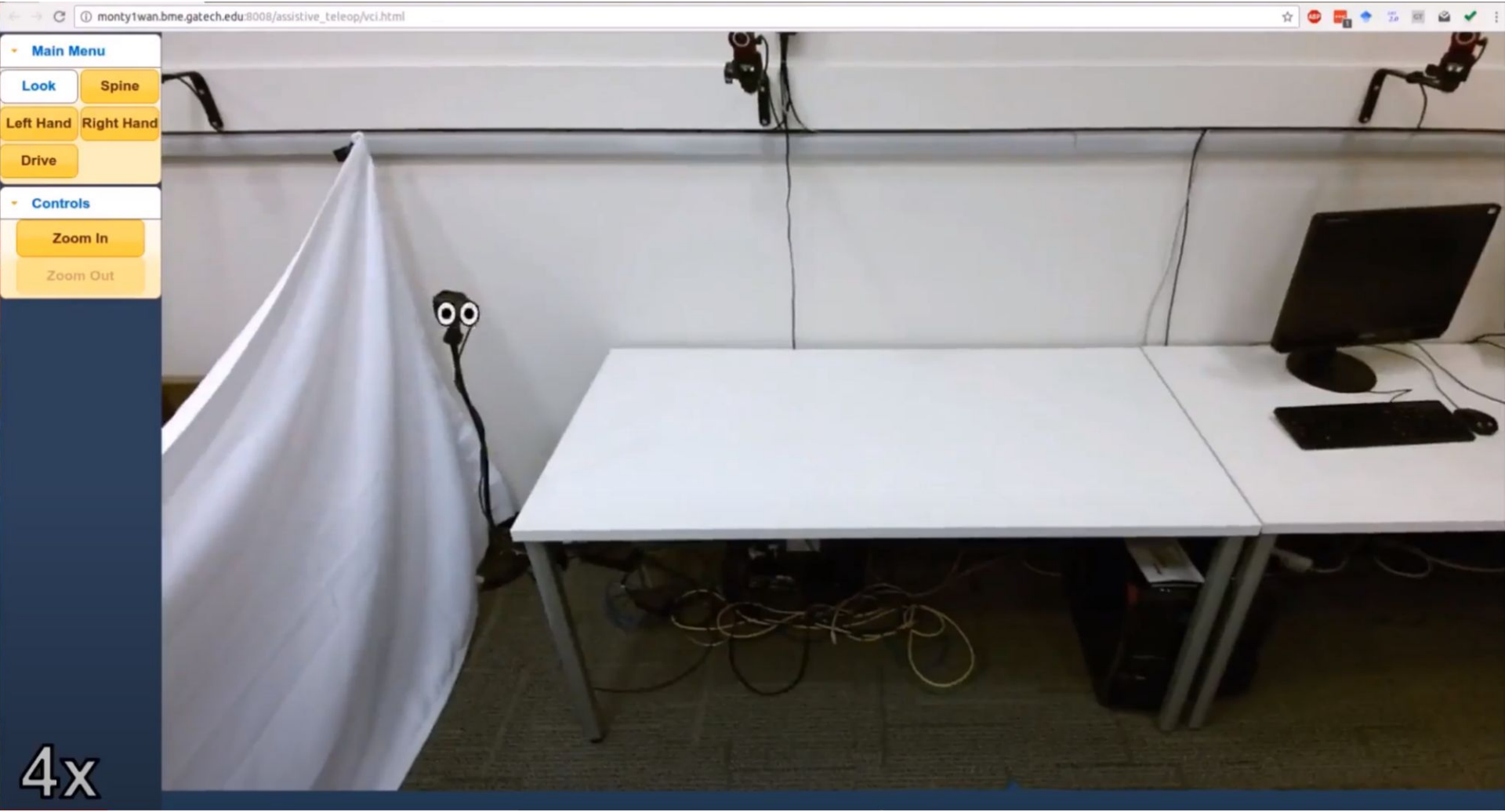
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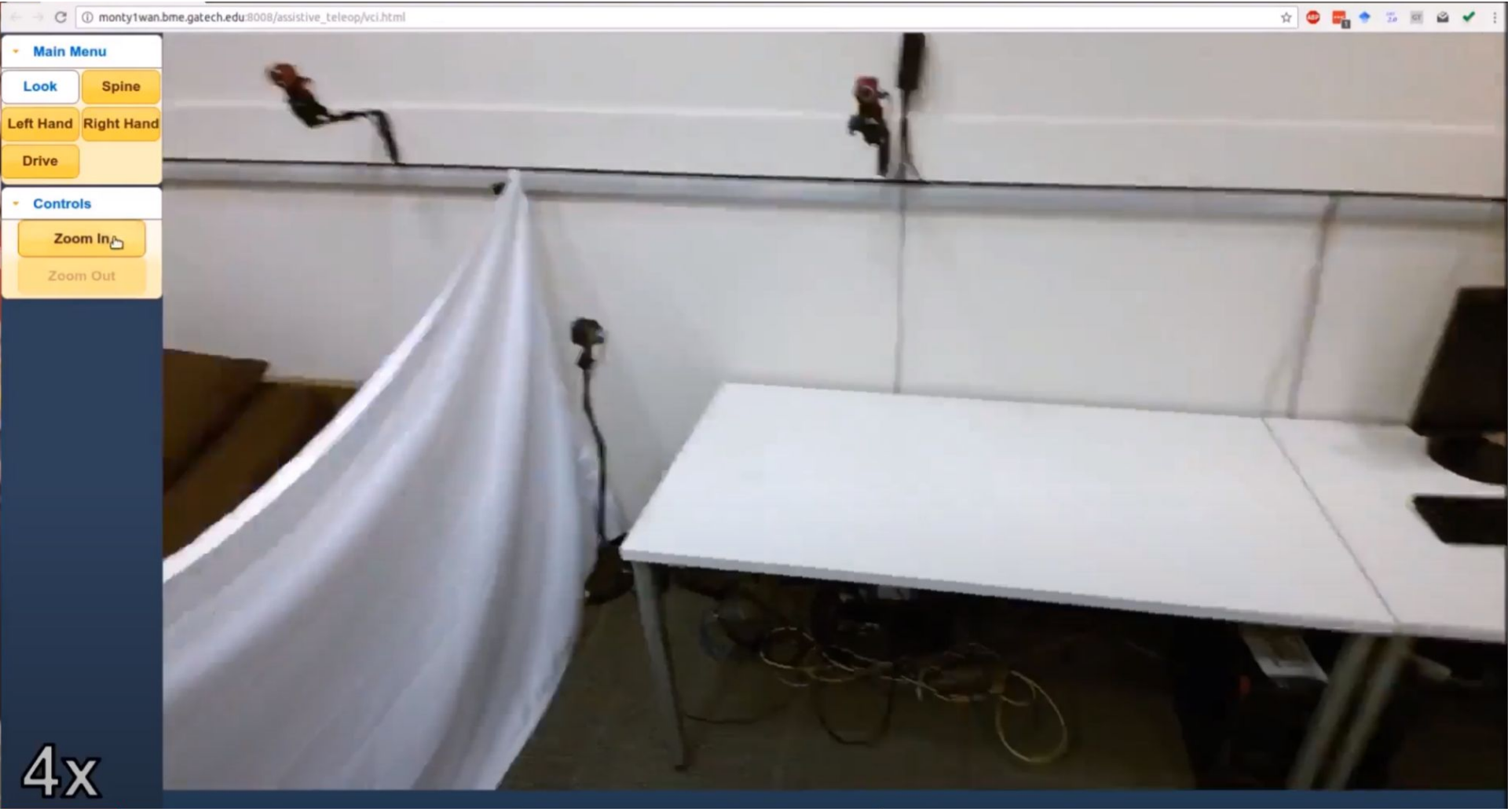
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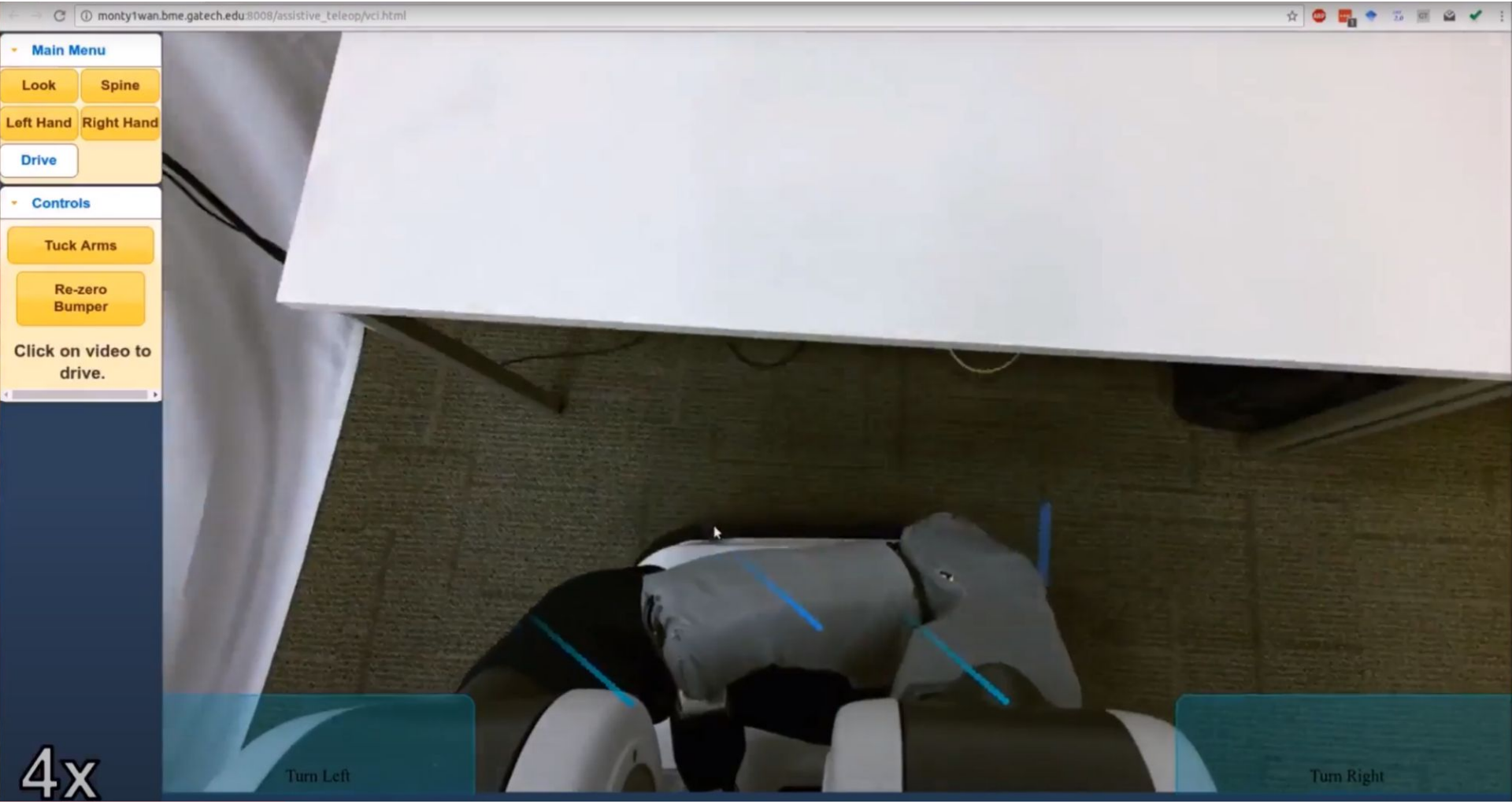
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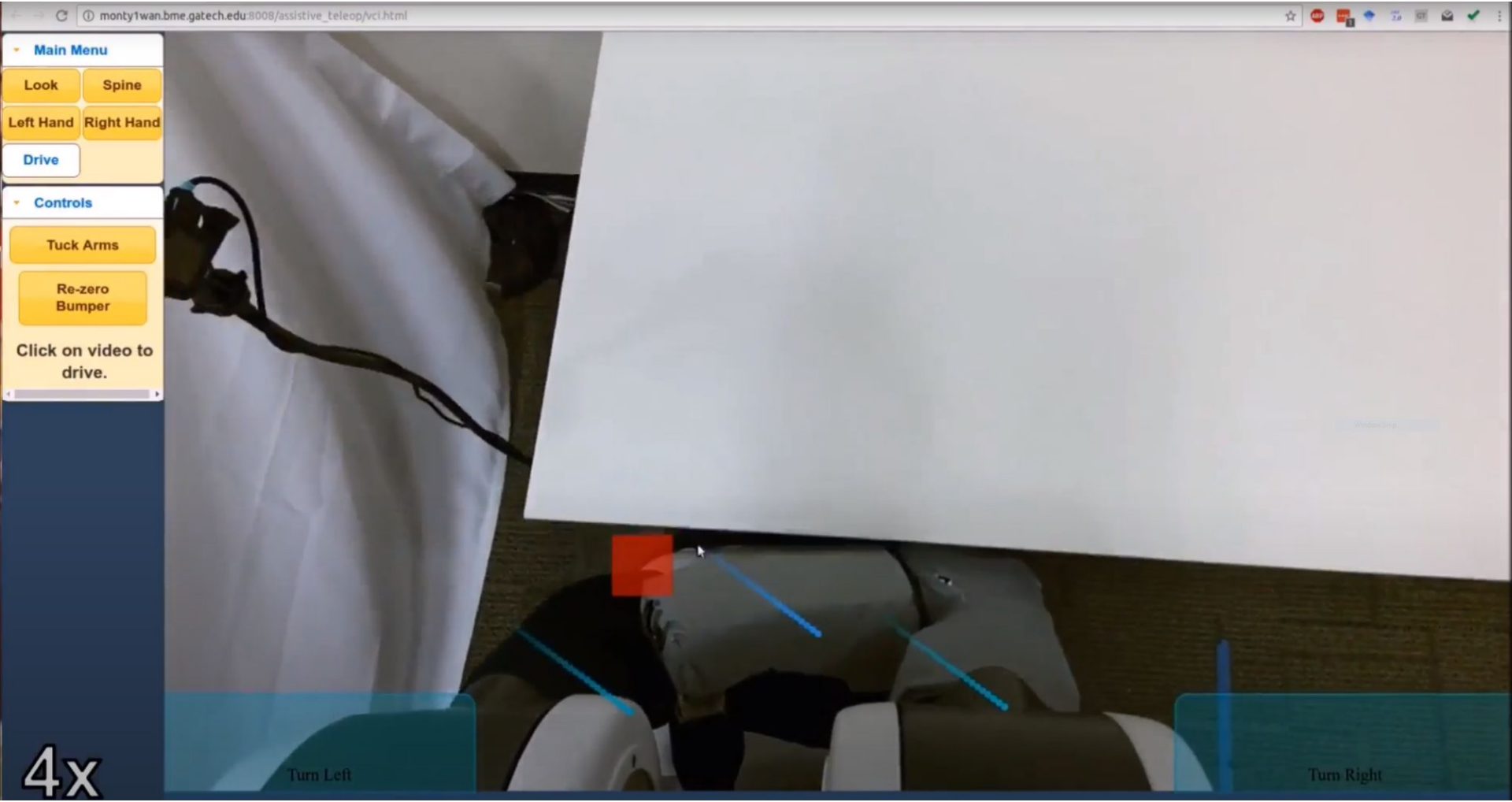
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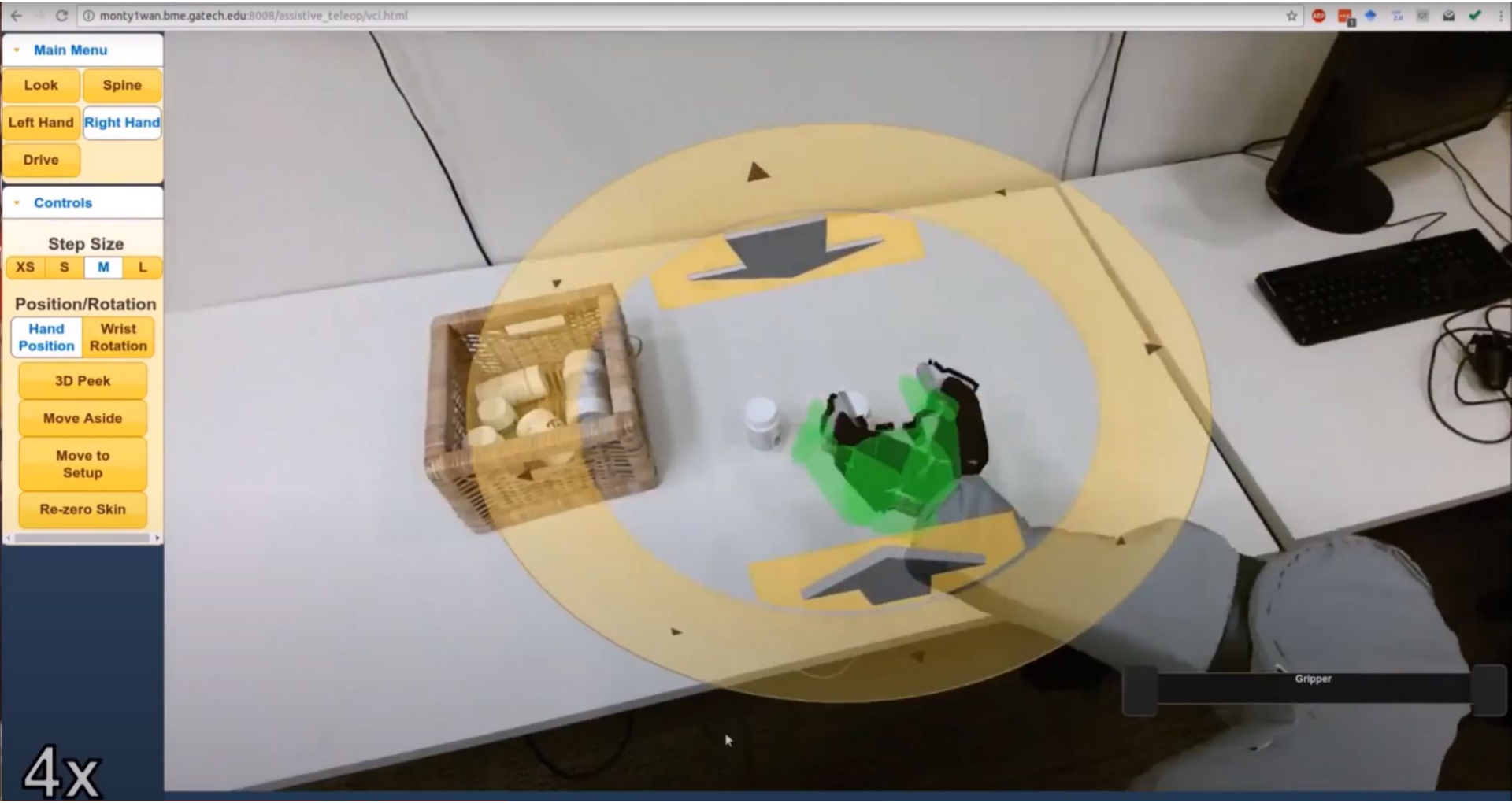
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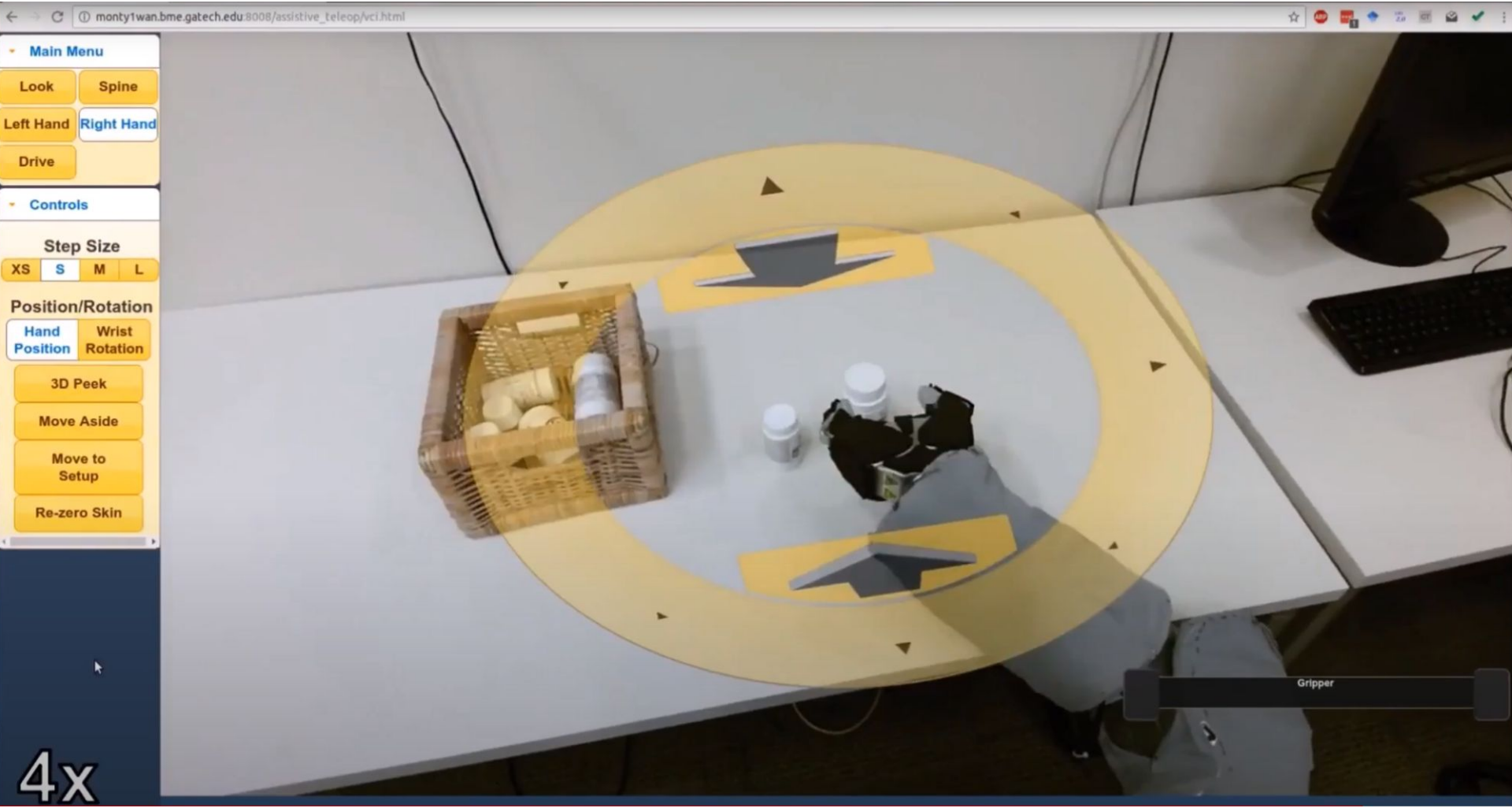
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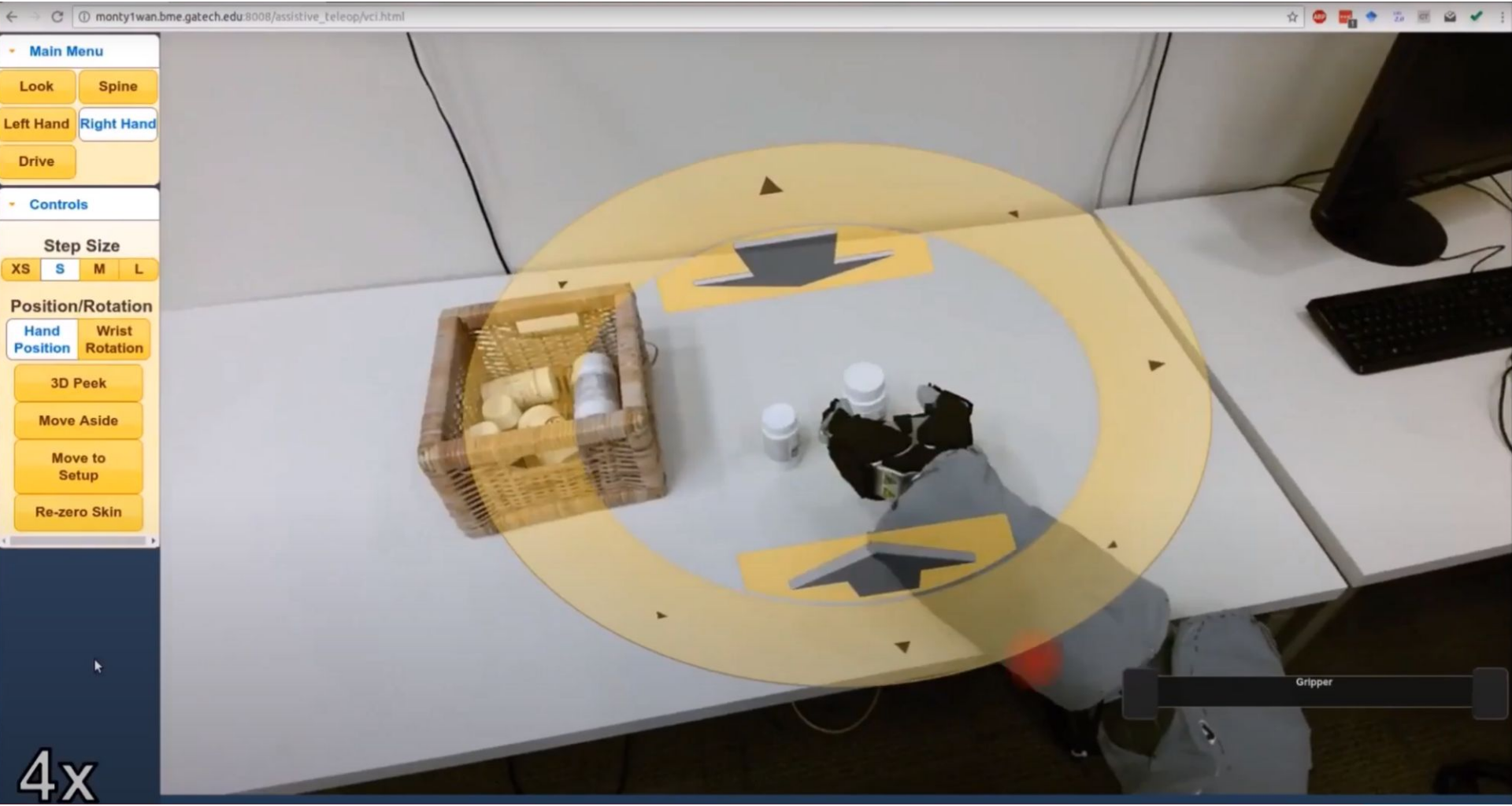
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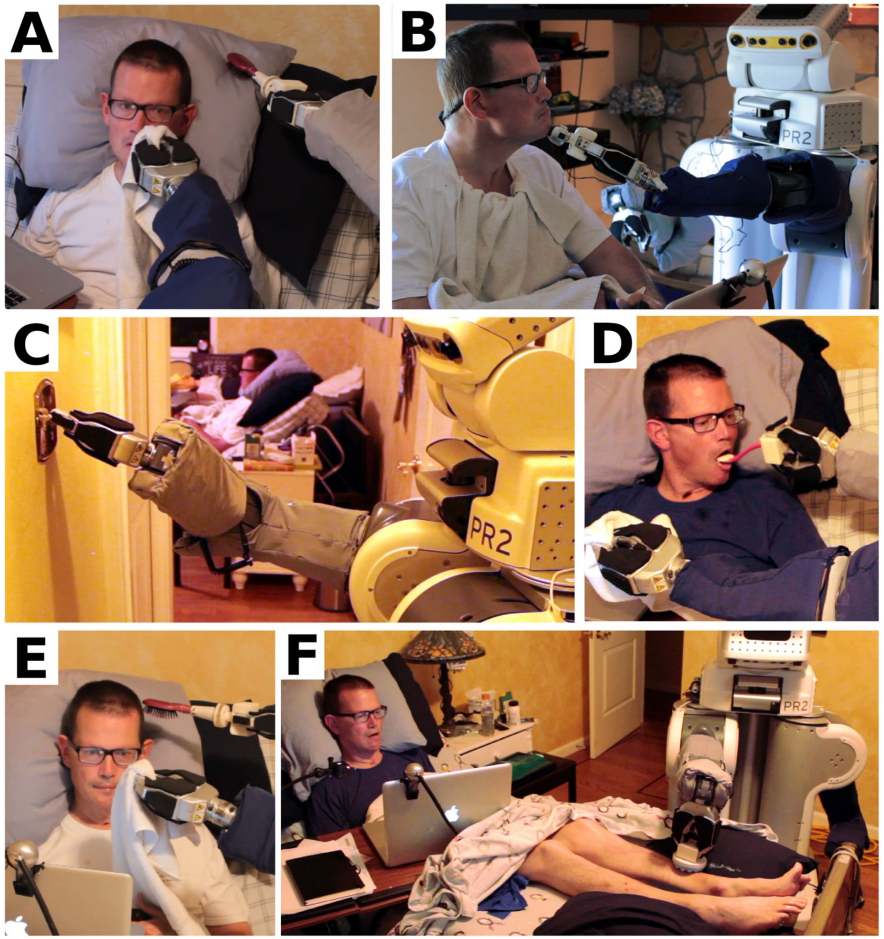

In-home and remote use of robotic body surrogates by people with profound motor deficits, Phillip M. Grice and Charles C. Kemp, PLoS ONE 14(3), 2019.

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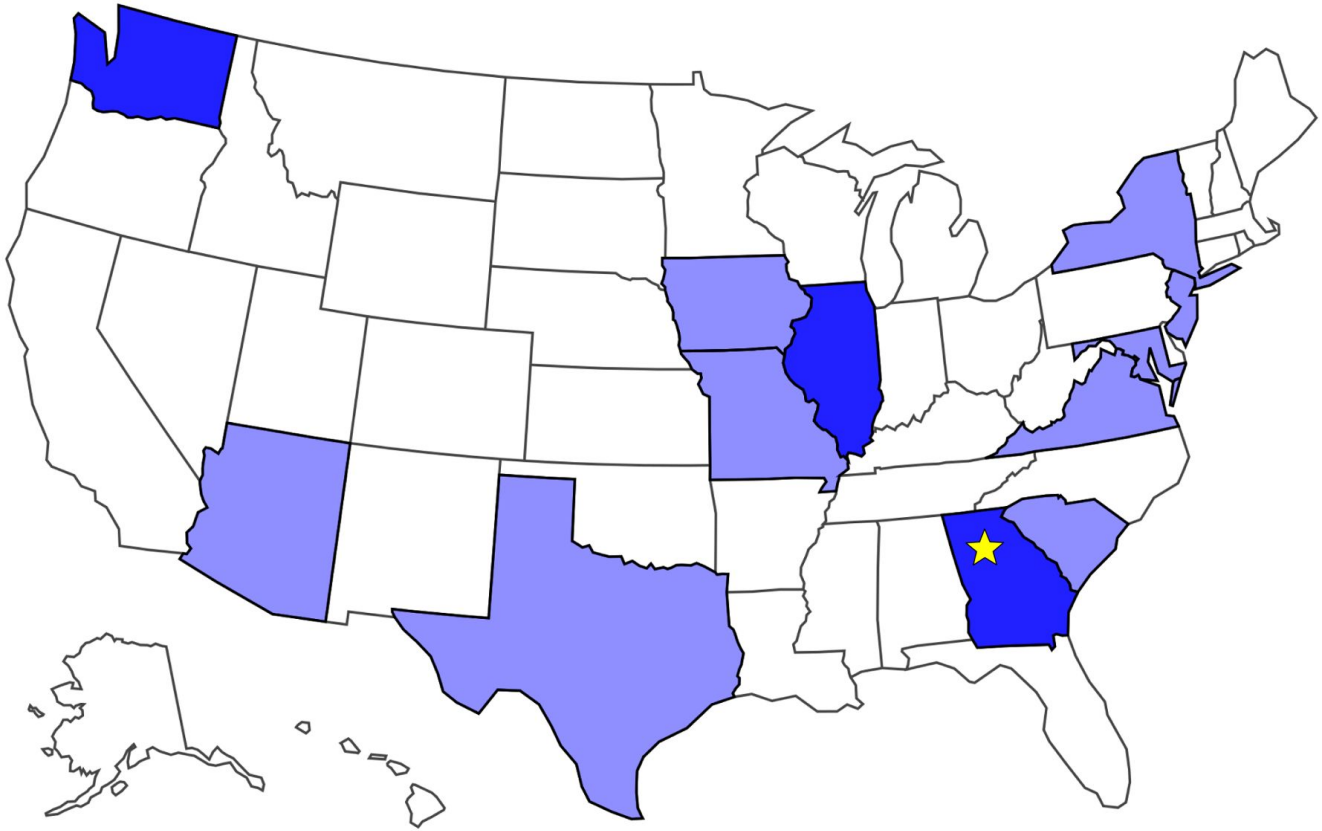
15 Participants



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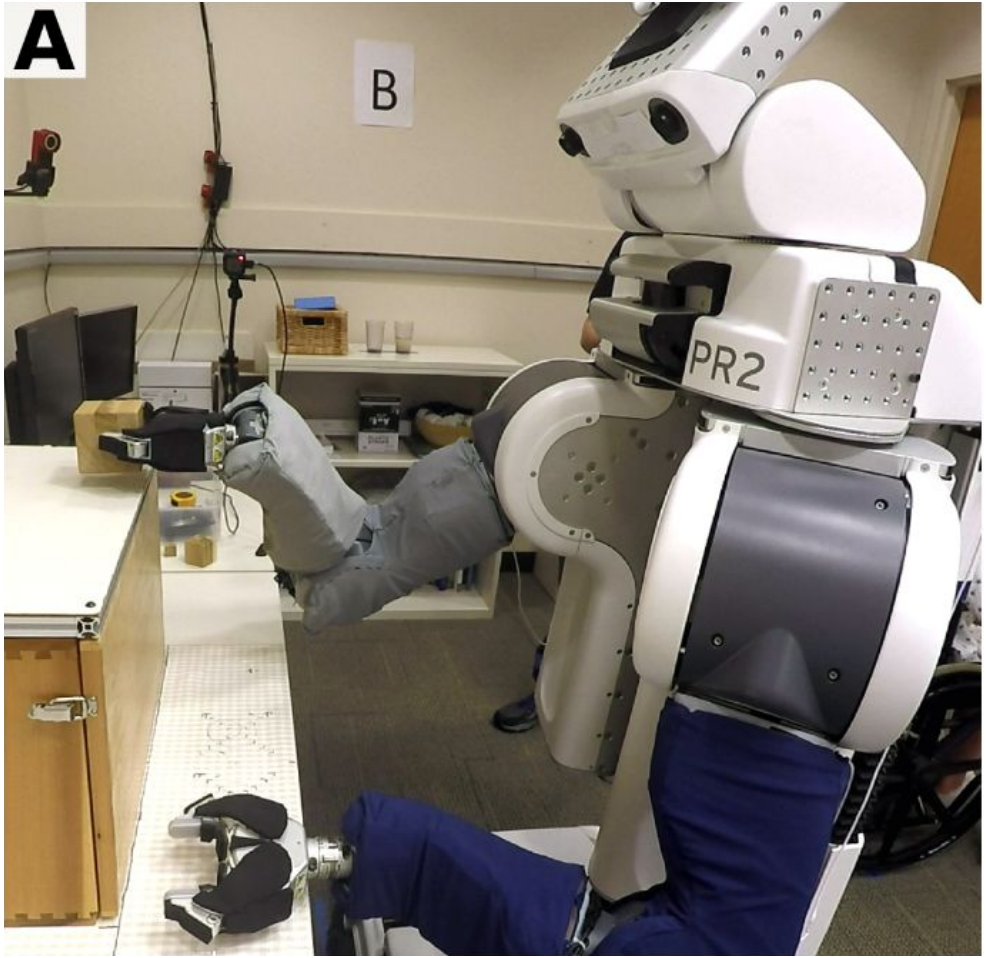

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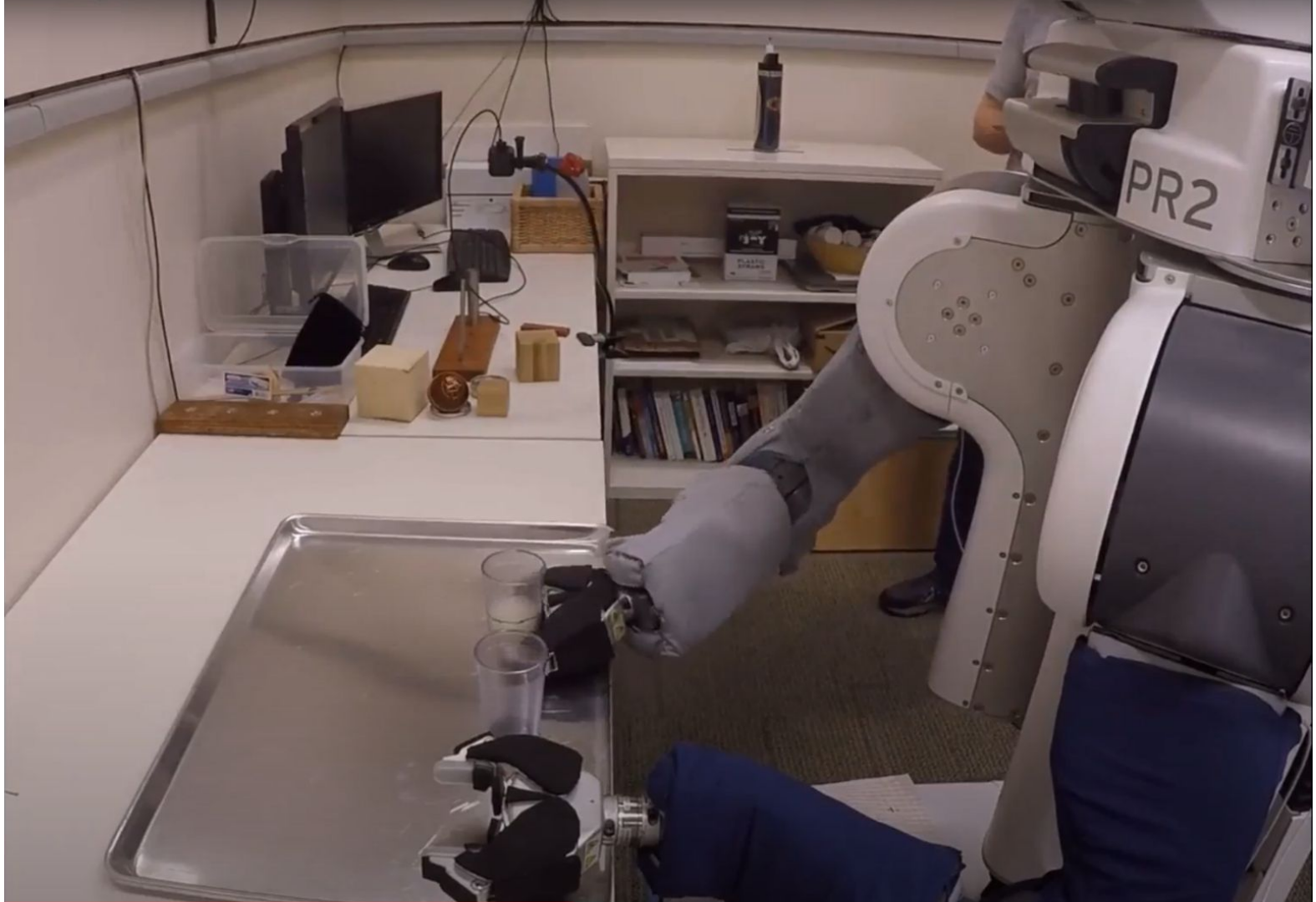
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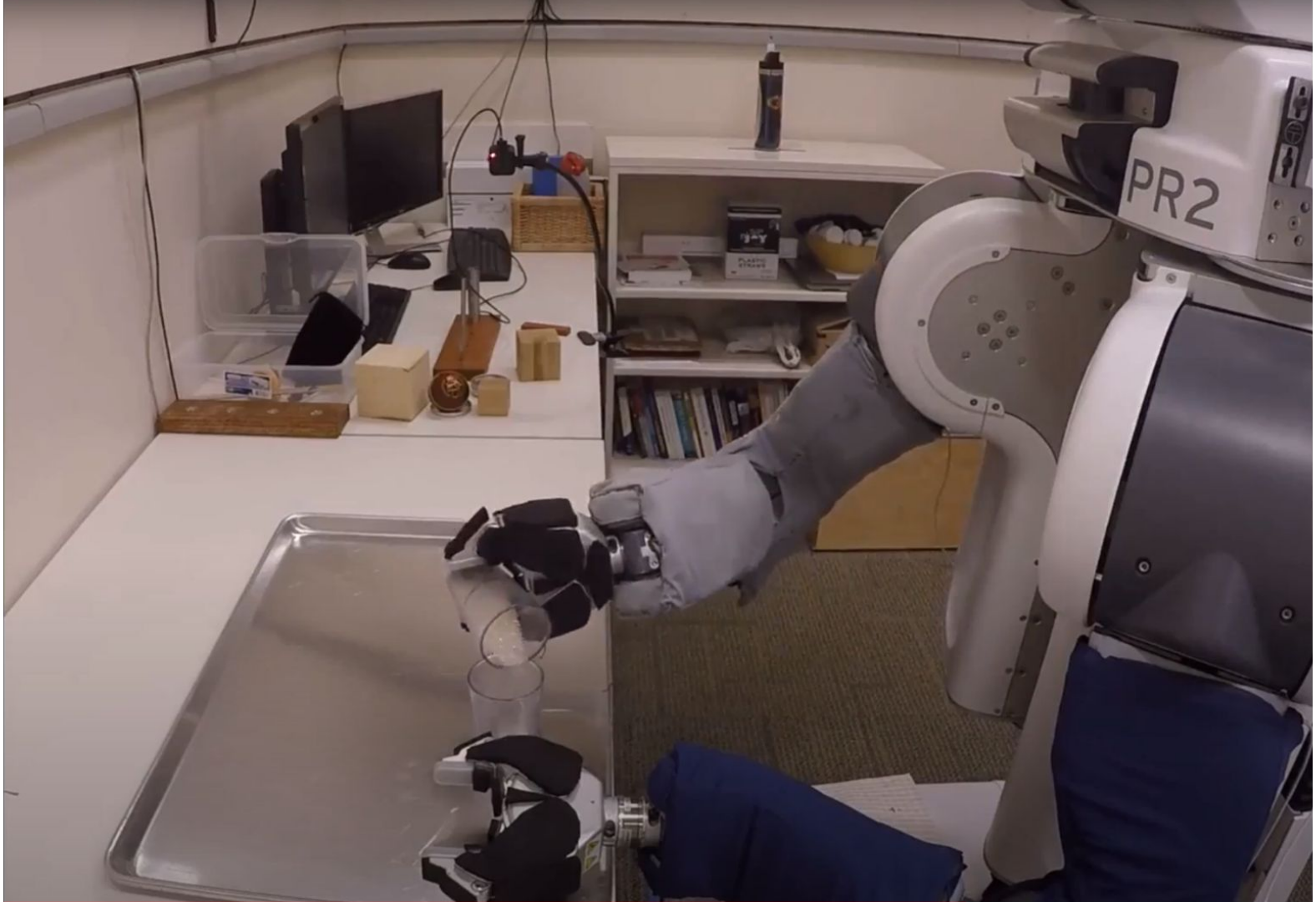
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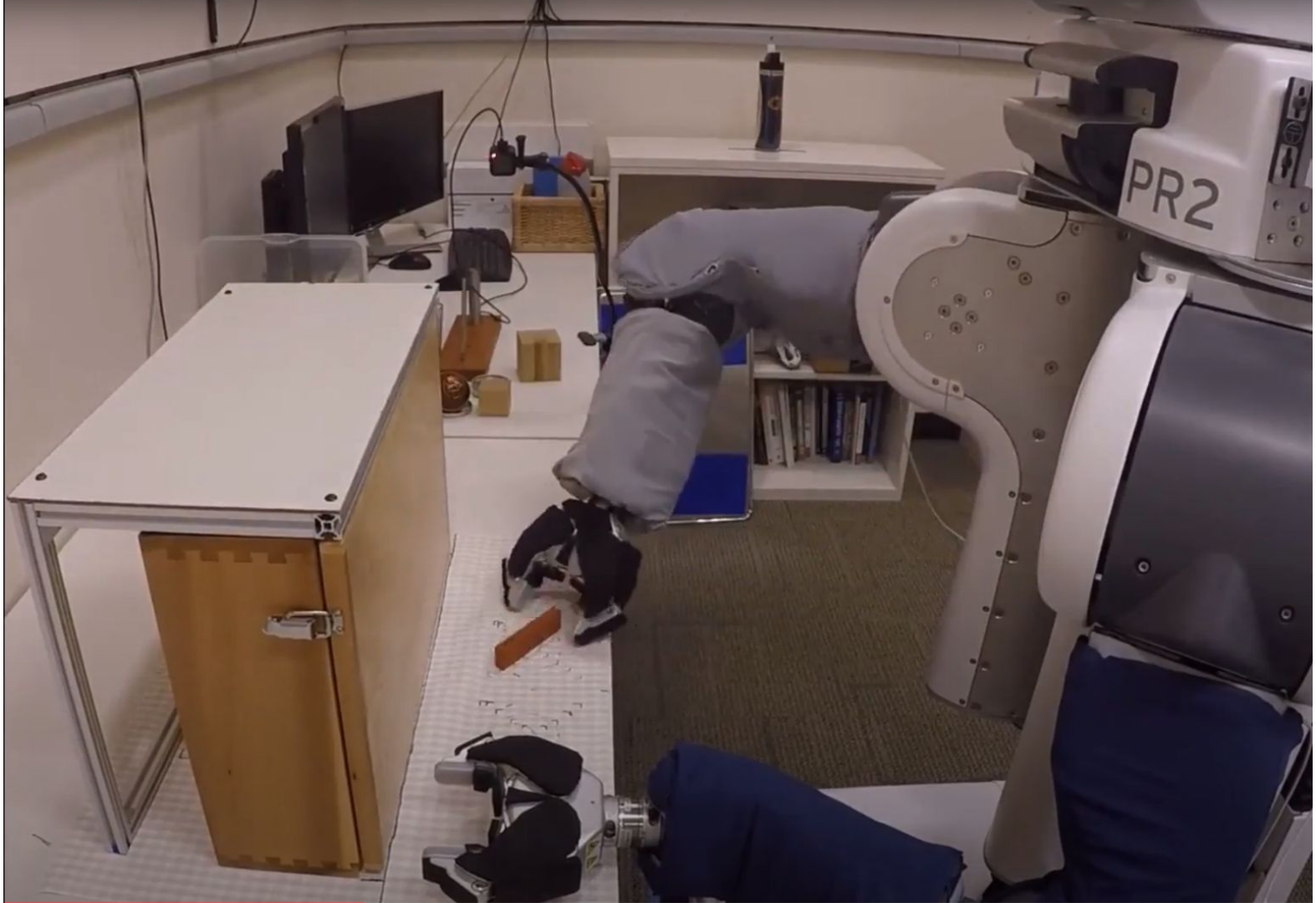
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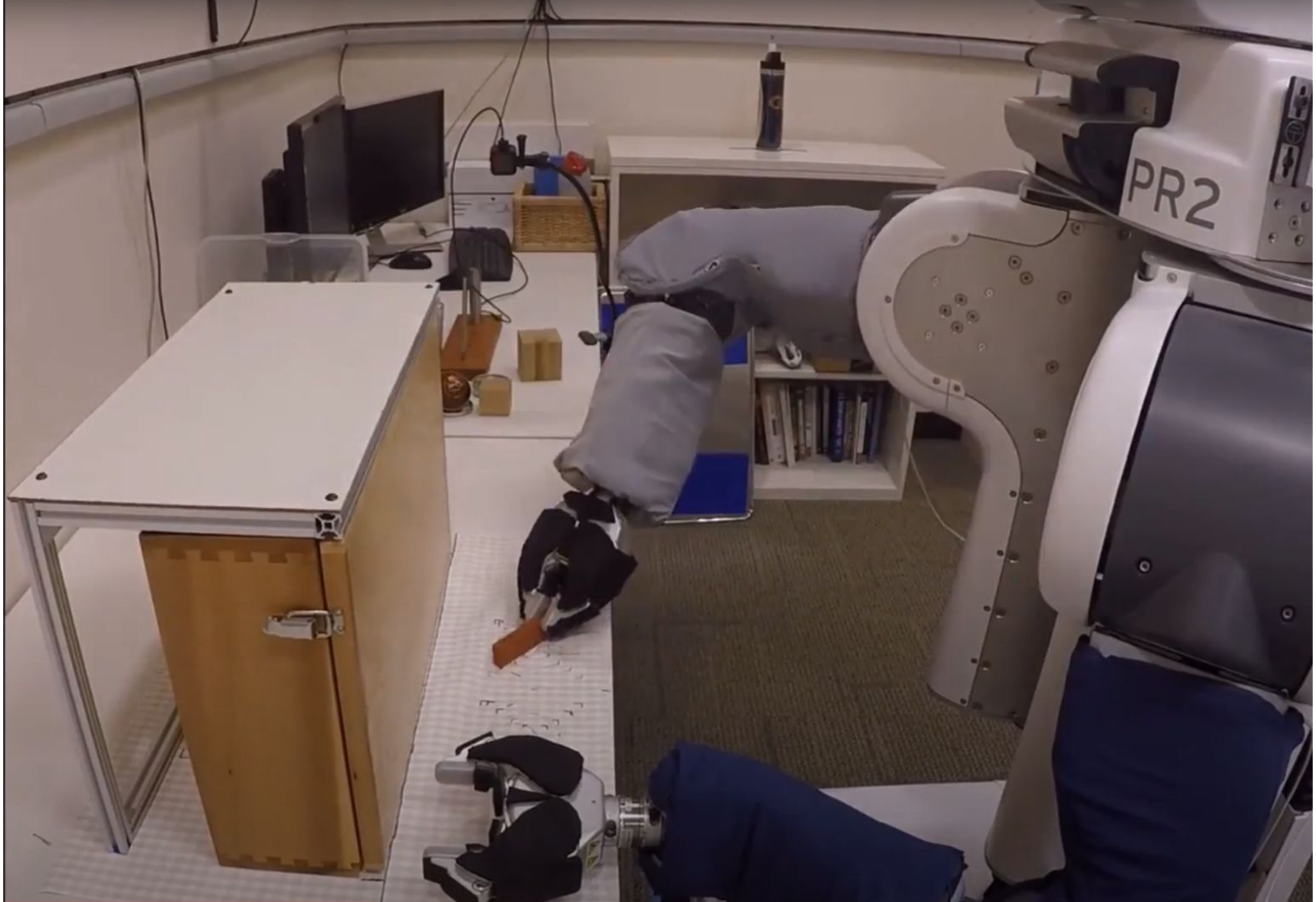
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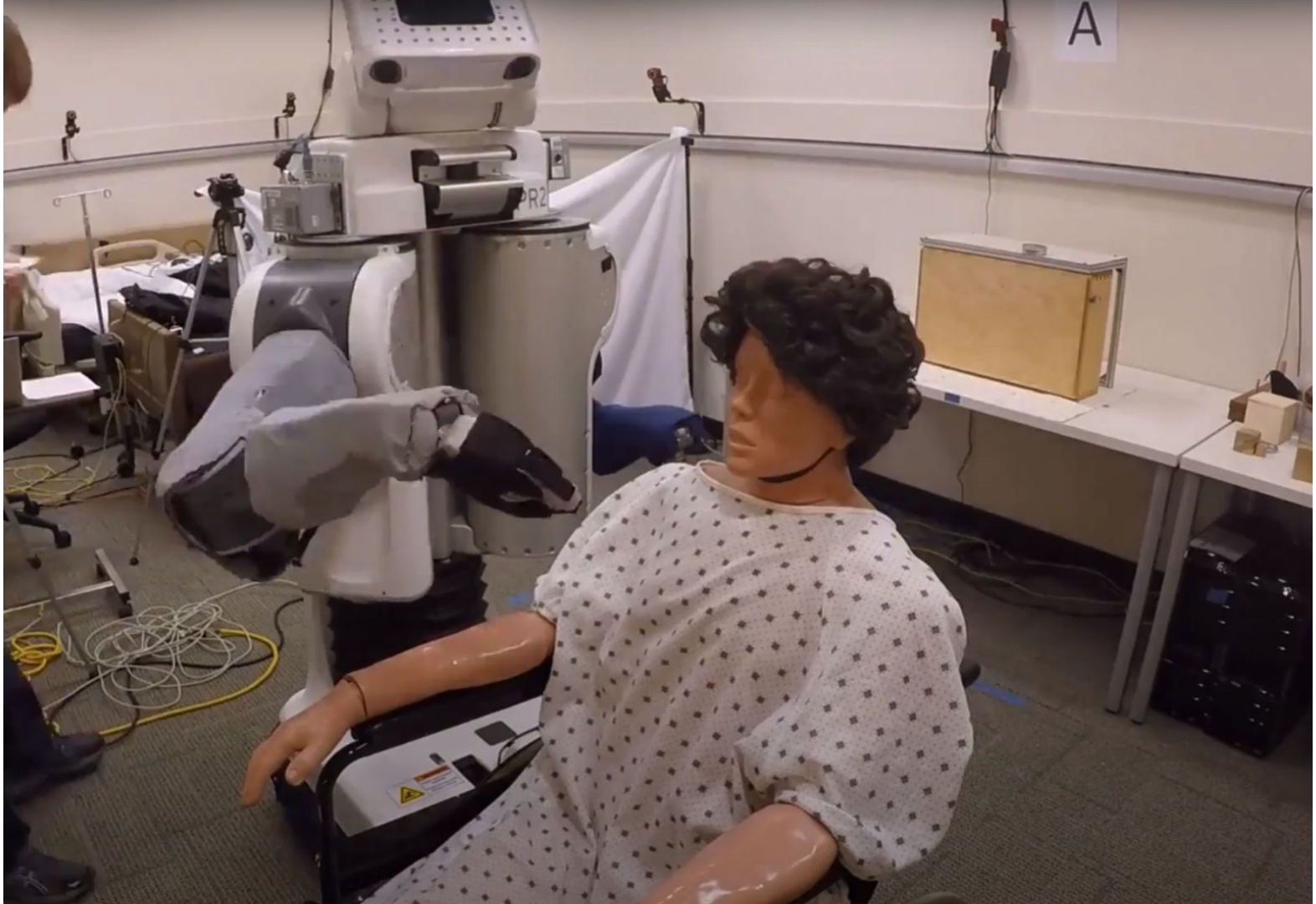
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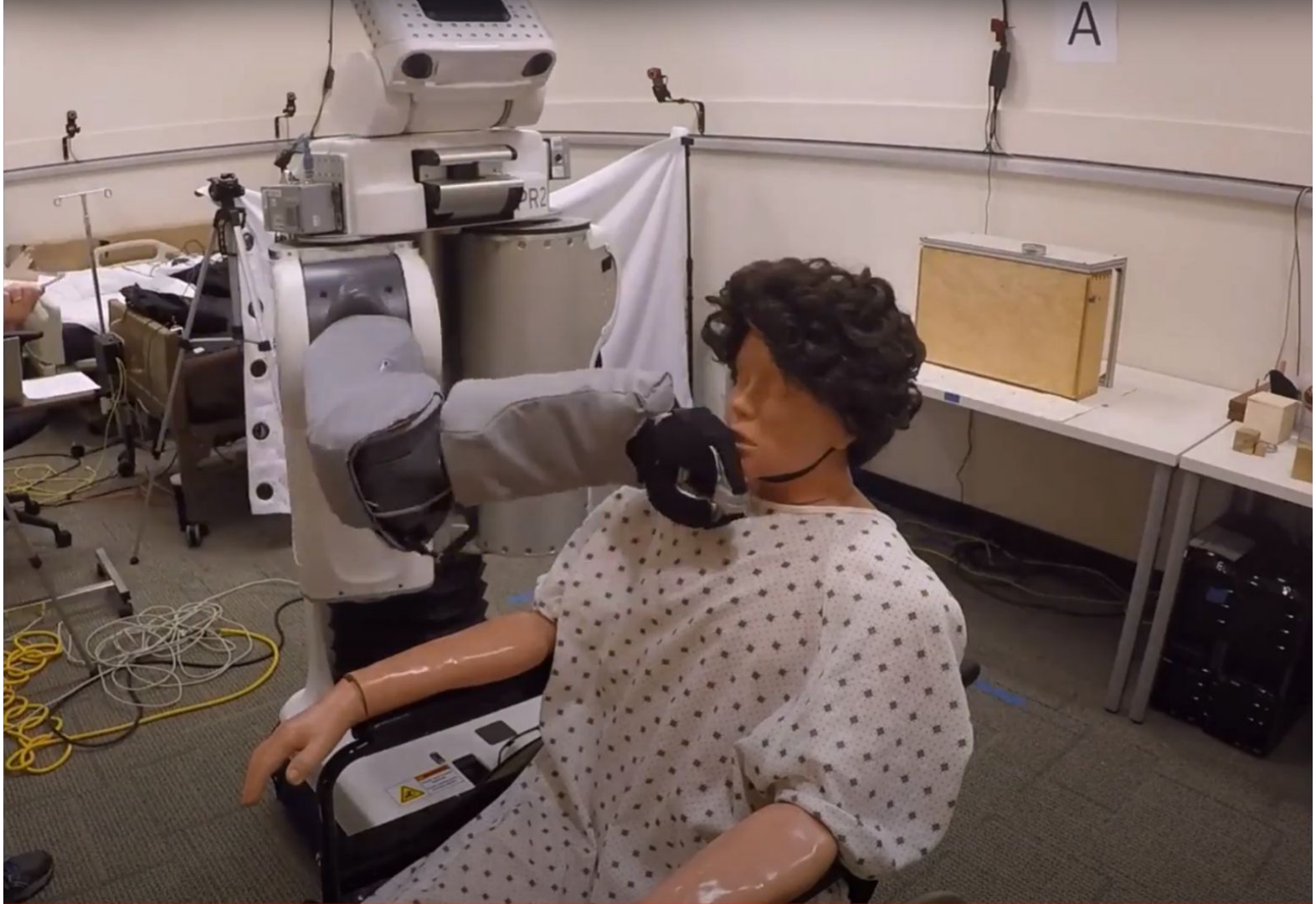
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Causes of Motor Impairment

6 Spinal Muscular Atrophy (SMA)

3 Muscular Dystrophy (Duchenne/Becker)

3 Spinal Cord Injury

1 Amyotrophic Lateral Sclerosis (ALS)

1 Arthrogryposis

1 Dejerine-Sottas

ARAT Threshold: 9/57 with best arm

Computer Access Devices

4 – Trackball

3 – Touchpad

3 – Head-mouse (TrackerPro, 2x HeadMouse Extreme)

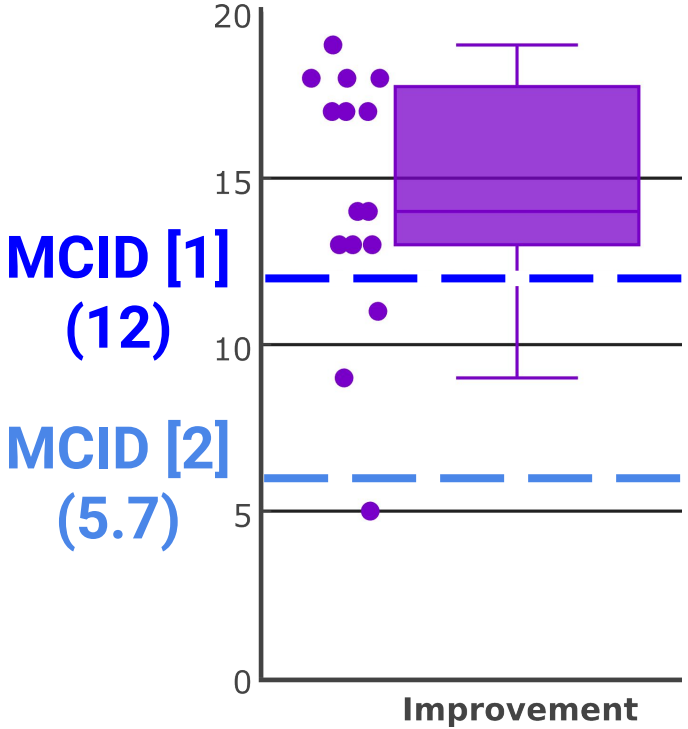
2 – Standard mouse

1 – Eye-gaze (Tobii)

1 – Touchpad w/Stylus held in mouth

1 – Speech (Dragon MouseGrid)

Improvement Exceeded Conservative Minimal Clinically Important Difference (MCID)

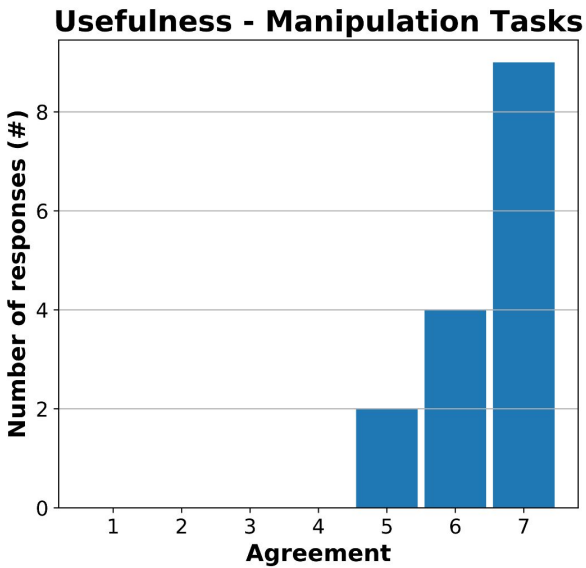


[1] C. E. Lang, D. F. Edwards, R. L. Birkenmeier, and A. W. Dromerick, **"Estimating minimal clinically important differences of upper-extremity measures early after stroke,"** Archives of physical medicine and rehabilitation, vol. 89, no. 9, pp. 1693– 1700, 2008.

[2] J. H. Van der Lee, V. De Groot, H. Beckerman, R. C. Wagenaar, G. J. Lankhorst, and L. M. Bouter, **"The intra-and interrater reliability of the action research arm test: A practical test of upper extremity function in patients with stroke,"** Archives of physical medicine and rehabilitation, vol. 82, no. 1, pp. 14–19, 2001.

1-tailed Wilcoxon signed-rank test vs MCID: W=96, **p=.021**

Perceived Usefulness

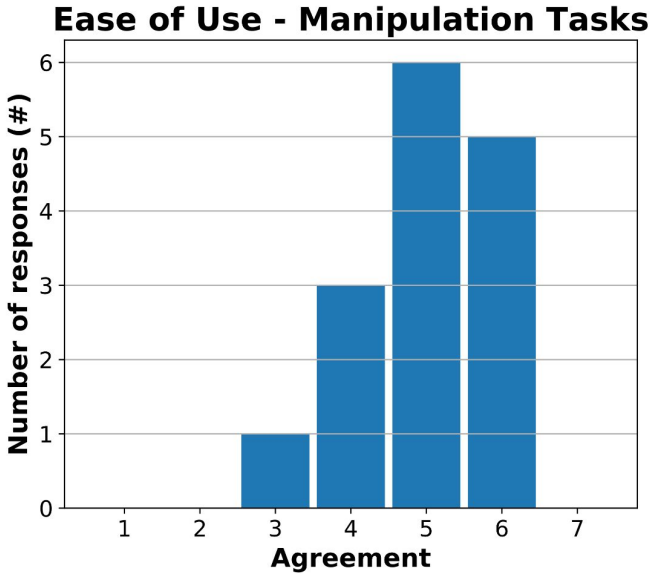


Wilcoxon signed-rank test vs neutral:
W=120, p=.000258

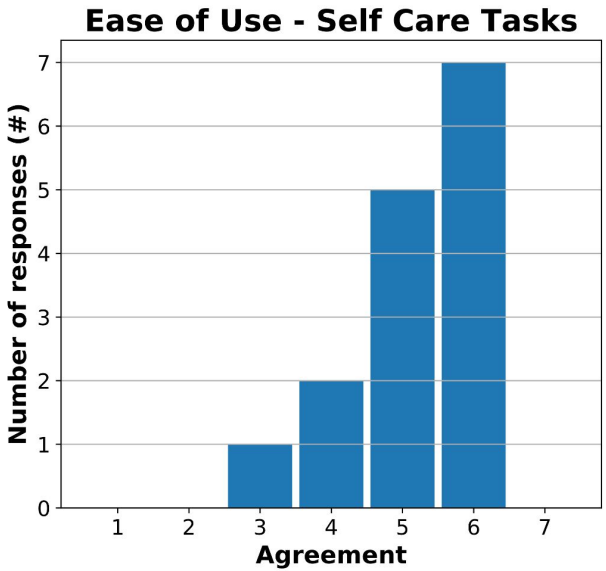
Wilcoxon signed-rank test vs neutral:
W=105, p=.000402

1: Strongly Disagree
2: Disagree
3: Somewhat Disagree
4: Neither Agree nor Disagree
5: Somewhat Agree
6: Agree
7: Strongly Agree

Perceived Ease of Use



Wilcoxon signed-rank test vs neutral:
W=74, p=.00264



Wilcoxon signed-rank test vs neutral:
W=87.5, p=.00142

1: Strongly Disagree
2: Disagree
3: Somewhat Disagree
4: Neither Agree nor Disagree
5: Somewhat Agree
6: Agree
7: Strongly Agree

Limitations

- Slow operation
- Errors
- Depth perception

Limitations

- Slow operation
- Errors
- Depth perception
- **The robot**

The Robot

- Willow Garage shut down in 2014
- PR2 was impractical
  - 227 kg (~500 lb)
  - 67 cm wide (~2.2 ft)
  - $400,000

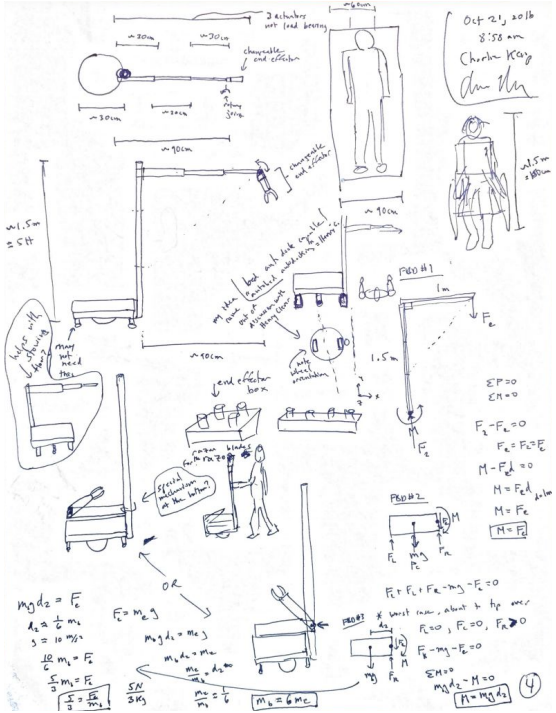
Photo from Willow Garage

Part 2: *A Novel Commercialized Robot*

Frustration Leads to Invention

Goals

- affordable
- compact
- lightweight
- humancentric
- capable



My Initial Georgia Tech Notes
October 2016

The Design of Stretch: A Compact, Lightweight Mobile Manipulator for Indoor Human Environments, Charles C. Kemp, Aaron Edsinger, Henry M. Clever and Blaine Matulevich, IEEE International Conference on Robotics and Automation (ICRA), 2022. [4-min video presentation]

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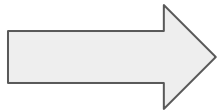
The Core Design Problem

Smaller

Lighter Weight

Lower Cost



Smaller Workspace

Lower Applied Forces

Fewer Degrees of Freedom

Photo from Willow Garage

Georgia Tech's 1st Prototype
March 2017

Hello Robot's Product - A Robot for Research
July 2020

2016	2017		2018	2019	2020

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Smaller, Lighter, More Affordable

- 34 cm wide (~1.1 ft)
- 23 kg (~51 lb)
- $20,000

The Design of Stretch: A Compact, Lightweight Mobile Manipulator for Indoor Human Environments, Charles C. Kemp, Aaron Edsinger, Henry M. Clever and Blaine Matulevich, IEEE International Conference on Robotics and Automation (ICRA), 2022. [4-min video presentation]

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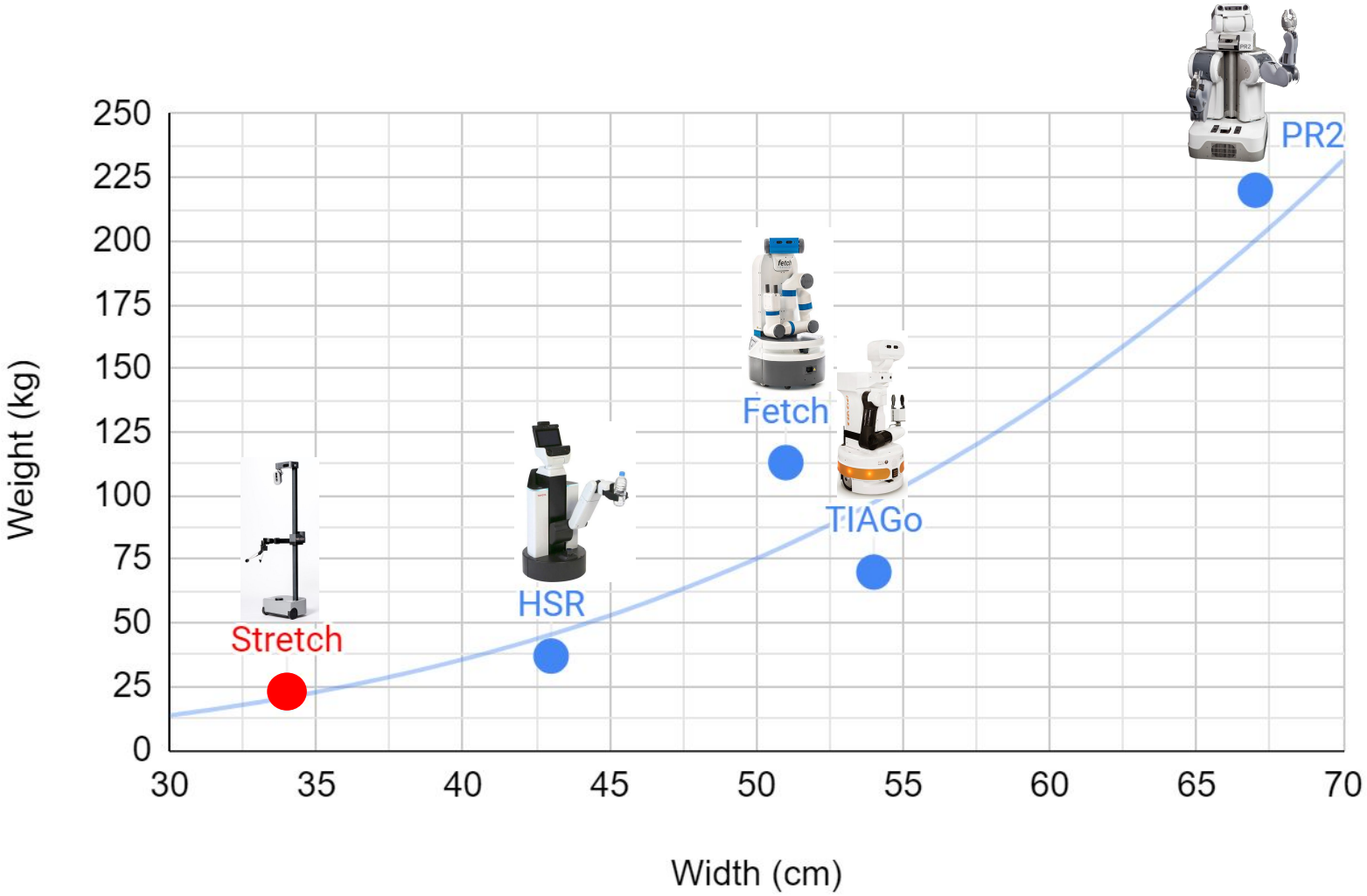
Photos from Willow Garage, https://fetchrobotics.com/fetch-mobile-manipulator/, https://pal-robotics.com/robots/tiago/, https://global.toyota/en/download/8725328



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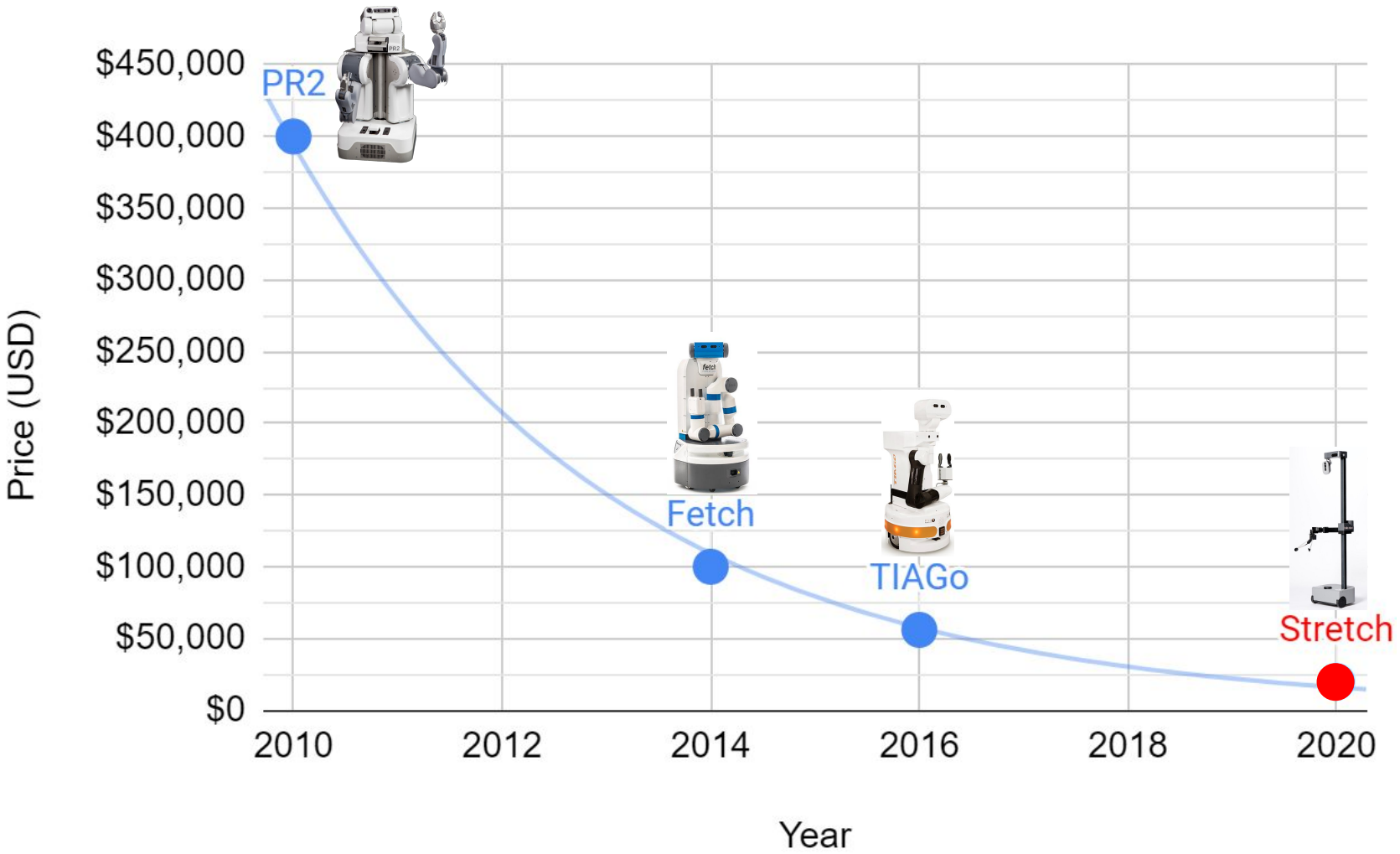

Cartesian Manipulator

The Design of Stretch: A Compact, Lightweight Mobile Manipulator for Indoor Human Environments, Charles C. Kemp, Aaron Edsinger, Henry M. Clever and Blaine Matulevich, IEEE International Conference on Robotics and Automation (ICRA), 2022. [4-min video presentation]

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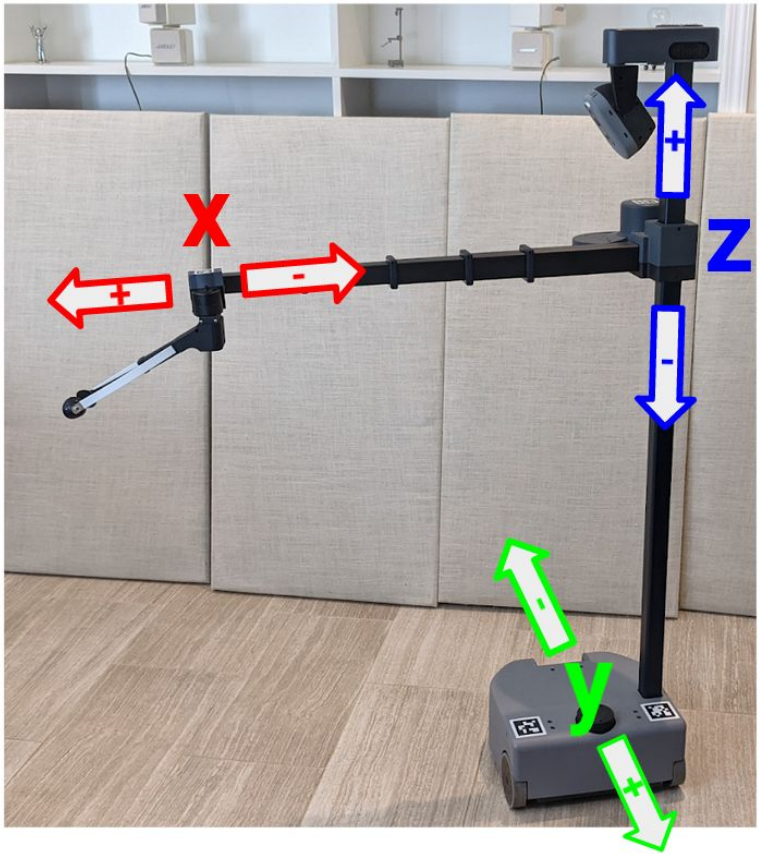
Cartesian Manipulator



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Arm & Tool Stow in the Footprint

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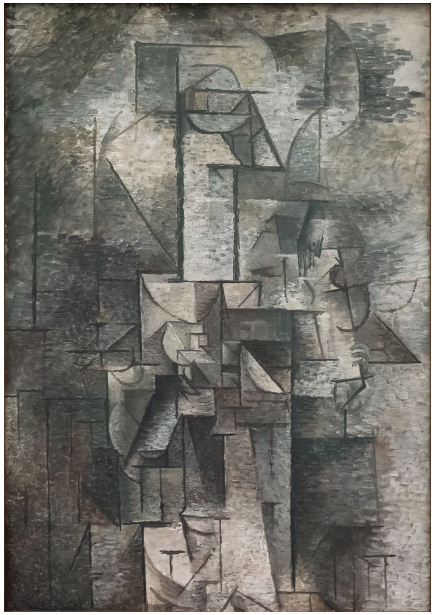
Robotic Cubism

- Dimensions matched to human environments
- The human form deconstructed and reassembled

La Femme au Violon - Pablo Picasso, 1911



“In Cubist artwork, objects are analyzed, broken up and reassembled in an abstracted form”
- https://en.wikipedia.org/wiki/Cubism

Image: https://openclipart.org/detail/260142/arms-akimbo-male

< 50th Percentile Hip Width

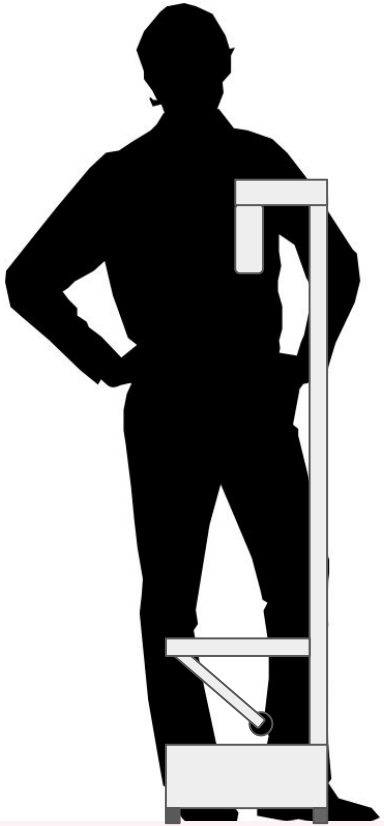
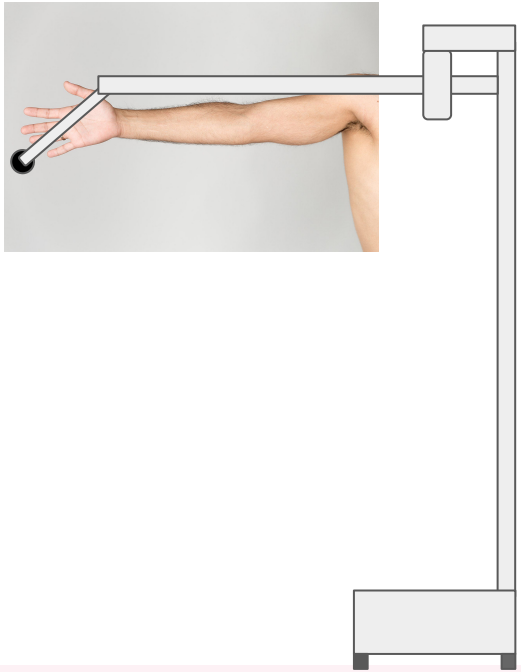


Image: https://en.wikipedia.org/wiki/Arm#/media/File:Extended_arm.jpg

50th Percentile Arm Length



Reaches the Floor

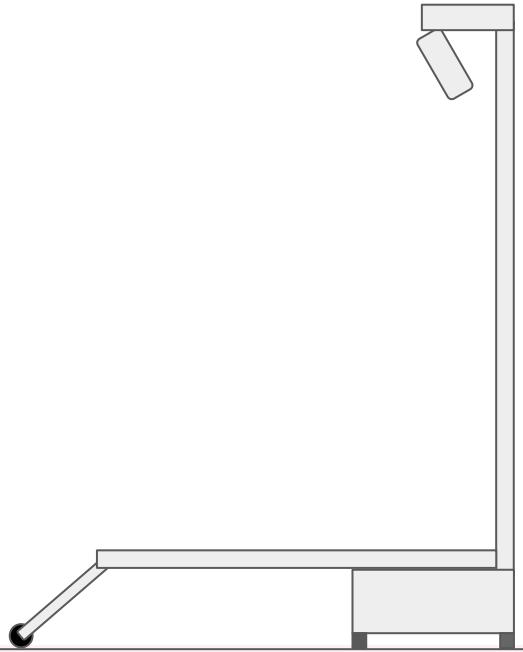


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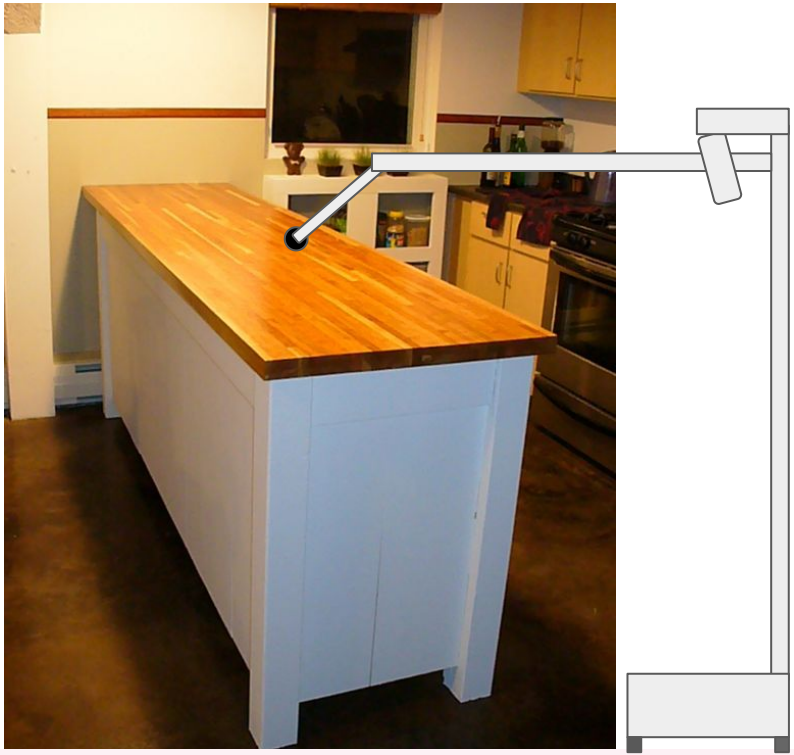
Image: https://commons.wikimedia.org/wiki/File:Butcher_block_counter_top.jpg

Reaches 36” Countertops



23 kg (51 lb)

Image: https://www.seekpng.com/ipng/u2q8y3i1o0r5a9o0_beautiful-silhouettes-of-children-boy-silhouette-transparent-background/

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Image from https://sites.gatech.edu/robotic-caregivers/ .

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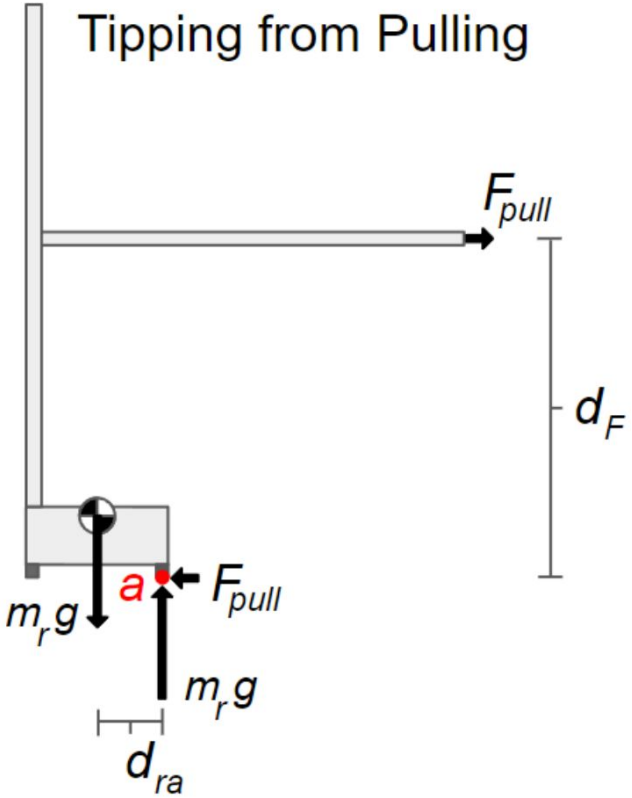
Models of Static Stability



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Simple Closed-Form Expressions

$$m_{payload} = m_r \frac{c}{t + \frac{2ld_p}{w}}$$

$$F_{pull/push} = m_r g \frac{cw}{2ld_F}$$

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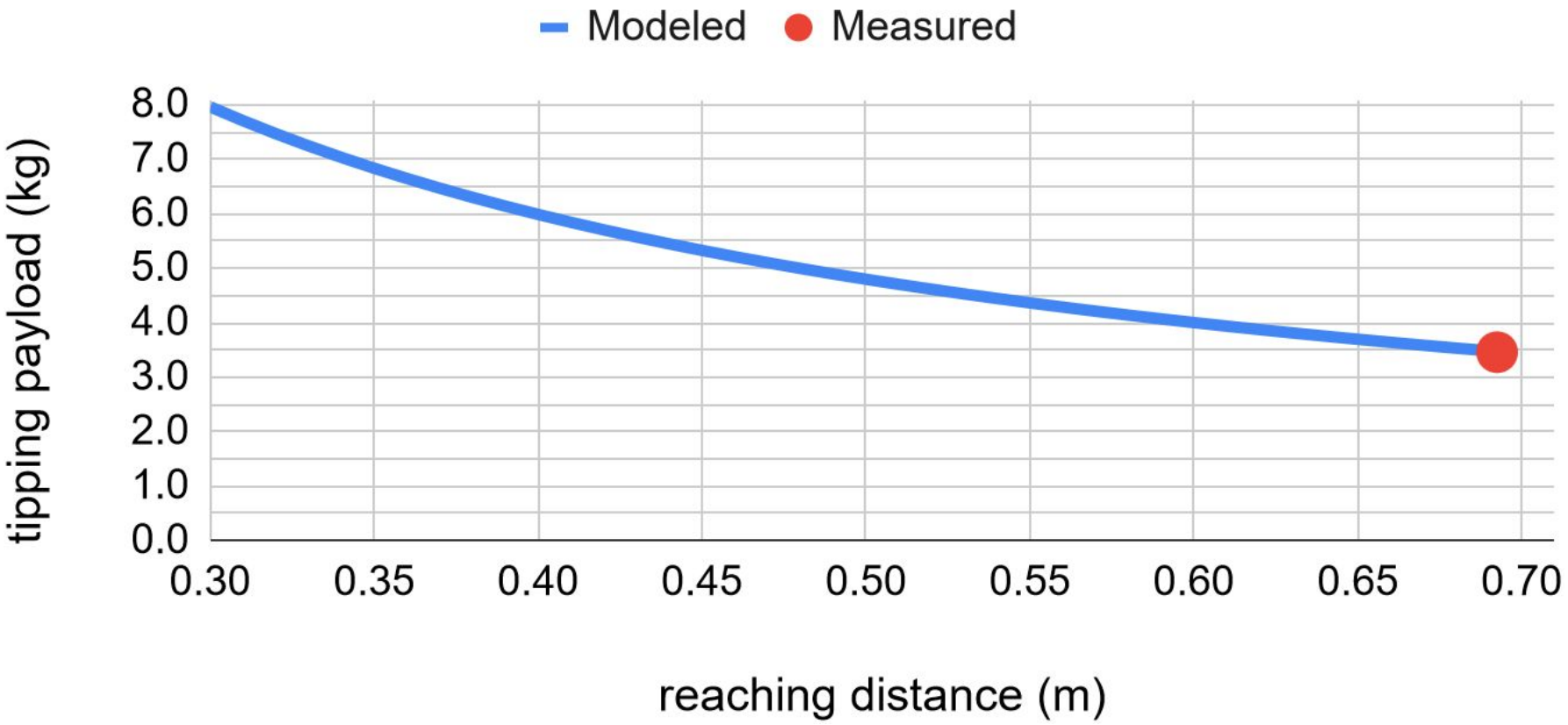

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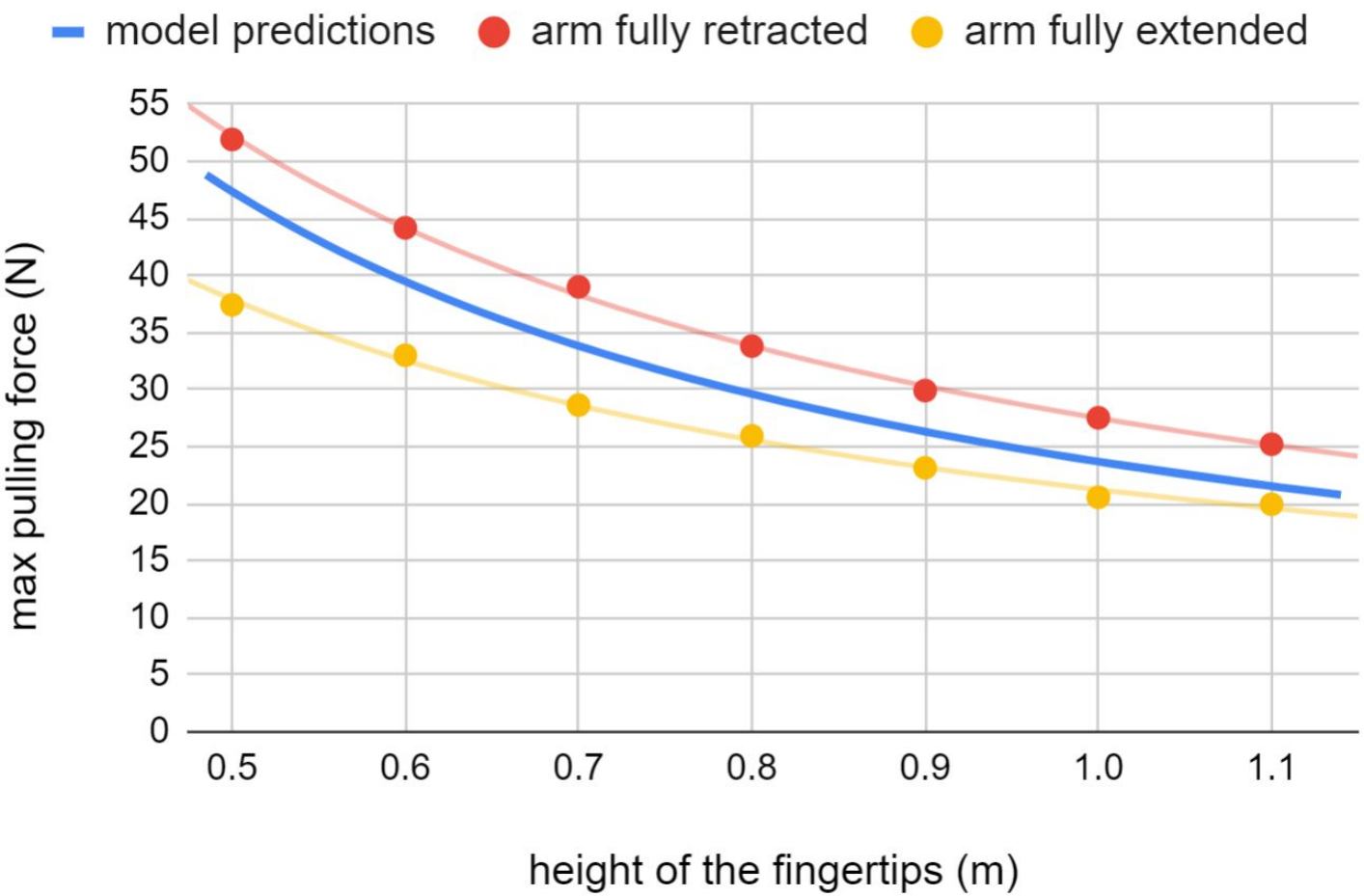

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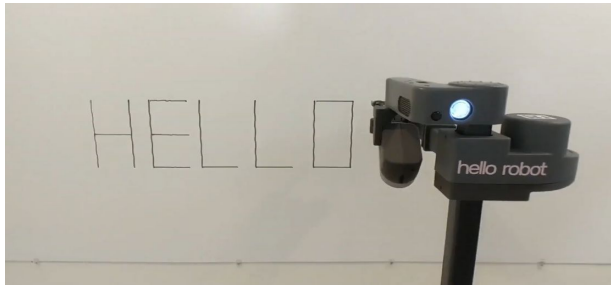
Teleoperated Home Examples

https://www.youtube.com/c/HelloRobot/videos
https://github.com/hello-robot

Autonomous Home Examples

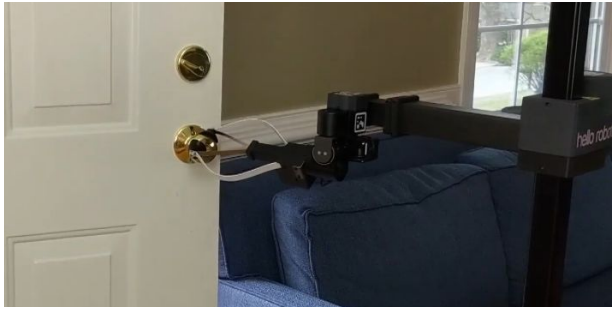


https://forum.hello-robot.com/t/autonomy-video-details

Teleoperated Examples with the Dexterous Wrist





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https://github.com/hello-robot

Successful Launch in July 2020

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Ex-Googler's Startup Comes Out of Stealth With Beautifully Simple, Clever Robot Design

Hello Robot's Stretch wants to reinvent how mobile manipulators perform tasks in home environments

By **Evan Ackerman and Erico Guizzo**

Photo: Hello Robot

Hello Robot, founded by former Google robotics director Aaron Edsinger and Georgia Tech professor Charlie Kemp, is introducing Stretch, a mobile manipulator that weighs only 23 kg and costs less than $20,000.

SVR Silicon Valley Robotics

supporting the innovation and commerc

Hello Robot wins Innovation Award in SVR 'Good Robot' Industry Awards

Posted on December 14, 2020 by Andra Keay

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Research robot helps with housework and other news

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Stretch is a Platform for Innovation

Hardware

ROS

python

GitHub

ARDUINO™

Software

Stretch is Empowering Innovators to Create the Future

Education

Artificial Intelligence

Telemanipulation

Machine Learning

Human-Robot Interaction

Core Innovation

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Hardware

ROS · python · GitHub · ARDUINO

Software

Use-Case Innovation

Physical Therapy

Home Assistance

Lab Automation

Vertical Farming

Micro-fulfillment

https://hello-robot.com/

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Stretch is Empowering Innovators to Create the Future

Education

Artificial Intelligence

Telemanipulation

Machine Learning

Human-Robot Interaction

Core Innovation

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ROS, python, GitHub, ARDUINO

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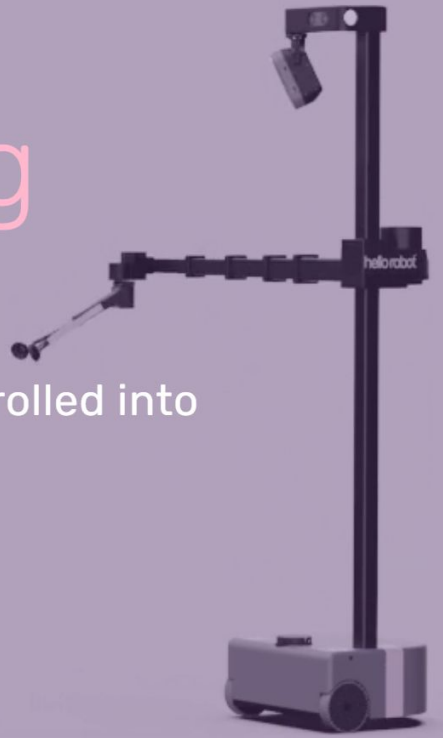
Introducing Stretch 2

Two years of customer feedback rolled into one great new robot



Toward Versatile and Inclusive Mobile Manipulators

Charlie Kemp, PhD
https://charliekemp.com